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10th INTERNATIONAL SCIENTIFIC CONFERENCE ON FLEXIBLE TECHNOLOGIES

MMA 2009
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PROCEEDINGS

Novi Sad, 9-10 October 2009

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DEPARTMENT FOR PRODUCTION ENGINEERING
21000 NOVI SAD, Trg Dositeja Obradovica 6, SERBIA

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Being held on a regular basis, like some other conferences of long tradition, the MMA – FLEXIBLE TECHNOLOGIES contributes to continuous application of scientific results and professional know-how in the metalworking industry, regardless of the difficulties this industry has been facing during the last fifteen years.

By organizing the MMA 2009 Conference, the research potential of our country relies on its traditional enthusiasm and perseverance in order to contribute to advancement of production engineering in this region – not only through application of scientific results and professional know-how in practice, but also in education of engineers in the area of production technologies and techniques.

The MMA Conference - FLEXIBLE TECHNOLOGIES is being held for the seventh time with international participation, while this is the first time that it has the official status of international conference. Throughout the years, by the number of contributions, their quality and participation of international authors, the Conference has earned a respectable reputation among scientists and industry professionals.

Initially, MMA - FLEXIBLE TECHNOLOGIES focused exclusively on TECHNOLOGIES, TOOLS AND EQUIPMENT FOR MACHINING BY CHIP REMOVAL with the following topics:

- ♦ *MACHINING AND PROCESS PLANNING*
- ♦ *MACHINE TOOLS*
- ♦ *TOOLS, FIXTURES, METROLOGY AND QUALITY*
- ♦ *FLEXIBLE MANUFACTURING SYSTEMS, CAD, CAPP, CAM, CAQ, ..., CIM systems*

However, the X Conference comes with a slightly broadened choice of topics:

- ♦ *ENVIRONMENTAL TECHNOLOGIES AND ECOLOGICAL SYSTEMS*
- ♦ *OTHER AREAS*

The organizers of this Conference are convinced that by broadening the scope they did not collide with the similar conferences of long tradition.

With around 80 papers and more than 50% contributions by international authors, 10th International Scientific Conference MMA 2009 – FLEXIBLE TECHNOLOGIES successfully maintains the high level set by the previous conferences. Participation of a large number of domestic and international authors, as well as the diversity of topics, justifies our efforts to organize this conference and contribute to exchange of knowledge, research results and experience of industry experts, research institutions and faculties which all share a common interest in the area of production engineering.

Novi Sad, October 2009 *INTERNATIONAL SCIENTIFIC AND ORGANISATIONAL COMMITTEE*

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Section D: FLEXIBLE MANUFACTURING SYSTEMS, *CAD*, *CAPP*, *CAM*, *CAQ*, ..., *CIM*

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10th INTERNATIONAL SCIENTIFIC CONFERENCE ON
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KEYNOTE PAPERS

Novi Sad, October 2009.

Pilipovic, M., Spasic, Z.

VIRTUAL MANUFACTURING – MODELING FOR CIM ENTERPRISE

Abstract: *Based on the own model of virtual manufacturing system for CIM enterprise the paper analyzes possibilities for modeling of the components of advanced manufacturing systems in the virtual world. The paper also describes the concept and architecture of the Control-Centered virtual manufacturing environment defined by integration of different tools for products, manufacturing processes and manufacturing resources modeling. The applications of developed concepts and environment for virtual manufacturing system modeling are also given with an example.*
Key words: *CIM, Virtual Environment, Modeling, Virtual Manufacturing.*

1. INTRODUCTION

The globalisation of the market of today requires the manufacture of increasingly complex products, with a great range of project design variants to adjust with and meet the specific needs of the end buyer. This imposes the need for as short as possible manufacturing cycle, as well as the distribution of design, development and manufacturing tasks to several geographically distant sites. Simultaneous decreasing or complete removal of inter-state barriers enables the existence and growth of efficient and innovative, i.e., agile companies. The designers of advanced products and workshops, as well as the management of business and production systems, have therefore to pass decisions each day in order to find the best balance between the product quality and price, deadlines and production equipment performance. In order to achieve success in this context, manufacturing company need to develop capabilities to quickly respond to customers needs and to make correct decision as earlier as possible during the product development process. Advanced manufacturing systems, however, require an increasing use of computer for accomplishing of a large number of activities for computer information processing, CAD/CAM or process control. Such intensive changes in the field of manufacturing and computer technologies demand continuous development of existing concepts and the creation of new concepts. In the design field a new concept is being defined - Virtual Manufacturing (VM).

Leading industries in many sectors use VM to support many of the stages of their product development process. Automotive industries identified very early VM as the emergency technology. For example, USCAR (United States Council for Automotive Research) in the project PNGV (Partnership for the new generation of vehicles) identified in advanced manufacturing technology, among all, agile manufacturing, rapid prototyping and virtual manufacturing as technological areas where improvements and innovation are needed [1]. In the last ten years, there are lot examples of the research in areas of VM from major automakers [2]. At the same time, there are trends for fundamental changes and transformation of the manufacturing industry from traditional, vertically-integrated value-chain to collaborations between specialised independent companies. These trends are resulting in global manufacturing virtual networks and the meaning of 'virtual manufacturing' has been extended to signify inter-firm relationships used to form a temporary supply chain [3].

2. VIRTUAL MANUFACTURING - DEFINITONS

According to the professional literature virtual manufacturing (VM) system may be defined in several ways. According to Onosato [4] and Iwata [5], this concept executes and estimates manufacturing processes in computers, without the use of real facilities. Computer system entitled as "virtual and informational system" simulates real and information system, and generates control commands for the real and physical system. The same authors extend and define this concept as the aggregation of various computer hardware and software, requiring wide range of modeling and simulation tasks. On the basis of an analysis dealing with the information dependence between the tasks, Iwata [5, 6] proposes that VM system architecture should be defined with seven types of the following activities: device model preparation, service development, virtual shop floor definition, operation definition, product handling, virtual shop simulation and simulation interface. The core idea of the other concept given by Kimura [7] is that a parallel to the real world of CIM enterprise is a modelled virtual world comprised from product model, virtual prototype model, manufacturing resource model and manufacturing environment model. According to Wiendahl and Scholtissek [8], this model of reality (engineering and business activities) creates the test field for experiments about the influence of production design on the production itself, as well as on planning of supported operations and tests of new methods in production management. Lin [9] defines the VM system as an integrated, synthetic manufacturing environment, whose purpose is to enhance all levels of decision and control comprising design-centered VM, production-centered VM and control-centered VM. According to Browne [10], an extended CIM enterprise is the integration of all computerized activities and information about customers, vendors and other business partners. According to Souza, Porto and Saco [11], virtual manufacturing proposes the creation of a synthetic and integrated environment, composed by many software tools and systems as simulation and virtual reality (VR), offering turnkey solutions for the entire product development process from design to manufacturing. VM represents an important step toward the factory of future providing ability to make changes in a virtual environment, saving money and time, and resulting in better design.

3. MODEL OF VIRTUAL MANUFACTURING SYSTEM FOR EXTENDED CIM ENTERPRISE

The research carried out during many years in the field of CIM models at the Faculty of Mechanical Engineering in Belgrade is based on world-known reference models such as CASA SME model (the Computer and Automated Systems Association of the Society of Manufacturing Engineers), CIM OSA model (Open System Architecture) of the European Union Consortium AMICE, and on many others. Our own model of extended CIM enterprise on data/knowledge base driven factory named JUPITER [12] has been defined. This model has hierarchical, multilevel and complex systems with the following levels: Company Business Environment, Factory, Workshop, Manufacturing Cell, Machine and Process. CIM-system component follows the hierarchical relation in this order CIM-subsystem - CIM -module - CIM-segment.

The approach in the creation of VM System for extended CIM enterprise is based on the adopted model of the data/knowledge driven factory illustrated in Figure 1 [13]. The virtual world consists from three models (product model, manufacturing model and one of enterprise models), with real world elements for the purpose of comparison and choice of product/process alternatives and production scenarios.

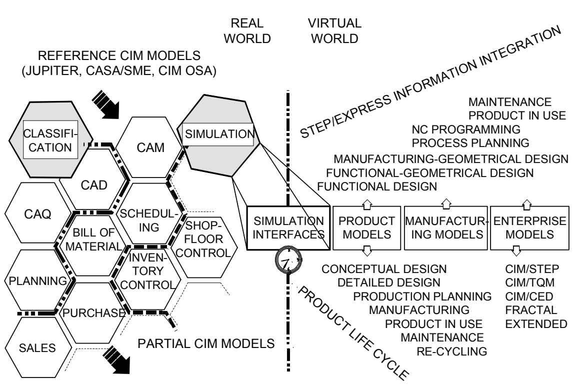


Fig. 1. Model of Virtual Manufacturing System for extended CIM enterprise

Virtual world of the extended CIM enterprise uses simulations based on partial and particular models of CIM-systems derived from the reference models. CIM subsystem Simulation has the ability to present all physical CIM-components in virtual environment with optimization and validation in the decision-making processes.

Some subsystems are under development within separate projects for the established model. This paper includes the results of the development of control-centered VMS as a part of an integral VMS model for extended CIM enterprise.

4. THE APPROACH OF CONTROL-CENTERED VIRTUAL MANUFACTURING

Three paradigms defining specific view of the VM, were proposed at the "Virtual Manufacturing User Workshop" held in Dayton, Ohio on 12-13 July 1994 and published in the "Technical Report, Compiled and Edited by Lawrence Associates Inc." (Obtained from the www address http://www.isr.umd.edu). These three paradigms, Design-Centered VM, Production-Centered VM and Control-Centered VM, have been analyzed in more detail by other authors as well, and particularly in [9]. Design-Centered VM uses manufacturing-based simulation to optimize the design of products and processes for specific manufacturing goals such as: design for assembly, quality, lean operations, and/or flexibility. Production-Centered VM provides an environment for generation of process plans, production plans and resource requirement planning. Simulation is used to allow inexpensive, fast evaluation of many processing alternatives. Control-Centered VM provides information for optimizing manufacturing processes and improving manufacturing systems with the use in simulation of control models and actual processes as well.

Taking into consideration the above mentioned paradigms with further development of the previously defined model of virtual manufacture for extended CIM enterprise, the authors of this paper have built the concept and the architecture of control-centered VM.

The basic concept of this model illustrated in Figure 2 was made with IDEF0 methodology for functional modeling. The main inputs are product and process models. For the established production planning/scheduling model different variants of shopfloor and machine control models may be defined and modeled, so that control optimization elements (control strategy, process performances and possible shopfloor layout) may be obtained through distributed simulation process. For this model, in agreement with the previous concept, detailed architecture and functional models of the control-centered virtual manufacturing system are defined in [14, 15, 16 and 17].

Four stages are defined: product design, manufacturing preparation, manufacturing resources modeling, simulation and analysis. It is possible to single out in the system the subsystems for modeling of virtual manufacturing system components (parts, processes, equipment and control resources), the distributed simulation controller, computer resources for the creation of virtual environment - simulation, as well as the system of joint data/knowledge base.

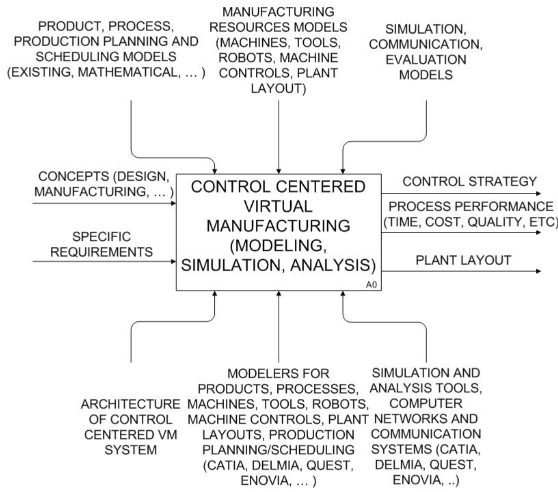
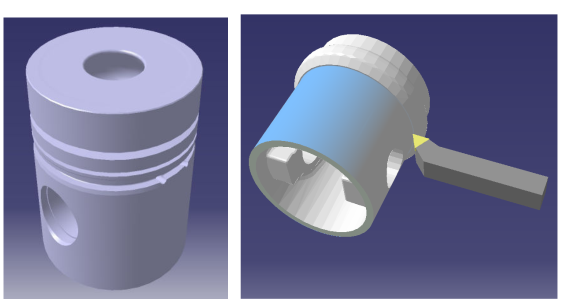


Fig. 2. Control-centered VM concept

5. MODELING FOR VIRTUAL MANUFACTURING - EXAMPLES

For the verification of the developed concept of control-centered virtual manufacturing for extended CIM enterprise, several examples are made. The virtual products, virtual processes and virtual resources are mainly modeled using standard advanced CAD/CAM/CAE software (CATIA or ProEngineer), with models based on STEP and others data file types and in some case with own developed software. Examples are made for advanced manufacturing automation [14, 16, and 17], Automotive [15, 18], Aerospace [19] and other manufacturing industries.

Without entering into detail about design, on the Figure 3 Catia 3D model for the piston (a) and turning simulation (b) are given [15]. The presented models are generated in internal Catia file format. For the defined concept of the virtual manufacturing and using of Internet/Intranet network, Virtual reality modeling language (VRML) file for presented CAD model are generated also.



a) Piston 3D model b) Piston turning simulation
Fig. 3. Piston model

The modelling of the manufacturing resources is of special significance for the virtual manufacturing system. The concepts of advanced manufacture such as flexible automation, holonic manufacturing systems, agile manufacturing systems, intelligent manufacturing systems and others represent development steps of 21st century factories - flexible, fully automated and, according to some, intelligent factories without men. All these concepts are based on advanced manufacturing programmable equipment such as CNC machine tools, industrial robots and other automated systems. According to that, manufacturing resources modelling includes modelling of physical resources (machines, robots, conveyers, tools and attachments), modelling of control resources and modelling of plant layout. The example of the assembly cell from the laboratory of the Faculty of Mechanical Engineering Belgrade is shown on the Figure 4 and 3D model and simulation of the work using own developed software on the Figure 5 [14, 16].

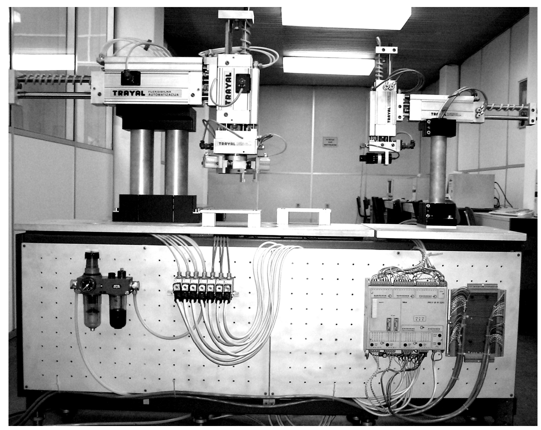


Fig. 4. Automated assembly cell controlled by PLC

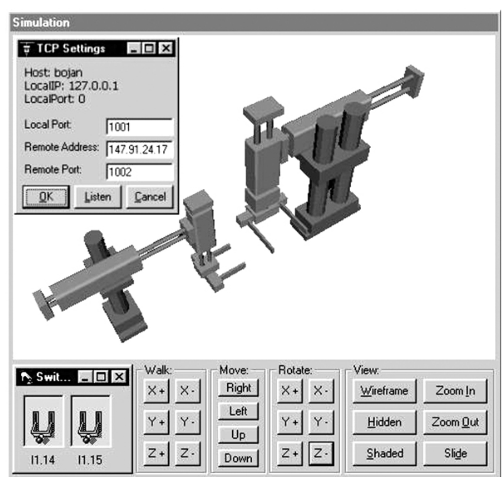


Fig. 5. Simulation of the assembly cell

6. CONCLUSIONS

In this paper, the concept of the Control-Centered virtual manufacturing environment is presented together with examples of the virtual models developed for domestic industry. Different virtual environment and the software tools where used for the particular cases. For example, the cylinder assemblies' application uses the standard CAD/CAM systems for products and processes modelling, Visual Basic and other object oriented programming languages for the mathematical and simulation models and virtual PLC etc. These experiences open the problem of the integration of different software tools and virtual environments subsystems. The further research will be directed to the integration of current and new technologies in integrated virtual environment solutions.

7. REFERENCES

[1] *Partnership for the New Generation of vehicles - Technology Areas*, United States Council for Automotive Research - USCAR, www.uscar.org, 1997.

[2] Hoffman, T., *Automakers Goes Digital*, Computer World, Vol. 36, Issue 49, p.p. 1-2, 2002.

[3] Shi, Y., Gregory, M., *Emergency of Global Manufacturing Virtual Network and Establishment of New Manufacturing Infrastructure for faster Innovation and Firm Growth*, Production Planning & Control, Vol. 16. No. 6, pp. 621-631, 2005.

[4] Onosato, M., Iwata, K., *Development of a Virtual Manufacturing System by Integrating Product Models and Factory Models*, Annals of the CIRP, Vol. 42/1, p.p. 475-478, 1993.

[5] Iwata, K., Onosato, M., Teramoto K. and Osaki, S., A *Modelling and Simulation Architecture for Virtual Manufacturing Systems*, Annals of the CIRP, Vol. 44/1, p.p. 399-402, 1995.

[6] Iwata, K., Onosato, M., Teramoto K. and Osaki, S., *Virtual Manufacturing Systems for Integrating Manufacturing Resources And Activities*, Annals of the CIRP, Vol. 46/1, p.p. 335-338, 1997.

[7] Kimura, F., *Product and Process Modelling as a Kernel for Virtual Manufacturing Environment*, Annals of the CIRP, Vol. 42/1, p.p. 147-150, 1993

[8] Wiendahl, H.-P., Scholtissek, P., *Management and Control of Complexity in Manufacturing*, Annals of the CIRP, Vol. 43/2, p.p. 533-540, 1994.

[9] Lin, E., Minis, I., Nau D. and Regli, W., *Contribution to Virtual Manufacturing Background Research Phase I & Phase II, Final Report F33615-92-D-5812*, Institute for System Research - University of Maryland, 1995.

[10] Browne, J., *Global Manufacturing/Extended Enterprise*, Proceedings of Conference on "Technology para una nova indusreta - CIME, p.p. 4-10, Guimares, Portugal, 1995.

[11] Souza, M. C. F., Porto, A. J. V., Sacco, M., *Virtual Manufacturing as a Way for the Factory of the Future*, J. Intelligent Manufacturing, Vol. 17, p.p. 725-735, 2006.

[12] Spasić, Ž., *Multilevel Architecture and Data Modelling in CIM System Design*, Proceedings of the International Conference on CIM - Manufacturing Enterprise of the 21st Century, p.p. 105-110, Singapore, 1991.

[13] Spasić, Ž. Stefanović, N., Stojadinović, A. and Pilipović, M., *Model of Virtual Manufacturing System for Distributed Simulation of Extended CIM Enterprise*, Proceedings of the 1st International Conference on Engineering Design and Automation, p.p. 1-4, Bangkok, 1997.

[14] Stojadinović, A., Pilipović M. and Spasić, Ž., *Development of Virtual PLC for Simulation and Education in Manufacturing*, Preprints of the 9th Symposium on Information Control in Manufacturing, Vol. III, pp. 255-260, Nancy - Metz, 1998.

[15] Pilipović, M., Vučković, D., Vićevac, Z. and Spasić, Ž., *Virtual Environment for Advanced Manufacturing of Cylinder Assemblies*, Proceedings of the X EAEC European Automotive Congress, . pp. 1-10, Belgrade, 2005.

[16] A. Stojadinović, *Contribution to the Development of Virtual Control System for Advanced Manufacturing*, Master Science Thesis, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 1999. (In Serbian).

[17] D. Vučković, *Contribution to the Development of Virtual Manufacturing for Control in Advanced Automation on Internet Global Network*, Master Science Thesis, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, 2004. (In Serbian).

[18] Pilipović, M., Spasić, Ž., Petrović. P., and Jakovljević, Ž., *Virtual Manufacturing – Automotive components manufacturers examples*, Proceedings of the XXII JUMV International Automotive Conference "Science and Motor Vehicles", . pp. 1-10, Belgrade, 2009.

[19] Alsawani, M., *Optimization Methods of Production and Integral Quality Management for Gas Generator Turbine*, Ph. D. thesis, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, 2004.

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Cus, F., Zuperl, U.

EMBEDDED LOAD CONTROL SYSTEM FOR MILLING PROCESSES

Abstract: *To increase productivity, a new automation system in milling processes has been developed. Based on proposed control system which consists of neural network, an on-line adjustment of machining parameters to achieve a constant spindle load under a variety of cutting conditions is shown. Architecture with two different kinds of neural networks is proposed, and is used for the on-line optimal control of the milling process. The feedrate is selected as the optimised variable, and the milling state is estimated by the measured cutting force. The controller is operated on IPC and the adjusted feedrates are sent to the CNC controls.*
Key words: *Milling, automation, load control*

1. INTRODUCTION

A remaining drawback of modern CNC systems is that the machining parameters, such as feedrate, speed and depth of cut, are programmed off-line. The machining parameters are usually selected before machining according to programmer's experience and machining handbooks. To prevent damage and to avoid machining failure the operating conditions are usually set extremely conservative. As a result, many CNC systems are inefficient and run under the operating conditions that are far from optimal criteria. Even if the machining parameters are optimised off-line by an optimisation algorithm [1] they cannot be adjusted during the machining process. To ensure the quality of machining products, to reduce the machining costs and increase the machining efficiency, it is necessary to adjust the machining parameters in real-time, to satisfy the optimal machining criteria. For this reason, adaptive control, which provides on-line adjustment of the operating conditions, is being studied with interest [2]. Adaptive control systems can be classified into: adaptive control with optimization (ACO) [3] and adaptive control with constraints (ACC). In this paper an ACO system is presented, which adjusts the machining parameters to maximize the milling performance under given limitations. Current research [4, 5] in machining has shown that neural network controllers have important advantages over conventional controllers. The first advantage is that a neural network controller can efficiently utilise a much larger amount of sensory information in planning and executing a control action than an industrial controller can. The second advantage is that a neural network controller has the collective processing capability that enables it to respond quickly to complex sensory inputs while the executing speed of sophisticated control algorithms in a conventional controller is severely limited. The most important advantage of neural controller is that good control can be achieved through learning [5]. Three controllers have played important roles in machining process control. They are: CMAC controller [4], hierarchical neural controller [5], and multilayer neural controller [4].

2. FEEDBACK FORCE CONTROL WITH OPTIMIZATION

The proposed architecture for adaptive control of the machining process and on-line optimization of cutting parameters is shown in Figure 1. Sequence of steps for on-line optimization of milling process is presented below:

- Neural network (NN) for optimization determines the optimal feedrate and sends it to the milling machine and network for modelling,
- the measured output of the milling machine are used to train the NN for modelling,
- NN for optimization uses the newly upgraded neural model to find the optimal feedrate and sends it to the machine and neural model,
- steps 2 and 3 are repeated until termination of machining.

3. NEURAL NETWORK FOR OPTIMIZATION

To realise real-time optimal control of the machining process, an ALM neural network is proposed. It is used to determine the optimal inputs (feedrate), so we shall refer to it as a NN for optimization. This architecture that uses the Lagrange multiplier (ALM) method converges more quickly than other penalty methods. Detail information about this type of network can be found in [4]. Combining both neural networks, an adaptive controller for the milling process is designed. The problem of the optimization of cutting parameters in milling can be formulated as the following multi-objective optimization problem: min Tp (f), min C_p (f), min R_a (f) subject to limitations L1-L4 (Equation 1). Where T_p, C_p, R_a are: production rate, operation cost and surface roughens. All the above mentioned objectives are represented as a function of the cutting speed, feed rate and depth of cutting.

These are two conflicting objectives, therefore a compromise must be reached.

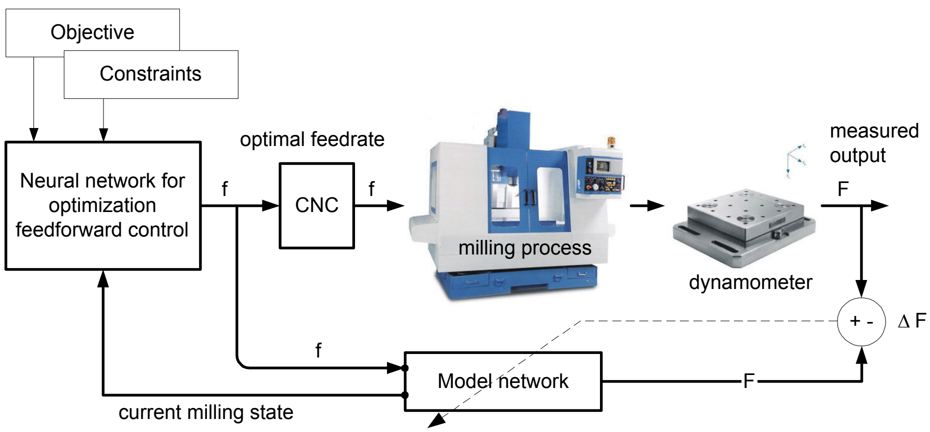


Fig. 1. Cutting force control with optimization in end milling

There are several factors limiting the milling parameters. Those factors originate usually from technical specifications. The following limitations are taken into account:

$$
\begin{aligned}
L_1(f) &= f - f_{max} \leq 0 \\
L_2(f) &= f_{min} - f \leq 0 \\
L_3(f) &= F(f) - F_{max} \leq 0 \\
L_4(f) &= R_a - R_{a,allowable} \leq 0
\end{aligned} \tag{1}
$$

4. MACHINING PROCESS MODEL SIMULATOR

A CNC machining process model simulator is used to evaluate the controller design before conducting experimental tests. The process model consist of a neural force model and feed drive model. The neural model estimates cutting forces based on cutting conditions and cut geometry as described by Zuperl [1]. The feed drive model simulates the machine response to changes in commanded feedrate. The feed drive model was determined experimentally by examining step changes in the commanded velocity. The best model fit was found to be a second-order system with a natural frequency of 3 Hz and a settling time of 0.4sec.

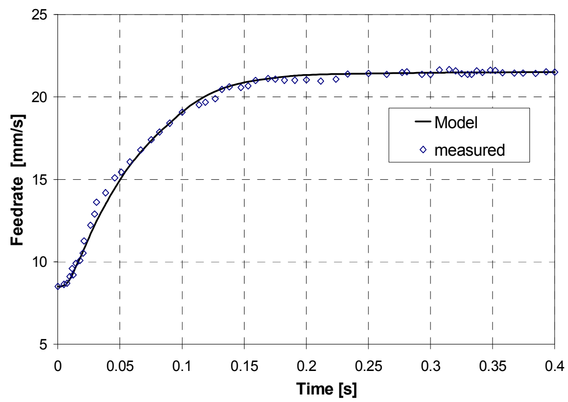
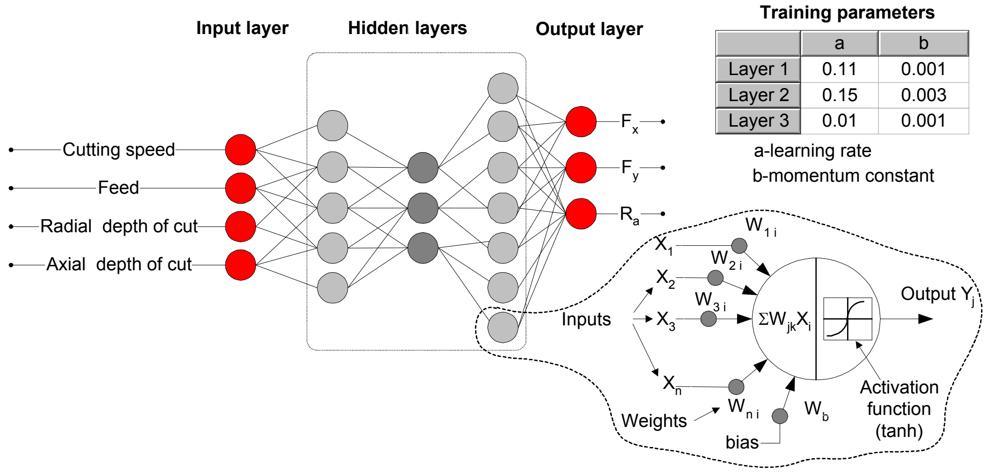


Fig. 2. Comparison of actual and model feedrate

Comparison of experimental and simulation results of a velocity step change from 7mm/sec to 22mm/sec is shown on Figure 2.

The feed drive and neural force model are combined to form the CNC machining process model. Model input is the commanded feedrate and the output is the X, Y resultant cutting force.

To realise the on-line modelling of cutting forces, a standard BP NN is proposed based on the popular back propagation leering rule.



Training parameters

	a	b
Layer 1	0.11	0.001
Layer 2	0.15	0.003
Layer 3	0.01	0.001

a-learning rate
b-momentum constant

Fig. 3. Neural network machining process simulator

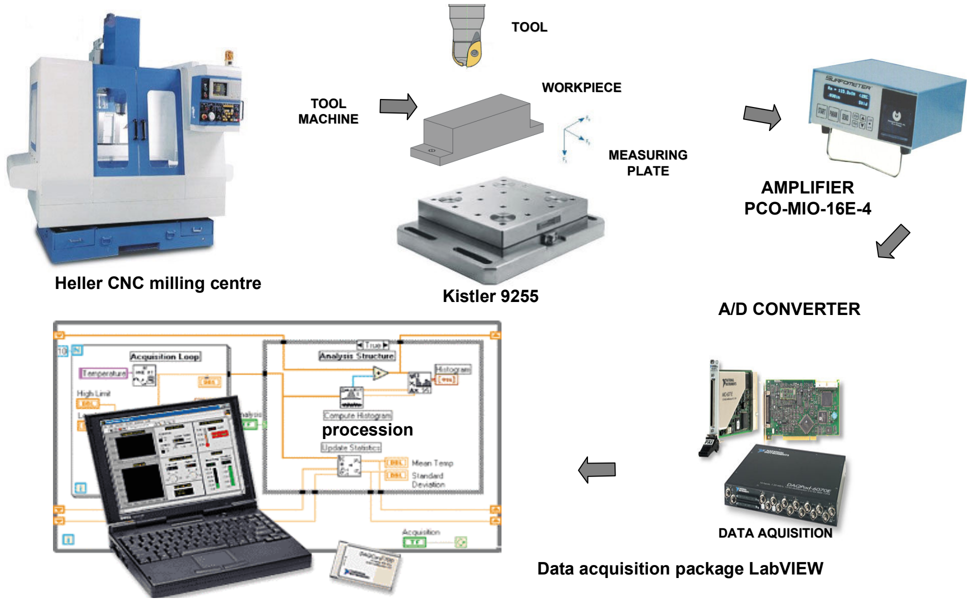


Fig. 4. The experimental set-up

During preliminary experiments it proved to be sufficiently capable of extracting the force and surface roughness model directly from experimental machining data. It is used to describe the cutting process. The NN for modelling (Figure 3) needs four input neurons for milling federate (f), cutting speed (v_c), axial depth of cut (A_d) and radial depth of cut (R_d). The output from the NN are cutting force components and surface roughness, therefore three output neurons are necessary.

5. EXPERIMENTAL EQUIPMENT

The data acquisition equipment used in this acquisition system consists of dynamometer, fixture, hardware and software module as shown in Figure 4. The cutting forces were measured with a piezoelectric dynamometer (Kistler 9255) mounted between the workpiece and the machining table. When the tool is cutting the workpiece, the force will be applied to the dynamometer through the tool. The ball-end milling cutter with interchangeable cutting inserts of type R216-16B20-040 with two cutting edges, of 16 mm diameter and 10° helix angle was selected for machining. The cutting inserts R216-16 03 M-M with 12° rake angle were selected. The cutting insert material is P30-50 coated with TiC/TiN, designated GC 4040.

6. TESTING OF FORCE CONTROL SYSTEM

To examine the stability and robustness of the adaptive neural control strategy, the system is first examined by simulation using Simulink and Labview neural Toolset. Then the system is verified by various experiments on a CNC milling machine (type HELLER BEA1) for Ck 45 and 16MnCr5(Xm) steel workpiece with variation of cutting depth (irregular profile, see Figure 5).

The ball-end milling cutter (R216-16B20-040) with two cutting edges, of 16 mm diameter and 10° helix angle was selected for experiments. Cutting conditions are: milling width R_d=3 mm, milling depth A_d=2 mm and cutting speed v_c=80 m/min. The parameters for neural control are the same as for the experiments for the traditional system performance. To use the neural control structure on Figure 1 and to optimise the feedrate, the desired cutting force is [F_{ref}]=280 N, pre-programed feed is 0.08 mm/teeth and its allowable adjusting rate is [0 to 150%].

The objective of neural control is keeping the metal removal rate (MRR) as high as possible and maintaining cutting force as close as possible to a given reference value. The controller is operated on PC and the adjusted feedrates are sent to CNC.

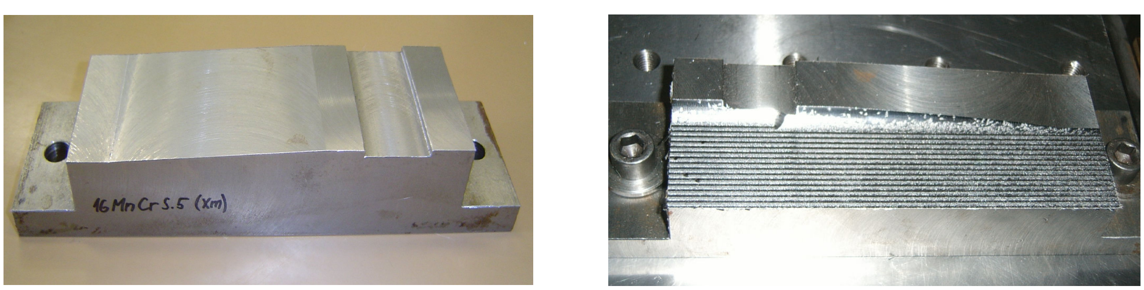


Fig. 5. Workpiece profile

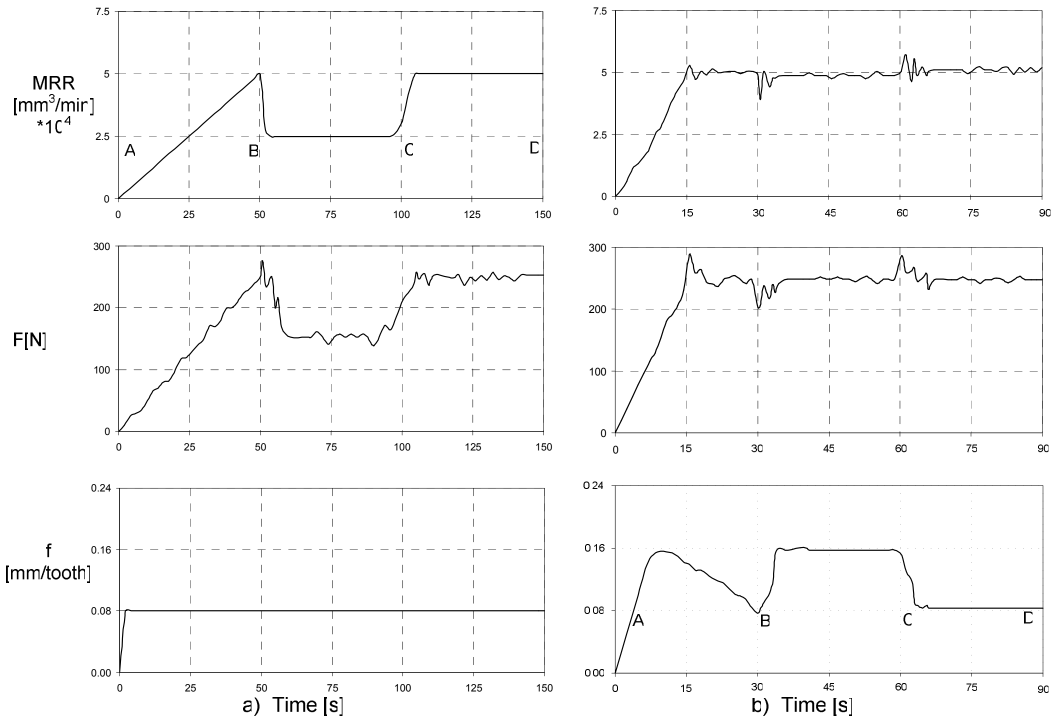


Fig. 6. Experimental results. Response of MRR, rezulting cutting force, feedrate. a) Conventional milling. b) Milling with NN control system.

For this purpose we carry out 18 tests. To optimise the feedrate, the constraints are [F]=240 N, pre-programed feed is 0.08 mm/teeth and its allowable adjusting rate is from 0 to 150%.

7. RESULTS AND DISCUSSION

Figure 6 is the response of the cutting force and the feedrate when the cutting depth is changed. It shows the experimental result where the feedrate is adjusted on-line to maintain the cutting force at the max. desired value. In the first experiment using constant feed rates (conventional cutting-Figure 6a) the MRR reaches its proper value only in the last step. However, in second test (Figure 6b), machining the same piece but using adaptive neural control, the average MRR achieved is much more close to the optimal MRR. Comparing the Figure 6a to Figure 6b, the cutting force for the neural control milling system is maintained at about 240N, and the feedrate of the adaptive milling system is close to that of the traditional CNC milling system from point C to point D. From point A to point C the feedrate of the adaptive milling system is higher than for the classical CNC system, so the milling efficiency of the adaptive milling system is improved. The experimental results show that the milling process with the designed neural controller has a high robustness, stability, and also higher machining efficiency than standard controllers. The experimental results show that the MRR can be improved by up to 27%.

8. CONCLUSION

The purpose of this contribution is to present a reliable, robust neural force controller aimed at adaptively adjusting feedrate to prevent excessive tool wear, tool breakage and maintain a high chip removal rate. The approach was successfully applied to an experimental milling centre Heller BEA 01.

9. REFERENCES

[1] Zuperl, U., Cus, F.: *Optimization of Cutting Conditions During Cutting by Using Neural Networks*, Robot. comput.-integr. manuf., Vol.19, p.p.189-199, 2003

[2] Balic, J.: *A New Nc Machine Tool Controller for Step-By-Step Milling*, Int. j. adv. manuf. technol., Vol.17, p.p.399-403, 2000

[3] Liu, Y., Wang, C.: *Neural Network Based Adaptive Control and Optimisation in the Milling Process*, International Journal of Advanced Manufacturing Technology, Vol.15, p.p.791-795, 1999

[4] Psaltis, D., Sideris, A., Yamamura, A.: *A Multilayered Neural Network Controler*, IEEE Control Systems Magazine, p.p. 17-21, 2000

[5] Cus, F., Balic J.: *Optimization of Cutting Process by GA Approach*, Robot. comput. integr. manuf., Vol.19, p.p.113-121, 2003

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SWARM INTELLIGENCE BASED ROBOT SYSTEM

Abstract: *The paper proposes the design of the intelligent robot system for resistance welding. The robot system incorporates the optimization module based on the swarm intelligence approach. The module is intended for optimization of robot path during welding.*
Key words: *Robotics, Robot cell, Optimization algorithm, Swarm intelligence, Ant colony optimization.*

1. INTRODUCTION

Robotics is gaining increasing importance in the modern world, since the demand for robots is growing due to opening of new, quickly growing areas of their use. At the beginning, as much as three thirds of robots were used, particularly for welding in the automobile industry, while now they are used also in other industrial branches, such as electronics, production and processing of food and drinks, pharmaceutics, production of household appliances etc. They are used wherever high quality of products is required, where the working operations are monotonous and harmful to health.

The basic reasons for automation and robotization are cost reduction, relief of people and assurance of adequate capacity and quality of production. The automation and robotization have a considerable influence on shortening of the manufacturing time, increasing of the capacity and reducing of production costs, which, however, is often hard to calculate accurately in advance and sometimes hard to justify.

The companies view the automation and robotization mainly from the stand point of savings and costs, but increasingly also as a chance to remain competitive in a certain industrial branch.

The paper proposes the design of the intelligent robot system by the swarm optimization of resistance welding application of the older ACMA XR701 robot made by Renault.

Swarm optimization is a swarm intelligence based algorithm for finding a solution to an optimization problem in a search space or model, and predict social behavior in the presence of objectives.

Swarm optimization is a stochastic, population-based evolutionary computer algorithm for problem solving. It is a kind of swarm intelligence that is based on social-psychological principles and provides insights into social behavior, as well as contributes to engineering applications. The swarm optimization algorithm was first described in 1995 by James Kennedy and Russell C. Eberhart. The techniques have evolved greatly since then, and the original version of the algorithm is barely recognizable in the current ones.

Intelligent optimization methods are finding their way into more and more diverse areas of human activity. The reason lies in the increase of the capabilities of computer systems and, consequently, in the increase of opportunities for the development and use of artificial intelligence systems (see, e.g., [1-2]).

Taking into account the problem encountered in designing of the welding application, the paper proposes the optimization algorithm with which the optimum time of transition of the electrode holder between welding spots will be reached.

When comparing the optimization algorithms, the analysis of optimization algorithms and methods was made and on the basis of the findings it was decided to use the optimization algorithm based on swarm intelligence with particle colony algorithm.

2. OPTIMIZATION WITH SWARM INTELLIGENCE (Particle Swarm Optimization)

This section is aimed at presenting the optimization with swarm intelligence and at describing the functioning of the optimization process.

The particle swarm optimization algorithm (PSOA) is the optimization algorithm based on the population stochastic optimization technique. The PSOA was developed by J. Kennedy and R.C. Eberhart in 1995, when they studied the social behaviour of swarms of birds and fish.

The PSOA is very similar to the genetic algorithm. In case of both methods (PSOA and GA) the optimization starts with randomly selected members of population searching for optimums with constant improvement of the subjects of the population in the course of improvements from generation to generation. Unlike the GA, the PSOA does not have evolutionary operators, such as crossover and mutation, which considerably simplifies the PSOA in comparison with the GA. In case of the PSOA the population members are called particles (to which the method owes its name) moving in the space of solutions in such a way that they follow the best particle. Like the GA also the PSOA is used for similar cases: optimization of functions, learning of neural networks, for setting of parameters of controllers by fuzzy logic etc., i.e., wherever the GA has already been well established.

2.1 How PSOA acts

The PSOA simulates the behaviour of swarms of birds or also insects. For example, let us imagine a swarm of birds randomly examining the space when looking for food. In the examined space there is only one source of food. None of the birds know where the food is, but each bird knows how far away from food it is. So, what is the best strategy of each individual bird in the swarm? The most effective strategy is to follow the bird nearest to the food.

The PSOA assumed the searching technique for solving optimization problems. In the PSOA each possible solution (bird, ant, bee) is called particle. All particles have the fitness value (distance of each particle from the food source) calculated by the fitness function for the purpose of optimization. Each particle also has its speed controlling "flying" of particles towards the optimum. The particles fly through the space of solutions so that they follow the currently most optimal particle [3-6].

The PSOA is initialized with the swarm of randomly placed particles into the space of solutions, afterwards searching for optimum from iteration to iteration (generation). In each iteration, each position of the particle is calculated again on the basis of three *"best"* positions of particles stored from iteration to iteration. The first best position of the particle is the position reached out of all hitherto iterations for the individual particle - it is called the local best (l_{best}). The next best position of the particle is the position reached out of all hitherto iterations among all particles - it is called the global best (g_{best}). The last best position of the particle is the position reached out of all hitherto iterations among the neighbouring particles - it is called the neighborhood best (n_{best}).

After searching for the said three best values (l_{best}, g_{best} and n_{best}), the particle speed is calculated for the particle $v_{ij}(k) = (v_1, v_2, ... v_j)i$, where the index i is the number of particles in the population and the index j is the dimension of the space of solutions, followed by the calculation of the new position of the particle:

$x_{ij}(k) = [x_1, x_2, \dots x_j]i$:

$$v_{ij}(k) = c_0 * v_{ij}(k-1) + c_1 * rand(0,1) * (g_{bestj}(k-1) - x_{ij}(k-1)) + c_2 * rand(0,1) * (l_{bestij}(k-1) - x_{ij}(k-1)) + c_3 * rand(0,1) * (n_{bestj}(k-1) - x_{ij}(k-1)) \tag{1}$$

and

$$x_{ij}(k) = x_{ij}(k-1) + v_{ij}(k). \tag{2}$$

The function *rand(0,1)* calculates the random value between 0 and 1 including 0 and 1. The constant c_0 represents the value of speed of particle from previous iteration and represents the particle movement inertia. The usual value of c_0 is between 0 and 1 (best values are slightly below 1). The constants c_1, c_2 and c_3 are the learning constants and, usually, have the value of approximately 2. The calculation of the fitness function represents the conversion of the j-dimensional information about the particle position in the space of solutions into a one-dimensional scalar value representing the quality of the particle position and/or its distance from the optimum.

The simple pseudo code for building of the computer programme of PSOA is as follows:

FOR each particle
  Initialize particle
END
DO
  FOR each particle
    Calculate fitness value
    IF fitness value is better than l_{best}
      set current value of particle as new l_{best}
    END
  END
Select particle with best fitness value of all particles in hitherto iterations as g_{best}.
  FOR each particle
  Calculate particle speed by equation (1).
  Calculate new particle position by equation (2).
  END
WHILE maximum of iterations or minimum criterion has not been reached.

3. TRAVELLING SALESMAN PROBLEM

Optimum movement between welding spots represents the travelling salesman problem. Therefore, this section of the paper presents the theoretical and applicative approach to solving the optimization travelling salesman problem with the algorithm of ant colony optimization for the case of resistance spot welding application.

3.1 Solving minimum path in graph

The theoretical approach requires the specification of the facts important in searching for minimum paths in the graph.

Similarly as in case of natural ants, the task of the artificial ants is to find the minimum path between points in the graph. For example, the set *G=(N,A)* represents the linked up graph, where the number *N* is the number of all points of the graph and the number *A* is the number of all paths.

The number of points is $|N|$ = n. Solution of the task (Fig.1) is the path in the graph connecting the starting point *f* with the desired point *d(target)*, the length being determined with the number of transitions on the path [7-9].

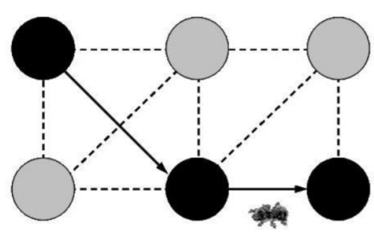

Fig. 1. Searching for minimum path in graph

Variable τ_{ij}, representing the artificial trace of the feromone, is connected with each transition *(i,j)* in graph *G*. Thus, the ants leave the trace of feromone. In each point of the graph the stochastic (random) decision as to which point is the next occurs. The *k-th* ant placed in point *i* uses the feromone trace τ_{ij} for the calculation of probability to which point $j \in N_i$ it is necessary to go. N_i is the group of neighboring points *i*. The probability of selection of point j is given with the term (3):

$$p_{ij}^{k} = \begin{cases} \dfrac{\tau_{ij}}{\sum\limits_{j \in N_i} \tau_{ij}}, & j \in N_i \\ 0, & j \notin N_i \end{cases} \tag{3}$$

As long as there is a solution, the ant leaves the feromone trace on the existing path $\tau_{ij}(t) \leftarrow \tau_{ij}(t-1) + \Delta\tau$. However, the solution so defined can lead to convergence towards optimum solution, if the mechanism of feromone evaporation is introduced. In each interaction the quantity of feromone is exponentially reduced according to the following term (4):

$$\tau \leftarrow (1-\rho)\tau \quad , \rho \in [0,1] \tag{4}$$

The behaviour of the algorithm depends on the number of neighbors of each point. If the points have more than two neighbors, the algorithm loses its stability.

Consequently, also the choice of parameters becomes difficult. The algorithm can be improved by changing the properties of the colony and by changing the individual ants in the colony.

For testing of the ant colony algorithm the algorithm, by which the above theoretical findings were verified also in the simulation, has been created in the programme environment MS Visual Studio.Net. The graphic environment has been created, with which solving of the travelling salesman problem between randomly placed spots was simulated. By changing the ant colony algorithm parameters various mutual dependences of the ant colony parameters were simulated [10].

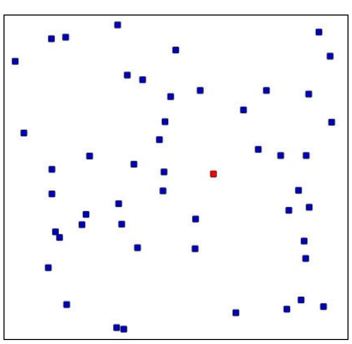

Fig. 2. Randomly placed spots

Fig. 2 shows the programme environment with randomly placed spots. The solution to be found by the ant colony algorithm represents the shortest path between all spots (in our case these are welding spots). Throughout the simulation process the solutions of the current iteration can be accompanied.

4. SIMULATION EXAMPLES OF THE WELDING APPLICATION OPTIMIZATION

The following are different examples of use of the optimum programme with ant colony. Particularly interesting is the incorrectly arranged configuration of placing of spots (random placing). It can be noticed on the final result that it is not deterministically determined and that the case can arise, when two output solution do not give identical solutions with the same number of spots and with the same parameters.

4.1 Incorrectly/randomly placed spots

In case of incorrect placing, the target function has a great number of local optimums and it may happen that the algorithm gets "caught" into the local optimum. As even the optimization with the ant colony algorithm does not represent an exact solution of optimization, it may happen that the final result is not the optimum solution. This can be seen in the examples in Fig. 3 and 4.

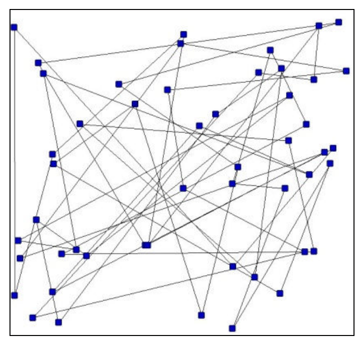

Fig. 3. First solution of travelling salesman problem

The first solution of the travelling salesman problem is the solution with random placing of spots in iteration 12 and with adjusted parameters (α = 1, β = 0, Rho = 1), the final solution being the length of 303333 units.

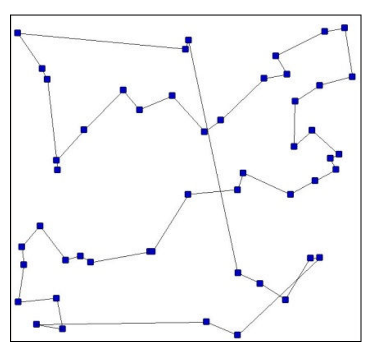

Fig. 4. Second solution of travelling salesman problem

The second solution of the travelling salesman problem is the solution with random placing of spots in iteration 11 and with adjusted parameters (α=1, β=0.5, Rho=1), the final solution being the length of 69213 units, which is a better solution than in the first case.

The layout of spots has a very important influence on the behaviour of the optimization algorithm of the ant colony. If the spots are correctly (circularly) arranged, the algorithm converges very quickly, irrespective of the spot number. In this case it is not necessary and/or not reasonable to use large colonies of ants (great number of ants).

Also the analysis of mutual influences of the parameters alpha, beta and Rho is interesting, since each of them has an important influence on the problem solution. The analysis of said parameters, mutual influences and the influence of the ant number on the final solution will be extensively included in further research work [11].

5. CONSLUSION

The paper has presented an example of building of the intelligent robot system by the swarm intelligence.

The central part of the research has been devoted to the area of use of swarm intelligence for optimization of the robot welding system. The primary design concepts of the swarm intelligence are adopted from the world of animals, whose life cycle associates them into colonies, by copying the laws from the natural life of swarms into the computer artificial life of the swarm, called particle swarm theory, and thus a computer algorithm for solving optimization problems in robot systems is obtained.

Through building of the applicative programme environment, the findings of some well-known authors (Dorigo, M., Gambardella, L.M.,), stating that the spot arrangement importantly influences the behaviour of the optimization algorithm of ant colony have been confirmed. If the spots are correctly (circularly) arranged, the algorithm converges very quickly, irrespective of the spot number. In this case it is unnecessary and/or inappropriate to use large ant colonies (great number of ants). When the spot arrangement is incorrect/random, it is already more contestable whether the algorithm is optimum. Also the final solution is not unambiguously determined.

The findings reached by simulations have been successfully incorporated into the robot welding application and the minimum time of transition of robot electrode holder between the individual welding spots has been assured

6. REFERENCES

[1] Pandza, K., Polajnar, A. and Buchmeister, B., (2005) *Strategic management of advanced manufacturing technology*, Int. j. adv. manuf. technol., vol. 25, 3/4, (pp. 402-408),

[2] Buchmeister, B., (2008) *Investigation of the bullwhip effect using spreadsheet simulation*, Int. j. simul. model., vol. 7, no. 1, (pp. 29-41), http://dx.doi.org/10.2507/IJSIMM07(1)3.093.

[3] Dorigo, M., Gambardella, L.M., (1997) *Ant Colonies for the Traveling Salesman Problem*, BioSystems, (pp. 73-819).

[4] TSPLIB:http://www.iwr.uni-heidelberg.de/groups/comopt/software/TSPLIB95, [accessed 10/5/2008

[5] Dorigo, M., Maniezzo, V. and Colorni, A., (1996) *Ant System: Optimization by a colony of cooperating agents*, IEEE Transactions on Systems, Man, and Cybernetics - Part B, (pp. 29-41).

[6] DiCaro G., Dorigo M., (1998) AntNet: Distributed Stigmergetic Control for Communications Networks, J. Artif. Intell. Res. 9, (pp. 317-365).

[7] Dorigo M., Gambardella L. M., (1997) *Ant Colonies for the Traveling Salesman Problem*, BioSystems 43, (pp. 73-81).

[8] Gambardella L. M., Taillard, E. D. and Dorigo M., (1999) *Ant Colonies for the Quadratic Assignment Problem,* J. Op. Res. Soc. 50, (pp. 167-176).

[9] Fu, K.S., Gonzales, R.C. and Lee, C.S.G., (1987) *Robotics Control, Sensing, and Intelligence*, Mc'Graw and Hill International edition.

[10] Bonabeau, E., Dorigo, M. and Theraulaz G., (1999) Swarm Intelligence: From Natural to Artificial Systems, Oxford Univ. Press, New York.

[11] Foo, K.S., Gonzales , R.C. and Lee C.S.G., (1987) Robotics Control, Sensing, Vision and Intelligence. International edition, McGRAW HILL.

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MAIN DEVELOPMENTS IN CUTTING TECHNOLOGY

***Abstract**: Reviewed in this paper are some of the most modern methods which are used in research of metal cutting technologies, as well as the methods which are already established in everyday application. Discussed are the methods of modeling and simulation of metal cutting processes, application of artificial intelligence in modeling and optimization of metal cutting processes, monitoring of cutting processes, high-speed cutting (HSC), high-productivity cutting (HPC), machining of hard materials and dry cutting or minimum-lubricant micro-spraying (MMS). The basics of every technology are presented with a discussion of their possible applications in research and manufacturing*

***Key words:** modeling, simulation, monitoring, HSC-machining, HPC machining, MMS-systems, Dry machining.*

1. INTRODUCTION

Cutting technology is multidisciplinary with economics playing an increasingly important role. Recent studies [1] came to the conclusion that there should be a strong integration of technologies and management using information technologies (IT), for example, integration of the process planning and production planning, simulation of manufacturing systems, agile manufacturing, fast redesign of new products, modeling of manufacturing equipment performance, including the human operator, functional product analysis, virtual machining and inspection algorithms etc.

Material removal processes can take place at considerably higher performance levels in the range up to Q_w = 150 - 1500 cm3/min for most workpiece materials at cutting speeds up to some 8.000 m/min.

The key change drivers in the case of cutting technology include: diminishing component size, enhanced surface quality, tighter tolerances and manufacturing accuracies, reduced costs, diminished component weight and reduced batch sizes (Figure 1). These change drivers have a direct influence on the primary inputs to the cutting process namely the cutting tool and tool material, the workpiece material and the cutting fluid.

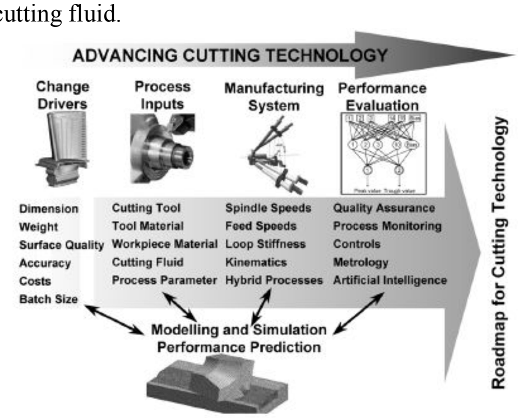

Fig. 1. Primary aspects associated with advancing cutting technology

Figure 2 shows the capability of micromachining relative to other processes such as laser machining, EDM, grinding and the LIGA process. It can be seen that Ra values in the range down to almost 5 nm can be attained for features down to 1µm. For the case of "normal machining" e.g. CNC turning and milling machines, accuracies of 10 to 100 µm can be achieved

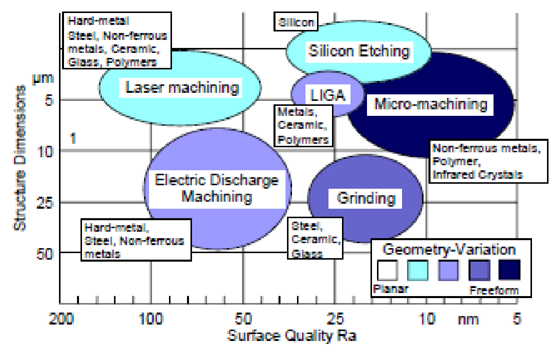

Fig. 2. Micromachining relative to other machining processes [1]

In parallel with the achievement of increased manufacturing accuracy there has been significant development in the reduction of the size of engineering components. In the period 1989 to 2001, the weight of the ABS system for automotive application has reduced from 6.2 kg to 1.8 kg. One of the important issues associated with miniature components is that the surface area to volume ratio increases. This being the case, the surface and its integrity takes on increasing importance. One of the key inputs to the cutting process is the cutting tool. When CIRP was founded, the range of cutting tool materials available was restricted primarily to: tool steels, high speed steel, stellite and tungsten carbide with ceramic materials coming on stream. For economic manufacture, the throughput time is the critical issue and the development of cutting tool materials has permitted a significant increase not just of cutting speed but also of feed rates.

The workpiece material has also been the subject of extensive development in recent years. Figure 3 shows an overview of the hard turning process as related to the ISO standard and the Rz values achievable [1]. The development is towards reduced Rz values and towards tighter ISO classes. Under controlled conditions IT 3 is now achievable at Rz values of below 1µm.

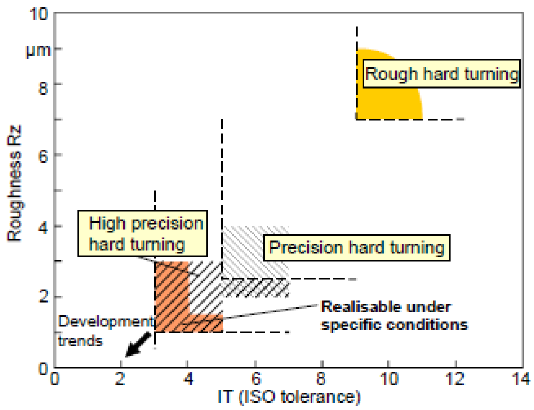

Fig. 3. Roughness versus IT Tolerances for Hard Turning

In the last 2 years emphasis has been placed on High Performance Cutting (HPC) and some fundamental issues are being addressed by the CIRP Working Group on High Performance Cutting (HPC) which was established in 2002. The working group identified the following aspects of cutting as being of particular significance in the quest for high performance cutting at high levels of productivity:

- Non Productive Times (NPT) in cutting processes,
- Dry and Near Dry Cutting (usage of minimal quantities of cutting fluids),
- Chip formation and chip handling processes and
- Strategies for burr minimization.

The economic efficiency of production facilities is a central issue for cutting technology. In-plant, adding of value to products and workpieces only takes place during essential operating time. Conventional processes such as grinding and turning have come under close scrutiny from a productivity perspective and process chains have been analyzed and redesigned to minimize throughput times. The trend in recent years has been towards integrated processes. For example, by replacing grinding with hard turning, process steps can be eliminated. The requirement for integrated processes place new and demanding challenges on the design and technology of the cutting processes. In parallel, it is also necessary to consider the technological and economic developments associated with the machine tool which has taken place in order to achieve these cutting speeds and the high level of productivity demanded.

2. PREDICTIVE PERFORMANCE

We generally use the terms modeling and simulation interchangeably in manufacturing research literature. In the case of cutting, there are many phenomenon that are not easily observed or not subject to direct experimentation so the models are developed so that the influence of a number of process parameters can be simulated using this model. Common models used are based on Eulerian or Lagrangian finite element techniques. Four primary categories of methodologies for modeling of cutting are evident over the past several decades.

- analytical modeling (determining the relationship between the forces in cutting based on cutting geometry and including experimentally determined values of shear angle, friction conditions and chip flow angle; for example, Ernst and Merchant's early work,
- slip-line modeling (predicts mechanical response and temperature distributions based on assumptions about slip line field geometry in the shear zone and around the tool; for example, Oxley's work,
- mechanistic modeling (predicts cutting forces for a wide range of complex machining processes based on the assumption that cutting forces are the product of the uncut chip area and specific cutting energy where specific cutting energy is empirically derived from workpiece material, cutting parameters, and cutting geometry; for example the work of Tlusty,
- finite element modelling (FEM techniques use small mesh representations of the material and tooling as the basis for determining material stress and strain conditions and, ultimately, flow of material based on assumptions of continuity between adjacent elements)

The application of these modeling techniques covers the range of cutting processes and interests including cutting forces (static and dynamic), power, tool wear and life, chip flow angle/curl/form, built up edge, temperatures, workpiece surface conditions and integrity, tool geometry, coating and design influences, burr formation, part distortion and accuracy, tool deflection, dynamic stability limits and thermal damage. Processes modeled range from orthogonal cutting to multi-tooth milling, hard-turning and drilling. The predominance of the work, as evidenced by research publications, is in turning (plane face tools), face milling, drilling (twist drills) and end milling and slotting.

A number of application areas are described here that have been motivated by increasing cutting performance where modeling has been shown to be effective (cutting hard materials, burr formation, chip formation, temperature and tool wear in cutting).

Understanding the mechanisms of chip formation combined with the thermo-mechanical influence of the work-tool zone is critical to controlling the generation of a machined surface by pure plastic deformation required in this application. Models describing elements of this are based on "mechanics of plasticity" analyses and, in particular, the work as early as 1964. They report on the use of 3D turning simulations using a commercial finite element code to estimate cutting forces and chip geometry. The simulation is based on flow stress data extrapolated from tensile test data using a velocity modified temperature. The cutting simulation includes realistic tool materials and a developed friction model to account for both sticking and sliding conditions. Chip flow, chip morphology, cutting forces, residual stresses, and cutting temperatures are predicted.

Burr formation – Understanding the mechanics of burr formation has been greatly enhanced by modeling of the burr formation process analytically, mechanistically and with finite element techniques. Although useful, analytical models are limited in their abilities to accommodate the important process variables associated with the tool geometry and exit conditions critical in burr formation. This is especially true in the case of drilling where drill geometry effects can substantially encourage or hinder burr formation Chip formation – Much attention has been paid to understanding the mechanisms of chip formation and the role of influential parameters. Traditionally, studies have relied on the collection of extensive sets of experimental data. The modeling of chip formation using any of the techniques outlined above has been challenging. However, much progress is being made and models, especially finite element, are having an impact on the ability to understand this complex aspect of cutting. This is due to the wide variety of cutting tool geometries, coatings, and tool materials and the inadequacy of current modeling techniques for fully predictive models. A goal is to predict chip form and breakability for a given tool geometry/work material combination. An explicit dynamic thermo-mechanically coupled finite element modeling technique was evaluated for chip breakage simulation in 2-D. The increasing use of high speed machining has encouraged modeling of chip formation as well since the optimization of cutting at high speeds (for example, up to 2000 m/min cutting speed) with exotic materials is not straightforward. Temperature and tool wear in cutting – Beside burr formation, cutting forces and chip formation quality of the cutting process is determined by the tool wear behavior and thermal load on the tool and workpiece [5]

A newer class of modelling of cutting, at the nanometer level, is referred to as molecular dynamics modelling and is distinguished from the other techniques discussed above. Suited best for simulating processes with chip sizes and surface features well below those capable of simulation with more "traditional" techniques as classical mechanics and finite element methods, molecular dynamics was first applied to ultraprecision in the early 90's. Molecular dynamics theory is well based in physics and is comprised of descriptions of the interactions between atoms at the atomic level instead of the electronic level thus allowing atomic level simulation of behavior of materials. To improve the correlation of experimental results with theoretical prediction, empirical elements have been added from material science. Time dependent processes such as surface generation and roughness development in cutting can be studied at this atomic level. Since this offers insight into the subsurface region of the work surface, effects such as dislocation formation and stress relief can be simulated and observed in both two and three dimensional machining configurations. With the increase in micromachining to create molds and other features for a variety of components, it is interesting to see the "scale-ability" of larger scale phenomena to the nanoscale and, thus, the ability to control the quality of these components.

3. HIGH SPEED MACHINING

The inventor of HSM, C. Salomon, found that above a certain cutting speed machining temperatures start dropping again. His fundamental research showed that there is a certain range of cutting speeds where machining cannot be made due to excessively high temperatures. For this reason, HSM can also be termed as cutting speeds beyond that range. In compliance with modem knowledge, some researchers modern high-speed machining as machining whereby conventional cutting speeds are exceeded by a factor of 5 to 10.

With the wide use of CNC machines together with high-performance C AD/C AM systems, high-speed machining (HSM) has demonstrated its superior advantages to other rapid manufacturing techniques. In addition to increased productivity, HSM is capable of generating high-quality surfaces, burr-free edges, and virtually stress-free components after machining, and can be used to machine thin-wall workpieces, because the cutting forces involved in HSM conditions are lower. Another significant advantage of high-speed machining is minimization of effects of heat on machined parts. Most of the cutting heat is removed, reducing thermal warping and increasing the life of the cutting tool. In many cases, the need for a cooling fluid is eliminated. Furthermore, the elimination of cutting fluids reduces subsequent contribution to pollution and aids in the recovery and recycling of such expensive materials as aluminum-lithium alloys. Since HSM has so many advantages, it is widely used in the aerospace industry, automotive industry, precision engineering industry for machine tools, equipment, and tooling used in the manufacture of domestic appliances, optics, etc.

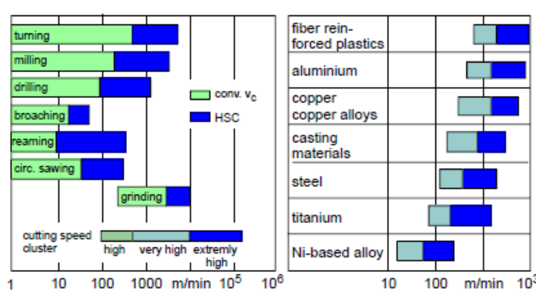

Fig. 4. Achievable cutting speeds [8]

Although high-speed milling of aluminum has been applied in industries successfully for more than a decade, high-speed applications on difficult-to-cut materials, such as titanium alloys, are still relatively new. Boeing's military aircraft group has begun to apply its expertise with aluminum toward faster milling of titanium. And they concluded that compared to aluminum, titanium imposes certain constraints. Speed is constrained as heat builds up more quickly. But within those constraints, there is still considerable room for faster cutting.

Titanium alloys have been widely used in the aerospace, biomedical, automotive and petroleum industries because of their good strength-to-weight ratio and superior corrosion resistance. However, it is very difficult to machine them due to their poor machinability. During the machining of titanium alloys with conventional tools, tool wear progresses rapidly because of their low thermal conductivity and high chemical reactivity, resulting in higher cutting temperature and strong adhesion between the tool and the work material. Titanium alloys are generally difficult to machine at cutting speeds of over 30 m/min with high-speed steel (HSS) tools, and over 60 m/min with cemented tungsten carbide (WC) tools, resulting in very low productivity. The performance of conventional tools is poor when machining TÍ6A14V. In 1955, was pointed out that machining of titanium and its alloys would always be a problem, regardless of the techniques employed to transform the metal into chips. The poor machinability of titanium and its alloys have led many large companies (for example Rolls-Royce and General Electrics) to invest much in developing techniques to minimize machining cost.

4. RECENT ADVANCES IN MECHANICAL MICROMACHINING

4.1 Process physics

Micromachining incorporates many characteristics of conventional machining. At the same time, micromachining raises a great number of issues mainly due to size or scale. Downsizing the scale of machining does not change the general characteristics of the process to some reasonable limit. However, when either the ratio of part size to be produced or size of the microstructure of the work material to the tool dimension used (say diameter) becomes small (approaching a single digit), size effects can change the whole aspect of machining. There are two different aspects of size effects of concern, e.g. when the depth of cut is on the same order as the tool edge radius, and where the microstructure of workpiece material has significant influence on the cutting mechanism
.

4.2 Homogeneous and isotropic micromachining

Many materials are considered to be homogeneous and isotropic in machining regardless of the tool edge radius/chip thickness ratio. The main difference between micromachining and micromachining resides in the cutting mechanism. In general, the cutting mechanism in micromachining is mainly shearing of the material in front of the tool tip and forming a chip. Micromachining relies on more complicated mechanisms depending on the degree of the size effect. Thus, the size effect is defined as the effect due to the small ratio of the depth of cut to the tool edge radius but for which the material still behaves as homogeneous and isotropic.

4.3 Anisotropic machining

When the tool dimension or a feature to be generated is of the same order as the grain size, or where material cannot be treated as isotropic and homogeneous, the cutting mechanism differs substantially from conventional machining. This can also be observed in conventional machining of single crystal or anisotropic materials however there is still a significant difference due to size effects. Typically, the cutting edge radius of a sharpened single crystal diamond tool is on the order of 10 nm and, then, the depth of cut with such a tool can be realized in the submicron range. Most polycrystalline materials are thus treated as a collection of grains with random orientation and anisotropic properties. Cutting force varied as the tool passed grain boundaries. It was suggested the use of about ten times larger depth of cut than the grain size for a specific material to avoid the crystallographic effects of grains.

Both isotropic and anisotropic cutting are greatly influenced by the ratio of the depth of cut to the effective cutting edge radius of the tool. In micromachining, the edge radius of the tool tends to be the same order-of-magnitude as the chip thickness. Thus, a small change in the depth of cut significantly influences the cutting process. This ratio predominantly defines the active material removal mechanism such as cutting, plowing, or slipping and thus the resulting quality, surface roughness for example. The concept of a minimum chip thickness, below which no chip will form, or a minimum depth of cut below which no material removal will occur, has been investigated by a few researchers. This is an attempt to understand the necessary minimum chip thickness to ensure proper cutting and avoid plowing and sliding of the tool.

4.4 Surface and edge finish

Various problems such as surface defects, poor edge finish, and burrs in conventional machining have plagued conventional manufacturing for some time. Some of these problems have been avoided by post processing and process optimization.

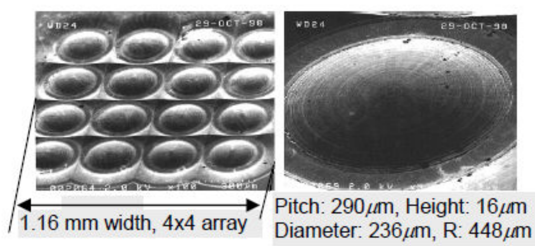

Fig. 5. Micro-lens array of silicon [4]

These problems are also significant in micromachining and require much more attention because, in many cases, inherent material characteristics or limitations in part geometry do not allow some of the solutions used in macromachining. Figure 5 shows micro-lenses on a silicon plate fabricated by rotating a circular arc diamond cutting edge and feeding the tool along an axis perpendicular to the silicon plate. The machining method corresponds to plunge cutting by a rotational tool. A suitable choice of cutting conditions allows for cutting of brittle materials.

4.5. State of art of ultra precision machine tools

Early development of ultra precision machine tools was largely geared towards the machining of large-scale optical devices. Precision diamond turning machines are a typical example.

In recent years, multi-axis control ultraprecision machining centers with varying degrees of freedom are commercially available. They are used to produce small workpieces with complex geometries and microscale patterns and texture such as molds and dies for CD pickup lenses, contact lenses, Fresnel lenses, etc. driven by increasing market trends in consumer products.

Currently available multi-axis controlled ultraprecision machining centers are in fact a progressive developmental form of traditional machine tools. Mechanisms include a screw-based system driven by a rotary motor, linear motor drives, and a ball screw or aero-/hydrostatic screw-based system. With respect to the table slide mechanism, two common configurations include the roller slide system or aero-/hydrostatic slides in order to feed the table with low friction and high straightness. Bearings for rotational elements are similar to those found in the table slide mechanism.

Fig. 6. Commercial 5-axis control ultraprecision machining center [9]

4.6 Micro-tools

Commercially-available micro-drills are typically on the order of 50 µm in diameter, and have similar twist geometry to that of conventional drills. Flat drills with simplified geometries are more common for diameters smaller than 50 µm.

Fabrication of micro-tools is another challenge in micromachining. Imprecise geometry and the irregularity of tools often negate the advantages of ultra precision process control, state of the art machine tools, and ultra fine tuning of process parameters. Figure 7. a-c shows the tool geometry deviation with respect to the size of the tool; as the tool size decreases from 2 mm to 0.2 mm, the deviation of the given tool geometry from the tool design increases. Also, scaling effects can play a significant role in process physics, which are closely related to the cutting mechanism, caused by a change in tool geometry during cutting.

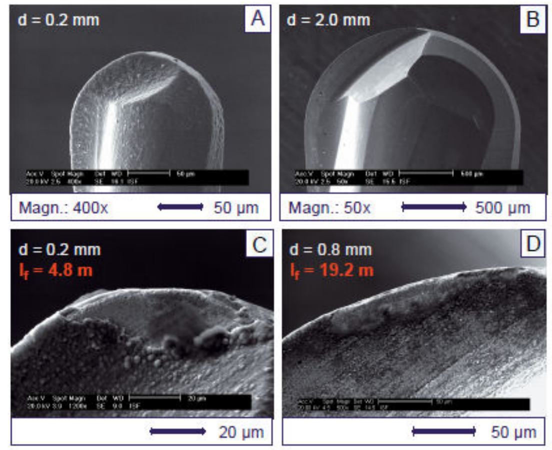

Fig. 7. Scaling effect on tool geometry and wear (work material: 40CrMnMo7, 50 HRC, cutting speed: Vc = 200/100 m/min, depth / width of cut: ap = ae = 0.04 x d, feed: fz = 0.01 x d, number of teeth: 2, down milling, tool material: cemented carbide with TiAlN coating) [10].

Due to its hardness, single crystal diamond is the preferred tool material for microcutting. Diamond cutting tools were used in most of the early micromachining research due to their outstanding hardness (for wear resistance) and ease by which a sharp cutting edge could be generated through grinding. However, as diamond has a very high affinity to iron, microcutting is mostly limited to the machining of nonferrous materials such as brass, aluminum, copper, and nickel. Hence, micromachining tests have been limited to non-ferrous materials. In [10] developed a machine tool fabrication process utilizing ELID grinding technology to fabricate various cross sectional shapes of the tool with high surface quality, Figure 8.

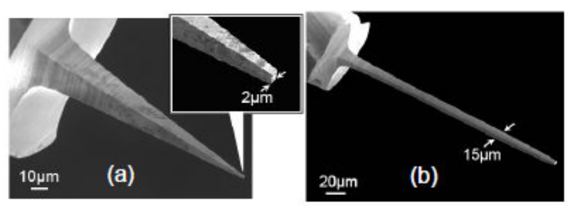

Fig. 8. Overviews of produced micro-tools under optimum machining conditions: (a) Ultra precise tool (b) Extremely large aspect ratio micro-tool [10].

4.7 Microfactories

In general, micromachining is performed on precision machine tools with conventional dimensions. However, the work size and the required power for processing are relatively much smaller for micromachining. Downsizing the machine tool itself has been pursued by several machine tool builders and researchers in order to achieve economic benefits such as structural cost savings, shop floor space savings, energy reduction and performance benefits including reduction of thermal deformation, enhancement of static rigidity and dynamic stability as well.

One unique effort is to build a microfactory system where one or several machine tools are small enough to be placed on the desktop. In late 1980s, Japanese researchers started fabricating microfactory prototypes, and the first realization of the concept was a microlathe smaller than a human palm with 1.5W spindle motor [11], followed by more powerful and precise desktop and portable machines.

5. TURNING OF HARDENED STEEL

In our days the machining of steel parts in hard state has great significance. The primary goal is to substitute the grinding technology with turning, milling or drilling.

Turning operations are called hard turning, which are performed

- in order to required shape and surface roughness,
- to substitute grinding operation, on at least 45 HRc hard steel part, with hard metal, ceramic or polycrystalline cubic boron nitride (PCBN) tools,
- in CNC lathe machines or a rigid conventional lathes.

The Table l shows the advantages and disadvantages of hard turning [7].

Hard turning	
Advantages	Disadvantages
Short operation	Heavy tool wear
Less investment	Cutting edge is reactive to break
Free grinding capacities	Rigid machine tool with high spindle speed
High accuracy in case of accurate blank	Up-to-date CNC control is needed (tool break control)
The heat of cutting is removed by chips	Tool holders for high speed machining is required
2-4 times higher material removal speed	Application of up-to-date tool materials and coats
Good surface roughness	Inhomogeneous part material is unfavorable
More operation elements are performed in one setup	In case of grinding the sparking process can increase accuracy and decrease surface roughness
Appropriate for dry machining	In certain cases, better surface roughness is produced by grinding

Table 1. Advantages and disadvantages of hard turning

The occasional occurrence of white layers in machining hardened steel proves that short-time metallurgical processes can be induced by the respective chip formation mechanisms. The occasional occurrence of white layers in machining hardened steel proves that short-time metallurgical processes can be induced by the respective chip formation mechanisms. The chip formation mechanisms in hard machining were first investigated by Ackerschott [7], who postulated high compressive stresses in the surface layer causing cracks in front of the cutting tool under an angle of 45° to the surface. At the same time the material is plastically deformed by the rounded cutting edge. The sliding of a chip segment along the crack reduces the compressive stresses until a further crack is induced due to the continuous movement of the tool.

In high speed cutting of steels segmented chips have also been observed. M´Sbaoubi and Lebrun postulated that at very high cutting speeds the high strained regions are localised in thin bands called adiabatic shearing bands. In these regions, white layers occur, which are expected to consist of austenite.

Due to their characteristics, the processes hard turning and grinding are not arbitrarily interchangeable. They rather complement each other. This motivated the development of machine tool concepts, which permit the hard turning and grinding operations in one chucking. As a result, the advantages of each process can be combined, Figure 9. [7].

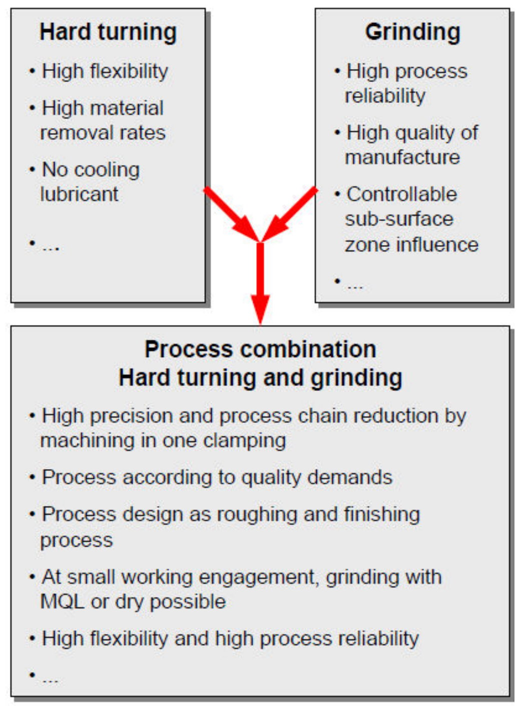

Fig. 9. Utilization of process specific advantages by process combination [7]

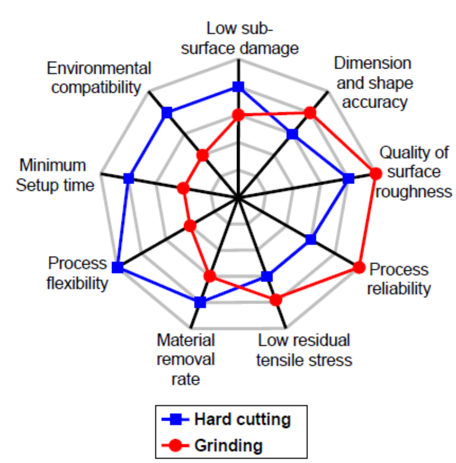

Fig. 10. Qualitative overview of capability of hard cutting and grinding processes

6. MONITORING OF CUTTING OPERATIONS

The complex interactions between machines, tools, workpieces, fluids, measurement systems, material handling systems, humans and the environment in cutting operations requires that sensors be employed to insure efficient production, protect investment, indicate needs for maintenance, and protect workers and the environment. Early developments have proven that process monitoring is essential for economic production. Most significant for availability and quality are tool wear and tool breakage. An excellent overview of monitoring of machining for tool condition monitoring can be found in [3]. Standard approaches on process monitoring are the measurement or identification of the interaction between process and machine structure. Particularly the vibration behavior plays an important role, since it significantly affects the workpiece accuracy as shown by simulation and experiment e.g. in [3].

An indication of the evolution of monitoring systems in manufacturing was presented by Tönshoff. An updated table from [1] illustrating this evolution is shown in Figure 11 and indicates the stage of development or implementation of the application area. Frankly, there has not been much advancement from the state outlined by Tönshoff. But now there are additional requirements for increased flexibility. Specifically, sensor systems must be able to be interfaced with open system architecture controllers for machines and systems must be designed to accommodate needs of so called "reconfigurable" systems. Activity in both of these areas is still predominately in the research stage with few industrial applications.

To achieve the "intelligent machine tool," which has as its objective to be able to maintain an optimized cutting performance, requires sensor along with control systems with the knowledge accumulation capability to store the acquired "experience" for use in future production.

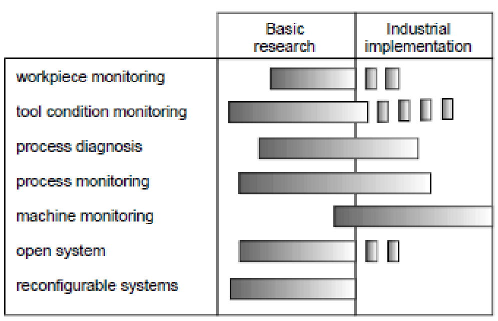

Fig. 11. Monitoring systems evolution in manufacturing

Further, given the development of reconfigurable systems, monitoring strategies must be flexible enough to accommodate different machine configurations and processes. This would be logically tied in with machine control hardware and software in an "open" environment. In that sense, this would be an example of the "intelligent sensor". Recent developments aim at different directions. Some are based on new fields of production, other use new sensor concepts. Most process monitoring systems are designed for processes of limited complexity like drilling, thread cutting or straight pass milling. Whereas solutions for sculptured surface milling, especially ball end finishing operations, are still not available on the market. These have a great significance in die and mould finishing with only small process forces. New approaches use special sensors to measure force or accelerations for process monitoring in milling of sculptured surfaces.

The standard fixed threshold method has been adapted to be more universal. Dynamic boundaries combined with neural networks. Neural networks have proven to be effective for small size productions. Especially flank wear of tools in milling can be monitored with neural networks.

It seems to be an obvious solution to use dynamic systems for the supervision of a dynamic process like a cutting process. Probably due to stability problems, the output of pure dynamic networks is limited. A promising approach is a model in which a static and a dynamic networks are combined hierarchically as a "state space representation" of the cutting process. The field of high speed cutting (HSC) introduces new dynamic effects to the process monitoring. The standard analysis methods dominated by the Fast Fourier Transformation (FFT) are extended by Wavelet Transforms and Cepstrum Analysis, the later proven to be especially sufficient for machine and process monitoring.

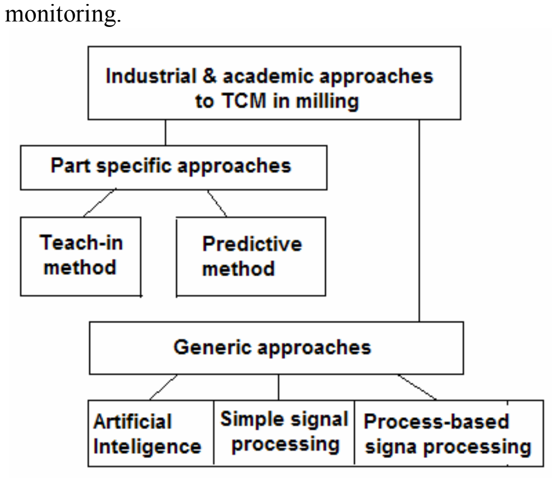

Fig. 12. TCM Classification

6.1 Integrated sensors

Considering the range of sensors and applications in the cutting process, the machine tool requires a large number of sensors. Integrated sensor systems can today accomplish several tasks and cooperate to insure process optimization. Cutting performance overall requires reduction in process and non-productive times, verification and maintenance of process capability, while reducing direct production costs and ensuring environmentally-friendly production. Inasaki discussed the concepts of *replicated* sensor systems and *disparate* sensor systems referring to similar sensors integrated to provide greater reliability and different types of sensors integrated to provide flexibility in sensor system application, respectively.

6.2 Integrated workpiece quality evaluation

Finally, we look at the ability to integrate evaluation of the workpiece quality into cutting performance. This remains an illusive goal due to many challenges. The first challenge is defining workpiece quality quantitatively over the range of processes and parts manufactured (for example, subsurface damage in machining, or surface roughness). Second, measuring or somehow assessing the quality elements of the workpiece as part of the production environment (for example, surface roughness that is dependent on so many independent variables in the process such as tool condition). Finally, it is not clear how to incorporate this information in some way into the machine and process control scheme.

7. DRY MACHINING AND MINIMUM QUANTITY LUBRICATION

A change in environmental awareness and increasing cost pressures on industrial enterprises have led to a critical consideration of conventional cooling lubricants used in most machining processes. Depending on the workpiece, the production structure, and the production location the costs related to the use of cooling lubricants range from 7 - 17% of the total costs of the manufactured workpiece [2]. By abandoning conventional cooling lubricants and using the technologies of dry machining or minimum quantity lubrication (MQL), this cost component can be reduced significantly. Besides an improvement in the efficiency of the production process, such a technology change makes a contribution to the protection of labor and the environment. The reduction of substantial exposure to cooling lubricants at the work place raises job satisfaction and improves the work result at the same time. Furthermore, an enterprise can use economically-friendly production processes for advertising purposes, which leads to a better image in the market.

The implementation of dry machining cannot be accomplished by simply turning off the cooling lubricant supply. In fact, the cooling lubricant performs several important functions, which, in its absence, must be taken over by other components in the machining process. Cooling lubricants reduce the friction, and thus the generation of heat, and dissipate the generated heat. In addition, cooling lubricants are responsible for a variety of secondary functions, like the transport of chips as well as the cleaning of tools, work pieces and fixtures. They provide for a failure-free, automated operation of the production system. In addition, cooling lubricants help to provide a uniform temperature field inside the workpiece and machine tool and help to meet specified tolerances.

7.1 MQCL

In many machining operations, minimum quantity cooling lubrication (MQCL) is the key to successful dry machining. Any move to manufacture functional components under dry machining conditions depends on an understanding of MQCL as a system, whose individual components – feed technology, MQCL media, parameter settings, tools, and machine tools mutually affect the operation of all of the others (Figure 13.). All of the components in the MQLC system must be very carefully coordinated in order to achieve the desired outcome, which is optimal, both technologically and economically.

In MQCL operations, the media used is generally straight oil, but some applications have also utilized an emulsion or water. These fluid media are fed to the tool and/or machining point in tiny quantities. This is done with or without the assistance of a transport medium, e.g., air. In the case of the former, the so-called airless systems, a pump supplies the tool with the medium, usually oil, in the form of a rapid succession of precision-metered droplets.

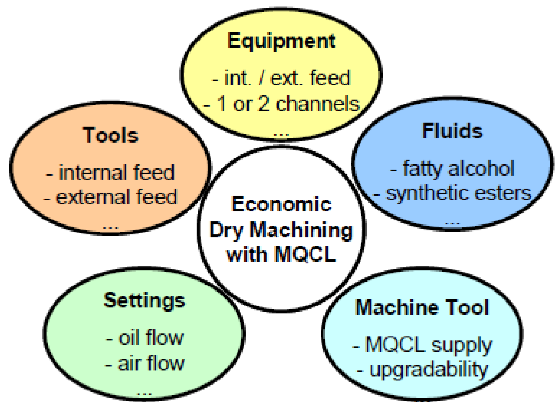

Fig. 13. Minimum quantity cooling lubrication system

In the case of the latter, the medium is atomized in a nozzle to form extremely fine droplets, which are then fed to the machining point in form of an aerosol spray.

Within the context of dry machining, the term MQCL is generally used to refer to the supply of the cooling lubricant in the form of an aerosol. Depending on the type and on the main function of the fluid medium supplied, a distinction can be drawn between minimum quantity lubrication (MQL) and minimum quantity cooling (MQC).

7.2 Supply Systems

A distinction is drawn in the minimum quantity lubrication technique between external supply via nozzles fitted separately in the machine area and internal supply of the medium via channels built into the tool (Figure 14). Each of these systems has specialized individual areas of application.

Fatty alcohols and synthetic esters (chemically modified vegetable oil) are the media most commonly used in MQL applications. The medium selected depends on the type of supply, the material involved, the machining operation, and subsequent finishing operations required by the part (e.g., annealing, coating, and painting).

7.3 Cutting Materials

Especially in dry machining processes cutting edges and guiding pads are subject to high mechanical,

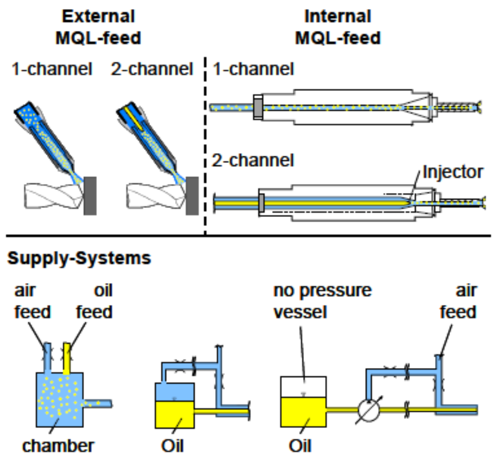

Fig. 14. MQL-feed systems [2]

thermal, and chemical loads. To ensure a good performance and a high wear resistance, the cutting materials have to fulfill certain requirements regarding their physical properties. Figure 15. illustrates an ideal cutting material, combining properties like high hardness, good toughness, and chemical stability. However, these requirements represent opposing properties so that an optimal and universal cutting material is not realizable from a technological point of view.

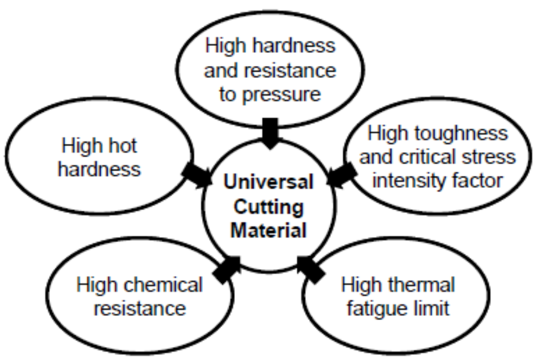

Fig. 15. Optimal cutting materials for dry machining

8. CONCLUSION

It is obvious that cutting technology has made remarkable progress in the last years. The thrust towards the application of higher performance workpiece and cutting tool materials, towards usage of minimal quantities of cutting fluid, to higher precision and to the application of micro-systems will continue. The technological capabilities of cutting systems will continue to develop and higher performance with enhanced safety standards and environmental cleanliness and lower manufacturing costs will result..

Disparate sensor systems as part of open architecture control will contribute to the development of “intelligent” machining systems with learning ability. Specific cutting process and process effects will benefit from continued modeling research including cutting hard materials, burr formation, and chip formation. Molecular dynamics modeling offers potential for coupling micro and nano scale process features with macro scale processes. The improvement in modeling capability from macro to nano scale processes drives improved process simulation and process understanding.

9. REFERENCES

[1] G. Byrne, D. Dornfeld, B. Denkena: Advancing Cutting Technology, CIRP Annals, 52/2, 2003, pp 483-507

[2] K. Weinert1, I. Inasaki, J. W. Sutherlan, T. Wakabayashi: Dry Machining and Minimum Quantity Lubrication, Anals of the CIRP Vol 55/2, 2004, pp

[3] Byrne, G., Dornfeld, D., Inasaki, I., König, W., Teti, R., 1995, Tool Condition Monitoring (TCM) – The Status of Research and Industrial Application, Anals of the CIRP 44/2:541-567

[4] Dorfeld D., Min S., Takeuchi Y.: Recent Advances in Mechanical Micromachining, Anals of the CIRP Vol 55/2, 2006, pp 745-768

[5] F. Klocke, H. W. Raedt, S. Hoppe: 2D –FEM Simulation of orthogonal High Speed Cutting Process. Mach. Sci. And Tech, 5/3, 2002, 323-340

[6] Komanduri, R., Chandrasekaran, N., Raff, L.M.: MD Simulation of Exit Failure in Nanometric Cutting, Materials Science and Engineering A, 311/1-2, 2001, pp 1-12F.

[7] Klocke1, E. Brinksmeier, K. Weinert: Capability Profile of Hard Cutting and Grinding Processes, CIRP Annals, 55/2, 2005, pp 557-580

[8] Schulz H., at all.: 20 Jahre HSC, Sonderfeld, Werkstadt und Betrieb, 1981

[9] P. Sriyotha, K. Nakamoto, M. Sugai, K. Yamazaki:, A Design Studyon, and the Development of, a 5-Axis Linear Motor Driven Super-Precision Machine, CIRP Annals, 55/1, 2006

[10] Ohmori, H., Katahira, K., Uehara, Y., Watanabe, Y., Lin, W, Improvement of Mechanical Strength of Micro Tools by Controlling Surface Characteristics, CIRP Annals, 52/1, 2003467-470.

[11] Tanaka, M.: Development of Desktop Machining Microfactory, Riken Review, 34, 2001, 46-49.

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10th INTERNATIONAL SCIENTIFIC CONFERENCE ON
FLEXIBLE TECHNOLOGIES

PROCEEDINGS

TOPIC:

METAL CUTTING

Novi Sad, October 2009.

Invited Paper

Kovac, P., Gostimirovic, M., Sekulic, M., Savkovic B.

MODELING AND SIMULATION OFCUTTING PROCESS

Abstract: *Generally is used the terms modeling and simulation interchangeably in manufacturing research literature. In the case of cutting, there are many phenomenon that are not easily observed or not subject to direct experimentation so the models are developed so that the influence of a number of process parameters can be simulated using this model. Common models used are based on Eulerian or Lagrangian finite element techniques. Four primary categories of methodologies for modeling of cutting are evident over the past several decades. Analytical modeling (determining the relationship between the forces in cutting based on cutting geometry and including experimentally determined values of shear angle, friction conditions and chip flow angle. Next is mechanistic modeling and finally FEM. The principle procedure of an integrated Simulation of machine tool, workpiece and process in time domain is shown as well.*
Key words: *modeling, simulation, FEM, virtual machining process*

1. INTRODUCTION

The manufacturing process research should lead to improved design of tools, machine tool structures, spindle and feed drives and the optimal planning of individual machining operations based on physical constraints. The research activities and industrial applications of metal cutting process simulation are presented in the following sections. The amplitude and frequency of cutting forces, torque and power are used in sizing machine tool structures, spindle and feed drive mechanisms, bearings, motors and drives as well as the shank size of the tools and the fixture rigidity.

The stress and temperature field in the cutting tool edge, chip and finished work piece surface are used in designing the cutting edge shape as well as in optimizing feed, speed and depth of cut to avoid residual stresses on the finished surface. Modeling the interaction between the cutting process and structural vibrations of machine tool, cutting tool and fixture leads to the identification of weak links in the machine structure and to the determination of chatter vibration free spindle speeds and depths of cut [5]. The complete model of the machining process is therefore used in both design of cutting tools and machine tools, as well as in planning of machining operations for maximum productivity and accuracy.

1.1 Analytical modeling of cutting processes

The first step is to model the cutting process as a function of work material, tool geometry and material, chip load and cutting speed. The macro-mechanics of cutting lead to the identification of cutting coefficients, which are used in predicting the cutting forces, torque, power and chatter stability limits for a specified tool geometry and work material. The cutting coefficients can be modeled using either orthogonal cutting mechanics or mechanistic models. The micro-mechanics of metal cutting on the other hand, are used to predict the stress, strain and temperature distribution in the chip and tool. This simulation results are primarily used for tool design, the analysis of material behavior under high strain and temperature, and optimal selection of chip load and speed to avoid tool chipping, tool wear, and residual stresses left on the finished surface. The directions of cutting forces in turning and milling are given in Figure 1.

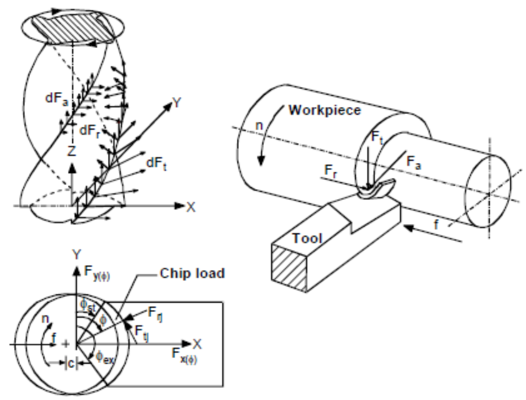


Fig.1. Prediction of cutting forces for turning and milling operations

The major cutting forces (F_f) act in the direction of cutting speed, followed by the thrust force (F_r) acting in the direction of chip thickness and the axial force (F_a). The cutting forces are proportional to the instantaneous chip area which is expressed as a product of depth of cut (a) and uncut chip thickness (h) coefficients as proposed by Kienzle.

1.2 Numerical simulation of cutting processes

For cutting processes involving geometrically defined cutting edges, high speed cutting (HSC) is widely used in aerospace, and the die and mold machining industry. High speed machining allows the operation of machine tool spindles in large stability pockets where deeper cuts are possible. While keeping small chip loads to avoid thermal overload of the tool edge and mechanical overload of the spindle power limits, high material removal rates can be achieved with high spindle speeds and table feeds while maintaining a good surface finish on the part. However, the practical application of HSC methods depends on empirical cutting data which has to be obtained through cost- and time-consuming cutting experiments.

The Finite-Element-Method (FEA) is a tool that is suited for optimisation of the cutting edge geometry and material. Hence the cutting edge can withstand high thermal and impact loads during machining. Finite-Element- Analysis belongs to the class of micro-mechanics of metal cutting and is widely used by the cutting tool industry. However, the key bottle neck is to model the flow stress of the work material reflecting high strain, strain rate and temperature experienced in metal cutting processes. The thermo-plastic properties of the material are usually evaluated under high strain rate conditions using either Orthogonal Cutting Tests or Hopkinson Bar tests [1]. Three main methods of mechanical formulation are commonly used in Finite-Element-Modeling of metal cutting [1], [2]:

- Eulerian formulation, where the grid is not attached to the material, is computationally efficient but needs the updating of the free chip geometry,
- Lagrangian formulation, where the grid is attached to the material, requires updating of the mesh (remeshing algorithm) or the use of a chip separation criterion to form a chip from the workpiece,
- Arbitrary Lagrangian Eulerian (ALE) formulation, where the grid is not attached to the material and it can move to avoid distortion and update the free chip geometry.

A successful simulation is dependent on the accurate knowledge of the boundary conditions and the material behavior which is different from simple metal models obtained from tensile tests due to the influence of large strain, strain rate, and temperature. In order to achieve an accurate prediction of chip flow, stress and temperature distribution within the chip and tool, an accurate model of flow stress of the material and friction between the rake face of the tool and chip is absolutely necessary. The validity of all numerical models is proven experimentally by comparing predicted forces, average shear angles and shear stresses in metal cutting tests.

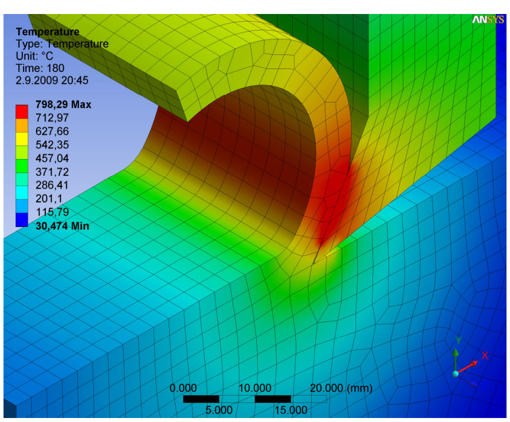


Fig. 2. FEM simulation of cutting temperature during turning and mesh

Authors FEM simulation of cutting temperature distribution during turning is shown in Fig 2.

Afore mentioned FE modeling is primarily for isotropic micromachining where no crystallographic effects were considered. Chuzhoy et al. [1] developed a FE model for micromachining of heterogeneous material, Figure 3. Their model was capable of describing the microstructure of multi phase materials and thus captured the microcutting mechanism in cast iron. Microcutting of multi phase materials exerts larger variations in the resulting chip shape and the cutting force than seen in cutting of a single phase material.

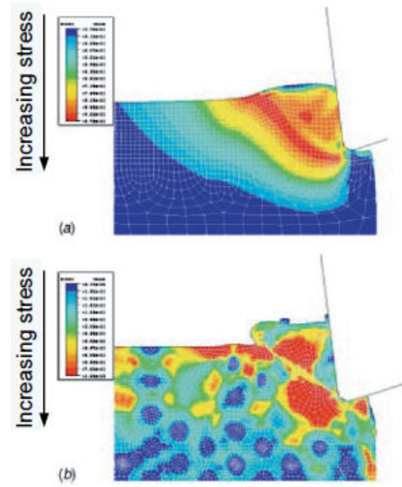


Fig. 3. Computed equivalent stress for 125 μm depth of cut and 25 μm edge radius at t=0.00012 s with (a) ferritic workpiece, (b) ductile iron workpiece [1]

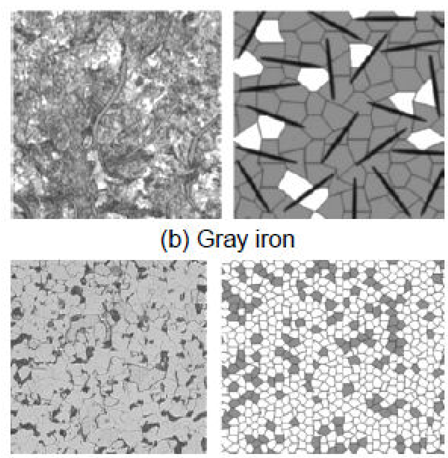


Fig. 4. Actual (left column) and simulated (right column) microstructures of different ferrous materials [2]

Park et al. [2] tried to calibrate the mechanistic cutting force through FEM simulation for ferrous materials including increasing stress Increasing stress -751- ductile and gray irons and carbon steels. Their model is primarily based on analysis of the microstructure of the work materials in their various phases, such as the graphite, ferrite, and pearlite grains seen in ductile iron, gray iron, and carbon steel microstructures. Their model was mainly used to calibrate a cutting force model, Figure 4.

2. MOLECULAR DYNAMIC SIMULATION

Research work on molecular dynamic simulation (MD) of cutting can be traced back to early 1990s. Most of the early researchers used copper as a work material because of its well established structure and potential function. A diamond was used as a cutting tool since it can be reasonably assumed to have a very sharp edge, needed at the MD level.

The work of Inamura et al. focused on a trial of molecular dynamics at an atomic level cutting simulation with a couple of potential functions. This computational study showed that MD is a possible modeling tool for the microcutting process. The simulation was able to correlate the intermittent drop of potential energy accumulated in the workpiece during cutting with the heat generation associated with plastic deformation of the workpiece and impulsive temperature rise on the tool rake face. In a simulation of cutting of polycrystalline copper, the plastic deformation first initiated at the grain boundaries and then propagated into neighboring grains in the direction of dislocation development. They also reported that the rate of energy dissipation in plastic deformation at this scale is larger than in conventional cutting and that a concentrated shear zone did not appear, contrary to what is normally observed in conventional cutting. In general, MD simulation requires impressive computational power in order to model a cutting process. Hence, many MD models have been applied to two dimensional orthogonal cutting with a very small model size, or unrealistically high cutting speed. Komanduri et al. [3] proposed a new method called a length-restricted molecular dynamics (LRMD) simulation by fixing the length of the work material and shifting atoms along the cutting direction and applied it to nanometric cutting with realistic cutting speeds. They also studied the effect of tool geometry using several ratios of tool edge radius to the depth of cut with various parameters such as cutting force, specific energy, and subsurface damage [7] and further investigated the effect of crystal orientation and direction of cutting on single crystal aluminum and silicon. They also applied MD simulation to exit failure and burr formation in ductile and brittle materials with a face centered cubic (FCC) structure. They successfully simulated burr formation on a ductile material and crack propagation in brittle material, Figure 5 [3].

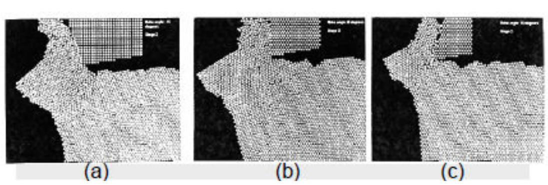


Fig. 5. MD plots of the nanometric cutting process performed on a ductile work material with no elastic constraint at the exit for various tool rake angles (a) −15° (b) 0° (c) 15° (d) 30° (e) 45° and (f) 60° [3]

3. CHIP FORMATION

Experimental results showed a different chip type at each scale of cut. This variation in chip type meant that the plastic deformation process varied as the scale of cutting increased from the microscale to the macroscale. At the microscale, quasi-shear-extrusion (QSE) chips as described by Simoneau et al. [2] were observed. At the mesoscale, a transitional chip somewhere between a QSE and continuous chip was observed, while at the macroscale, continuous chips were formed.

Scale	Uncut Chip Thickness(μm)	Cut Speed (m/min)	D.O.C. (mm)
Microscale	2-10	60	2
Mesoscale	30, 50	60	2
Macroscale	100-400	60	2-4

Table 1 cutting tests parameters

The same variation in chip formation across different scales was also observed in the heterogeneous FE models as detailed in Figure 6. The heterogeneous FE models proved to be valuable aids in explaining the chip formation process, and demonstrated the impact of material microstructure on the machining process. While a detailed account of the chip formation mechanism during microscale cutting of AISI 1045 has been done by Simoneau et al. [2], some of the unique features of the QSE chip from Figure 6a are discussed. At an uncut chip thickness below 10μm, which is smaller than the average size of the smallest grain type – ferrite, the chip is comprised of layers of plastically deformed pearlite and ferrite as shown in Figure 6a photomicrograph. A distinct feature of a QSE chip is the plumes of softer material (ferrite) ejected out the free surface of the chip. This indicates that the ferrite must have been extruded between the harder pearlite grains during the chip formation process. The microscale FE model showed similar results, and confirmed that the softer material B was not only shearing due to the cutting action of the tool, but was also being extruded between the harder A grains during cutting. The microscale FE model predicted very large plastic strains as high as 13.5 at the A-B grain boundary along the tool-chip interface. The large plastic strain along the grain boundary was attributed to the plume formation at the chip free surface and friction at the tool-chip interface, both causing material to be pulled along the grain boundaries during chip formation.

At mesoscale cutting with an uncut chip thickness of 50μm, the uncut chip thickness is larger than the average ferrite grains, but smaller than the average pearlite grains in the workpiece microstructure. The experimental chips were transitional chips, somewhere between a QSE and a continuous chip. Plastically deformed pearlite grains with bands of deformed ferrite are clearly visible throughout the chip thickness in Figure 6b photomicrograph. Of interest is the fact that plume formation does still occur. From the FE model in Figure 6b, strain localization is still observed at the grain boundaries at the tool-chip interface with the largest plastic strains being 10.5. During experimental macroscale cutting, continuous chips were formed as shown in Figure 6c photomicrograph for an uncut chip thickness of 100µm. The continuous chips show a severely plastically deformed microstructure with veins of deformed ferrite throughout a series of plastically deformed pearlite grains. At this scale it is extremely difficult to isolate a single pearlite or ferrite grain in the chip thickness. As a result, when considering the plastic strains involved in this type of chip formation, an average plastic strain is commonly used

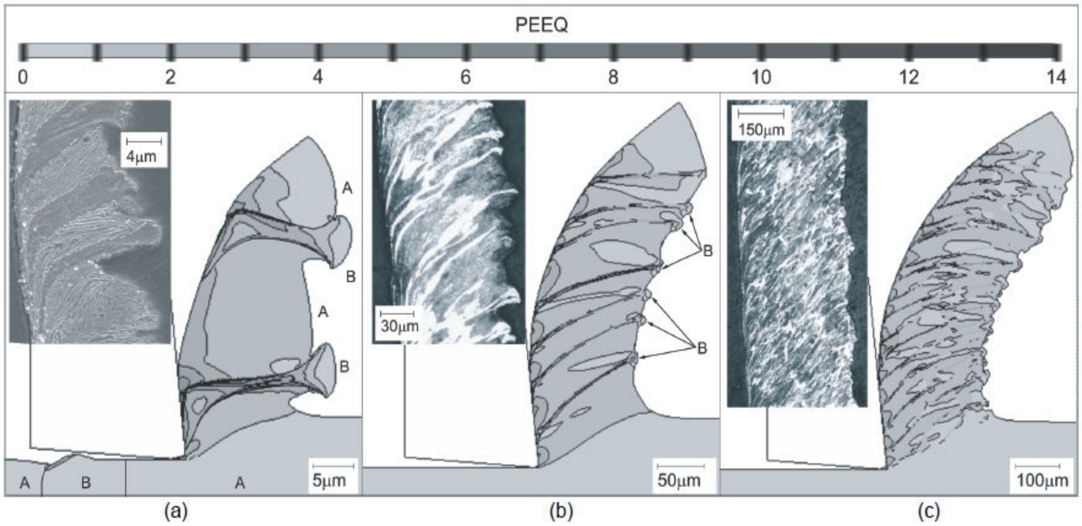


Fig. 6. Resulting plastic equivalent strain during chip formation from the heterogeneous (a) microscale, (b) mesoscale, and (c) macroscale FE models. The inset at each scale shows a corresponding chip from the experimental cutting tests [4]

By considering the evolution of plastic dissipation energy during cutting and its relation to stress and strain, an explanation linking material microstructure, chip formation, and the formation of dimples on a machined steel surface could be drawn up. The plastic dissipation energy during the QSE chip formation process from the microscale FE model in Figure 7. was closely examined. Initially, the cutting process is concentrated in the first A grain (harder material). As cutting progresses the shear plane movesforward in front of the cutting edge. As the shear plane encounters the first B grain (soft material), the softer B grain begins to absorb the cutting energy as shown in Figure 7a. Energy absorption in the softer B grain well before the cutting edge nears the actual B grain results from the fact that less work is required to plastically deform the soft material. The absorption of cutting energy in the softer B grain results in the immediate bulging of the B grain at the chip free surface. This softer grain eventually forms a large plume at the chip free surface as the softer material is extruded out the chip free surface. As cutting approaches the A-B grain boundary, the plastic dissipation energy continues to increase inside the soft B grain with little change in the hard A grain. This indicates that once the soft B grain began to absorb the cutting energy, very little work was being done in the first A grain except at the tool-chip interface. Early absorption of cutting energy in the soft B grain can be explained by considering that cutting energy can be translated into stress and plastic strain. While cutting a hard grain, a stress field will exist and a corresponding plastic strain will occur. As cutting approaches the softer grain, the stress field will decrease in magnitude. In order for an energy balance to exist at the grain boundary, the corresponding strain must increase in this lower stress field. As a result, there is a strain mismatch at the A-B grain boundary and a dimple forms as in Figure 6a. When the cutting edge is inside of the B grain exclusively as in Figure 7b and 7c, all of the plastic dissipation energy is absorbed by the soft B grain with little change in the hard A grain.

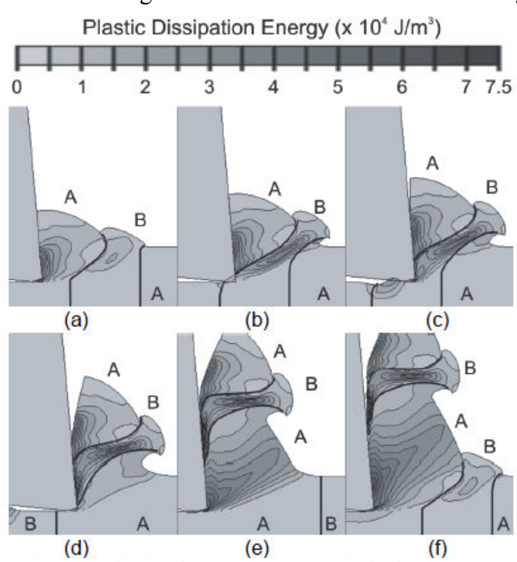
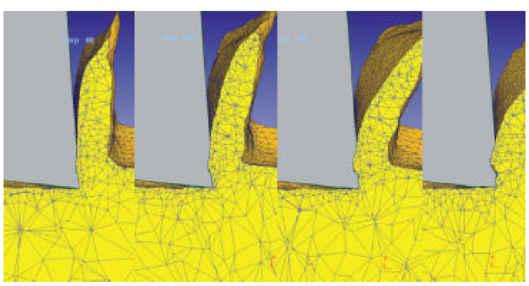


Fig. 7. Plastic dissipation energy during microscale cutting from the microscale FE cutting model [4]

This indicates that once the soft B grain began absorbing this energy, very little work was being done in the first A grain. In the B grain, the relatively soft material is ‘pulled’ as the cutting edge moves across the B grain. This ‘pull’ at the newly machined surface contributes to an already existing strain mismatch and aids the dimple formation at the A-B grain boundary. As cutting approaches and crosses the B-A grain boundary in Figure 7d, the strain mismatch is very small compared to the mismatch that was observed at the A-B grain boundary as shown in Figure 7a and 7c. If an energy balance exists at the B-A grain boundary then there should be a large strain mismatch given the change from a relatively low to a relatively high stress field as cutting moves from material B to material A.

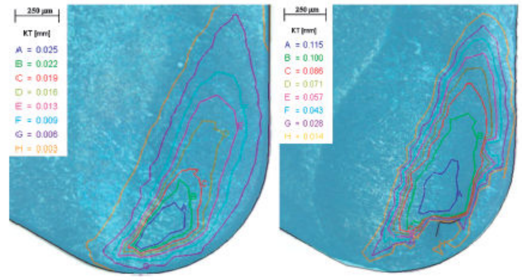
4. 3D NUMERICAL MODELING

The 3D ALE simulation was carried out using SFTC Deform 3D1 V. 6.1. The utilized numerical procedure can be summarized as follows: the first step is a coupled thermo-mechanical analysis using an updated Lagrangian formulation, to reach mechanical steady state conditions. Then, the Eulerian step is carried out to determine temperature distribution. Finally, the wear subroutine is called, tool wear is calculated and the geometry of the worn tool is updated. For each tool node the wear rate is calculated, afterwards the direction of the node movement is identified and, in the last step of the subroutine, the tool mesh and the tool geometry are updated. The procedure is carried out subdividing the total cutting time in several steps and repeating the procedure until the total cutting time is reached. It is important to underline that the geometry updating is carried out starting from the tool worn geometry of the previous step and changing the node positions on the basis of the new wear rate values. Indeed, the first step of the wear loop starts from the new flat tool geometry. Fig. 8 shows the updated tool geometry after 1, 2, 4 and 6 min cutting time.



Fig, 8. Development of tool wear after 1, 2, 4 and 6 min cutting time (V_c=160m/min, f=0,25mm/rev)

Good results were found for crater wear simulation too. Fig. 9 shows the experimental and simulated crater wear images super imposed for the case of VC = 160 m/min and f = 0.25 mm/rev after a cutting time of 1 and 6 min. The overall good matching is evident. Fig. 9 shows the trend of simulated and experimental crater wear (KT/KM) for the analyzed cases at different cutting times. Also for the crater wear parameters, the experiments were repeated three times showing a combined uncertainty of 8–13% with a confidenceinterval of 95%.



Fig, 9. Experimental and simulated crater wear after 1 and 6 min cutting time (V_c=160m/min, f=0,25mm/rev)

5. INTEGRATED SIMULATION OF MACHINE AND PROCESS

While Frequency Domain chatter stability solutions provide a direct relationship between the dynamic stiffness of the machine and the process, the time domain simulation allows prediction of dynamic cutting forces and dimensional surface errors for complex tools and processes while machining a specific part under defined cutting conditions. A sample prediction of stability lobes in both frequency and time domain for an indexed cutter milling aluminum alloy is shown in Figure 10.

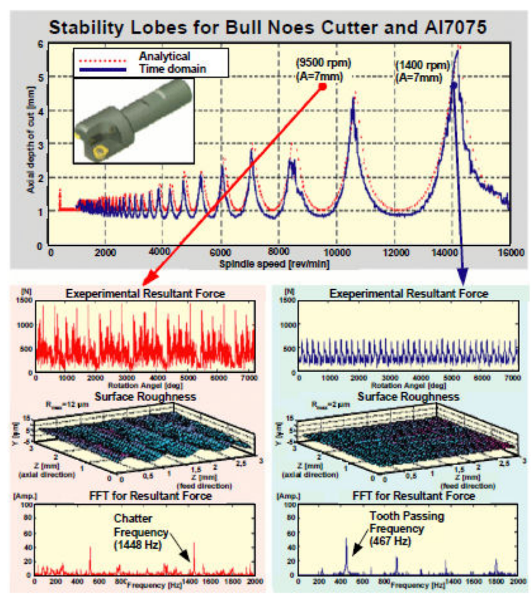


Fig. 10. Chatter stability, force, vibration and surface error prediction in milling [5]

Nowadays the simulation of single processes or machine characteristics is state of the art. Generally, these simulations are carried out separately for the process as well as for the ma-chine tool. Interactions between machine tool, workpiece and process caused variations of the tolerances and characteristics of the workpiece, which are not taken into account by common simulation approaches [5]. It would be of great economic interest for the design of machine tools as well as for process planning if the resulting quality of the workpiece was predictable prior to the start of production. The principle procedure of an integrated Simulation of machine tool, workpiece and process in time domain is shown in Figure 11.

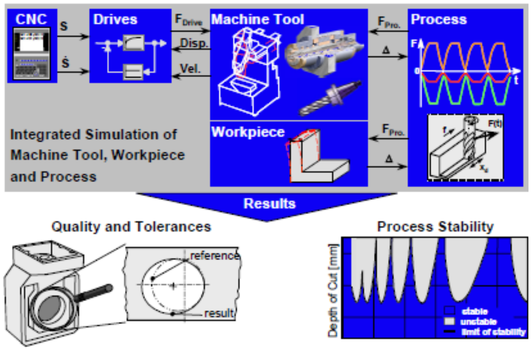


Fig. 11. Integrated simulation of machine tool, work-piece and process [5]

Current NC tool path and machining simulation systems consider only the rigid body kinematics of the machine tool, and do not take the physics of the machining process into consideration. The magnitude of cutting forces, torque, power and thermal energy produced during machining depends on the tool geometry, structural dynamics between the workpiece and the tool, work material properties, and cutting conditions such as feed, speed and depth of cut. Currently, the cutting conditions are selected from either tool manufacturers' handbooks or experience, which may or may not lead to productive and accurate production of parts.

The objective of next generation CAM systems is to include the physics of manufacturing processes in order to produce the first part accurately and optimally. Sample architecture for Virtual Machining Process simulation was proposed by Altintas et al. [5] as shown in Figure 12. The geometric model of the part, blank and NC tool path in the form of a standard CL file are imported from current CAD/CAM systems using IGES or STEP NC standards. The cutter – part intersection along the tool path is evaluated at feed rate increments using solid modeling techniques. The intersection geometry is required to solve machining process simulation algorithms.

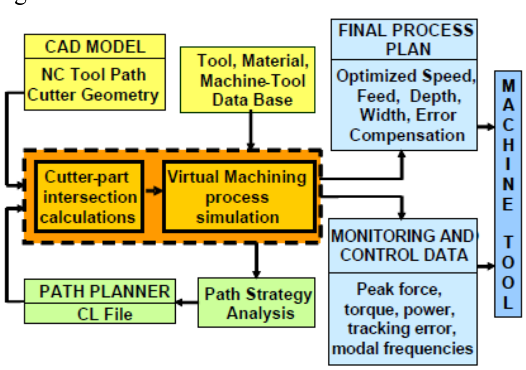


Fig. 12. Virtual machining process simulation and optimization architecture

The machining process simulation engine is based on the laws of metal cutting mechanics and dynamics, it pulls the required machine tool and work material parameters from the data base and predicts the cutting forces, torque, power, static and dynamic deformations of the machine tool-part-fixture along the tool path. For a given set of constraints, such as maximum power-torque-dynamic stiffness of the machine and chip thickness limit of the cutting edge, the speed and feed can be optimized to maximize the material removal rate.

8. CONCLUSION

Specific cutting process and process effects will benefit from continued modeling research including cutting hard materials, burr formation, and chip formation. Molecular dynamics modeling offers potential for coupling micro and nano scale process features with macro scale processes. The improvement in modeling capability from macro to nano scale processes drives improved process simulation and process understanding. Integrated simulation of machine tool, workpiece and process is nowadays reality.

9. REFERENCES

[1] L. Chuzhoy, R. E. DeVor, S. G. Kapoor: Machining Simulation of Ductile Iron and Its Constituents, Part 2: Numerical Simulation and Experimental Validation of Machining, Journal of Manufacturing Science and Engineering, Transactions of the ASME, 125/2, 2003, pp 192-201.

[2] S. Park, S. G. Kapoor, R. E. DeVor: Mechanistic Cutting Process Calibration via Microstructure-Level Finite Element Simulation Model, Journal of Manufacturing Science and Engineering, Transactions of the ASME, 126/4, 2004, pp 706-709.

[3] R. Komanduri, N. Chandrasekaran, L. M. Raff, MD Simulation of Exit Failure in Nanometric Cutting, Materials Science and Engineering A, 2001, 311/1-2, pp 1-12.

[4] A. Simoneau, E. Ng, M.A. Elbestawi: The Effect of Microstructure on Chip Formation and Surface Defects in Microscale, Mesoscale, and Macroscale Cutting of Steel , Annals of CIRP Vol.55/1/2006, pp 97-102

[5] Y. Altinas, C. Brecher, M. Weck, S. Witt: Virtual Machine Tool, Annals of CIRP Vol.54/2/2005, pp 651-674

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Invited Paper

Kuzinovski, M., Tomov, M., Cichosz, P.

EFFECT OF SAMPLING SPACING UPON CHANGE OF HYBRID PARAMETERS VALUES OF THE ROUGHNESS PROFILE

Abstract: *The study presents results gained from analysis of roughness measurements on deterministic and stochastic etalon surfaces, representatives of machining processes: turning and grinding. The effect of the sampling spacing change upon hybrid parameter values of roughness profiles is determined. Measurements were made by application of profilometer Surtronic 3+ with sampling spacing of 0,5 μm, while as hybrid parameter values of roughness were calculated by means of software TalyProfile. Sampling spacing change was provided by the program Microsoft Office Excel. Researches were made with sampling spacing of 0,5; 1,0; 1,5; 2,0; 2,5 and 3,0 μm. Analysis refers to change of hybrid parameter values RDa(RΔa), RDq(RΔq), RLa, RLq, RLo, Rfd and RVo for deterministic and stochastic etalon surface.*
Key words: *Hybrid parameters, surface roughness, contact (stylus) profilometer.*

1. INTRODUCTION WITH SHORT OVERVIEW OF APPLIED LITERATURE

Knowing geometric characteristics of surface on micro plan, expressed through roughness profile, are more often connected to functional characteristics of mechanical parts [1]. Roughness profile is described through parameters grouped per the profile characteristic they describe: peak, average, horizontal, hybrid, functional parameters and Rk parameters [2,3].

Against [2] hybrid parameter group consists of: Rda (or RΔa)- arithmetical mean slope, RDq(or RΔq)- root mean square slope, RLa- arithmetical mean wavelength, RLq – root mean square wavelength, RLo –developed profile length, Rfd – fractal dimension and RVo – volumetric parameter. Graphical presentation of some hybrid parameters is presented on Figure 1.

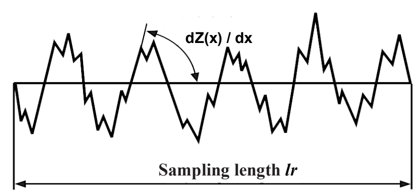
Hybrid parameters are not standardized yet however are of particular interest in the scientific-research activities of exploitation characteristics of the surface layer that are performed by method engineers and tribologists [1,2,5,6,7].

Friction, wear, reflectivity, surface elasticity, noise, adhesion, etc. are functional characteristics directly dependent upon hybrid parameter values for one surface [1,2].

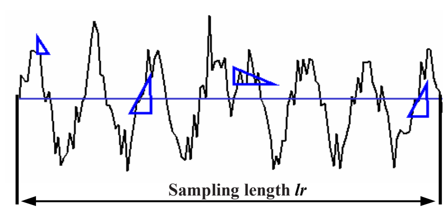
Therefore against [2], by increase of values of RΔa and RΔq also increase values of friction, wear, surface elasticity, noise and vibrations, while as reflectivity value decreases.

Against [5], by increase of values of RΔa, RΔq, Rfd and RLq, the coefficient of friction increases. Largest influence upon friction coefficient change for various materials has RΔa, where the correlation coefficient amounts 0,92. By RLa increase, friction coefficient decreases.

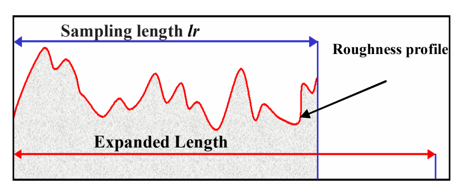
Against stated, it is certain that inclinations of roughness surface unleveled areas, expressed by hybrid parameters, have significant effect on behaviour of parts in exploitation process.



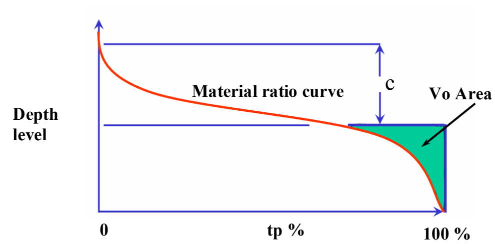
(a) RΔa and RΔq, [4].



(b) RLa, [2].



(c) Lo, [2].



(d) Vo, [2].

Figure1. Graphical interpretation of hybrid parameters

The determination of hybrid parameter values has direct effect upon forecasts for part behaviour in exploitation. In this sense researches were performed for determining the measurement condition effect upon the defining of hybrid parameter, by application of contact (stylus) profilometers [6,7].

Namely, the effect of sampling spacing change upon hybrid parameter value change is determined.

In ISO 3274-1996 the selection of max. sampling spacing is defined in dependence on stylus peak radius and size of λ_c and λ_s profile filters. In ISO 4288-1996 sampling length l_r (that is λ_c) is selected in dependence on expected values for Ra and Rz for random surface i.e. in dependence on value of RSm for periodical surface. Recommendation or dependence does not exist, at least not in international standards (ISO), between hybrid parameters and any segment of measurement conditions. This is the second reason for justification of researches performed in [6,7].

The effect of sampling spacing change upon roughness profile parameter values, as one of the measurement conditions for surface roughness measurement, is reviewed in references [6,7,8,9,10,11,12,13,14]. In [8] is determined the effect of sampling spacing change upon change of values of average Ra, Rq and peak Rp, Rv, Rz (ISO), Rt parameters of roughness profile. In [9] is determined the effect of sampling spacing change upon average slope of modeleded random profile. It is noticed that by sampling spacing increase the slope of modeleded random profile decreases.

Theoretically, by sampling spacing increase possibilities also increase for omission of some information for one roughness profile, thereof also “ironing” and reducing the slope of roughness. This would mean direct effect upon hybrid parameter values. This study presents the results of the research of the effect of sampling spacing upon hybrid parameter value change.

2. DEFINING MEASUREMENT CONDITIONS AND MEASURING EQUIPMENT

Original roughness profile is analyzed in the research, gained by measurements performed on realistic etalon surfaces with deterministic character (machined by turning with nominal Ra=0,2 μm) and stochastic character (machined by grinding with nominal Ra=0,2 μm).

Measurements of etalon surfaces were made in Laboratory for metrology of geometrical characteristics and quality research at the Faculty of Mechanical Engineering in Skopje by utilization of contact profilometer Surtronic 3+ connected to a Personal computer. Coordinates of original profile were taken by the professional software TalyProfile. Measuring unit was calibrated by means of etalon type C with value for Ra = 6 μm, in accordance with [15,16].

Profilometer Surtronic 3+ characterizes with vertical and horizontal resolution. Vertical resolution amounts 10 μm, while as horizontal resolution amounts 0.5 μm for cases where evaluation length (ln) is smaller or equal to 8 mm, and 1.0 μm for cases where evaluation length is larger than 8 mm.

Measurement conditions are in conformance with recommendations prescribed in ISO 3274-1996 and ISO 4288-1996. Pick-up TYPE 112-2672 (DCN 001) with stylus radius of 2 μm and skid radius of 8.7 mm is used, as well as pick-up TYPE 112-1502 (DCN 001) with stylus radius of 5 μm and skid radius of 8.7 mm.

A stylus of 5μm is also used in the research for measured etalons with Ra=0,2 μm, which is not in compliance with recommendations in ISO 3274-1996 and ISO 4288-1996. A deliberate omission is in question in order to determine the effect of mechanical filtration of profile caused by stylus radius and how such filtration is reflected upon further research procedure at sampling spacing change.

Reader speed used in researches is 1 mm/s. Sampling length (lr) is 0.8 mm, while as evaluation length (ln) contains five sampling lengths.

3. EXPERIMENTAL RESEARCHES

Independent variable in researches is the sampling spacing size, which is defined as distance between two adjacent points of roughness profile against x-axis. This is constant for all points of a profile. Applied measuring equipment does not have ability to provide sampling spacing change.

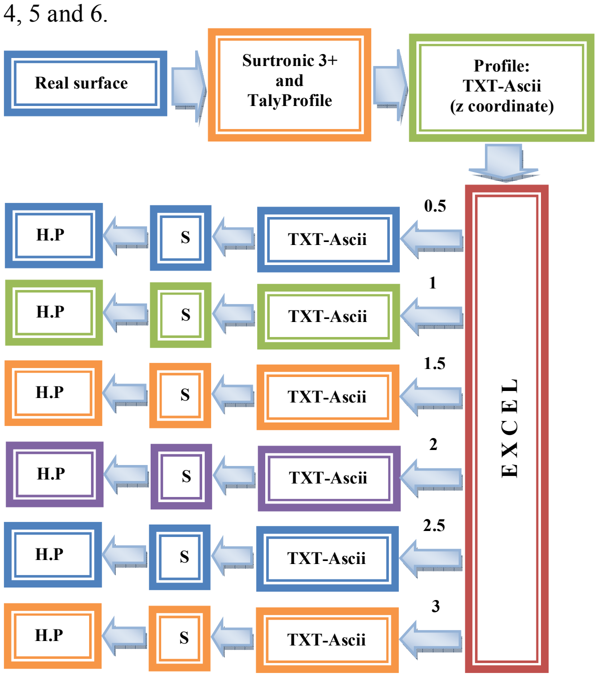
For the purpose of removing effects by measuring equipment mistakes at multiple measurements of researched dependence, it is necessary to generate various sampling spacing for one same recorded roughness profile. This condition, various lengths of sampling spacing for one same recorded profile was gained by using the program Microsoft Office Excel.

Sampling spacing change is simulated by change of x-distance between sampling points of original roughness profile through omission of one, two, three, four or five points, always starting from one same starting point. In this way roughness profiles are gained with sampling spacing of 1,0; 1,5; 2,0; 2,5 and 3,0 μm. An algorithm is presented on Figure 2 with which profiles with sampling spacing of 1,0; 1,5; 2,0; 2,5 and 3,0 μm are gained, from one same original profile with sampling spacing of 0,5 μm .

At sampling spacing change, evaluation length remains unchanged. Hybrid parameters are calculated by applying software TalyProfile. When calculating, the software uses Gaussian filter with size of 0,8 mm, and micro-filtration with filter λs with size 2,5 μm, while as values of hybrid parameters RΔa (^{0}), RΔq (^{0}), RLa (mm), RLq (mm), RLo (%), Rfd (not have unit of measurement) and RVo (mm^3/mm^2) are calculated as mean values of all sampling lengths (total five). These conditions are applied on all profiles.

4. ANALYSIS OF GAINED RESULTS

Results gained for reviewed hybrid parameters for various sampling spacing are presented in Table 1, 2, 3 and 4. The percentage differences among values of hybrid parameters for various sampling spacing and values of hybrid parameters of original profile are also shown in tables. The minus prior percentage difference indicates that gained values are smaller than values of original profile with sampling spacing 0,5 µm. Percentage differences gained for sampling spacing 1,0; 1,5; 2,0; 2,5 and 3,0 µm in terms of original roughness profile, are shown as a diagram on Figure 3, 4, 5 and 6.



Legend:
S-Software TalyProfile; H.P-Hibrid Parameters

Figure 2. Algorithm for gaining roughness profile with various sampling spacing from one same original profile

Results gained for various sampling spacing and percentage difference among them provide conclusion that significant effect by sampling spacing size upon hybrid parameter values exists, regardless whether a deterministic or stochastic surface is in question.
Change of values of RDa(RΔa) and RDq(RΔq) parameters confirmed the theoretical assumptions that by sampling spacing increase, the slope of roughness decrease

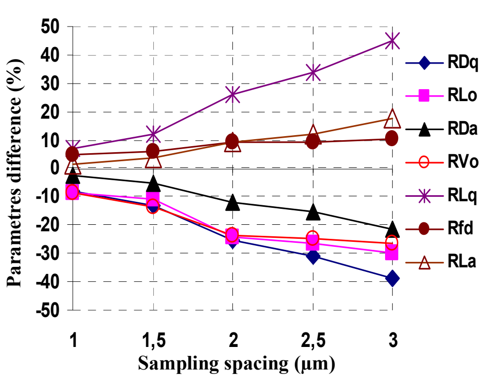


Figure 3. Percentage differences between hybrid parameters for various sampling spacing in terms of original profile with sampling spacing of 0.5 µm. Original profile is deterministic (turned etalon surface), measured with stylus of 2 µm.

Param-eters	Sampling spacing (µm) 0.5	1	1.5	2	2.5	3
RDq	4,24	3,89	3,69	3,17	2,92	2,59
RLq	0,0221	0,0237	0,0248	0,0278	0,0296	0,0321
RLo	0,283	0,258	0,252	0,214	0,208	0,198
Rfd	1,65	1,73	1,75	1,8	1,8	1,82
RDa	2,89	2,82	2,74	2,54	2,44	2,27
RLa	0,0258	0,0262	0,0267	0,0282	0,0289	0,0303
RVo (x 10^{-4})	4,52	4,12	3,91	3,44	3,39	3,32
Difference (%)						
RDq		-8,25	-12,97	-25,24	-31,13	-38,92
RLq		7,24	12,22	25,79	33,94	45,25
Rlo		-8,83	-10,95	-24,38	-26,50	-30,04
Rfd		4,85	6,06	9,09	9,09	10,30
Rda		-2,42	-5,19	-12,11	-15,57	-21,45
Rla		1,55	3,49	9,30	12,02	17,44
Rvo		-8,85	-13,50	-23,89	-25,00	-26,55

Table1. Hybrid parameter values for various sampling spacing. Original profile is deterministic (turned etalon surface), measured with stylus of 2 µm.

Param-eters	Sampling spacing (µm) 0.5	1	1.5	2	2.5	3
RDq	4,28	3,74	3,44	2,69	2,45	2,1
RLq	0,0213	0,024	0,0258	0,0318	0,0343	0,039
RLo	0,287	0,24	0,225	0,172	0,168	0,16
Rfd	1,57	1,61	1,6	1,65	1,64	1,63
RDa	2,85	2,6	2,43	1,97	1,8	1,56
RLa	0,0245	0,0264	0,0279	0,0332	0,0357	0,0403
RVo (x 10^{-4})	2,07	2,01	1,77	1,61	1,37	1,34
Difference (%)						
RDq		-12,62	-19,63	-37,15	-42,76	-50,93
RLq		12,68	21,13	49,30	61,03	83,10
Rlo		-16,38	-21,60	-40,07	-41,46	-44,25
Rfd		2,55	1,91	5,10	4,46	3,82
Rda		-8,77	-14,74	-30,88	-36,84	-45,26
Rla		7,76	13,88	35,51	45,71	64,49
Rvo		-2,90	-14,49	-22,22	-33,82	-35,27

Table 2. Hybrid parameter values for various sampling spacing. Original profile is stochastic (grinded etalon surface), measured with stylus of 2 µm.

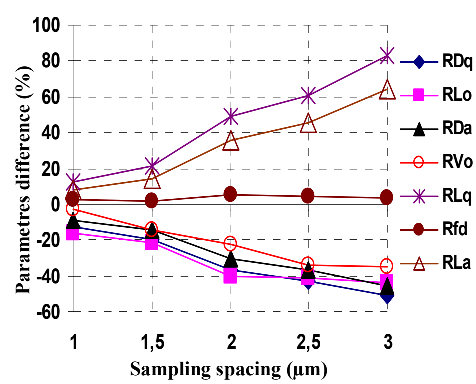


Figure 4. Percentage differences between hybrid parameters for various sampling spacing in terms of original profile with sampling spacing of 0.5 µm. Original profile is stochastic (grinded etalon surface), measured with stylus of 2 µm.

Param-eters	Sampling spacing (μm)					
	0.5	1	1.5	2	2.5	3
RDq	3,93	3,71	3,52	3,08	2,86	2,57
RLq	0,0231	0,0242	0,0251	0,0277	0,0291	0,0312
RLo	0,257	0,247	0,244	0,213	0,208	0,198
Rfd	1,68	1,76	1,78	1,84	1,83	1,84
RDa	2,89	2,82	2,77	2,59	2,47	2,28
RLa	0,0245	0,0249	0,0252	0,0266	0,0275	0,0293
RVo (x 10^{-4})	4,28	4,31	4,09	4,01	3,43	3,22
Difference (%)						
RDq		-5,60	-10,43	-21,63	-27,23	-34,61
RLq		4,76	8,66	19,91	25,97	35,06
Rlo		-3,89	-5,06	-17,12	-19,07	-22,96
Rfd		4,76	5,95	9,52	8,93	9,52
Rda		-2,42	-4,15	-10,38	-14,53	-21,11
Rla		1,63	2,86	8,57	12,24	19,59
Rvo		0,70	-4,44	-6,31	-19,86	-24,77

Table1. Hybrid parameter values for various sampling spacing. Original profile is deterministic (turned etalon surface), measured with stylus of 5 μm.

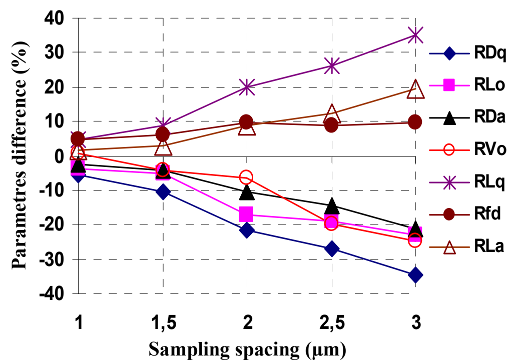


Figure 5. Percentage differences between hybrid parameters for various sampling spacing in terms of original profile with sampling spacing of 0.5 μm. Original profile is deterministic (turned etalon surface), measured with stylus of 5 μm.

Param-eters	Sampling spacing (μm)					
	0.5	1	1.5	2	2.5	3
RDq	3,95	3,57	3,32	2,66	2,4	2,04
RLq	0,0205	0,0222	0,0237	0,0284	0,0306	0,035
RLo	0,253	0,227	0,216	0,173	0,169	0,161
Rfd	1,59	1,63	1,36	1,66	1,65	1,65
RDa	2,89	2,65	2,47	2,03	1,83	1,57
RLa	0,0219	0,0235	0,025	0,0292	0,0316	0,0358
RVo (x 10^{-4})	1,5	1,46	1,44	1,3	1,46	1,15
Difference (%)						
RDq		-9,62	-15,95	-32,66	-39,24	-48,35
RLq		8,29	15,61	38,54	49,27	70,73
Rlo		-10,28	-14,62	-31,62	-33,20	-36,36
Rfd		2,52	-14,47	4,40	3,77	3,77
Rda		-8,30	-14,53	-29,76	-36,68	-45,67
Rla		7,31	14,16	33,33	44,29	63,47
Rvo		-2,67	-4,00	-13,33	-2,67	-23,33

Table 4. Hybrid parameter values for various sampling spacing. Original profile is stochastic (grinded etalon surface), measured with stylus of 5 μm.

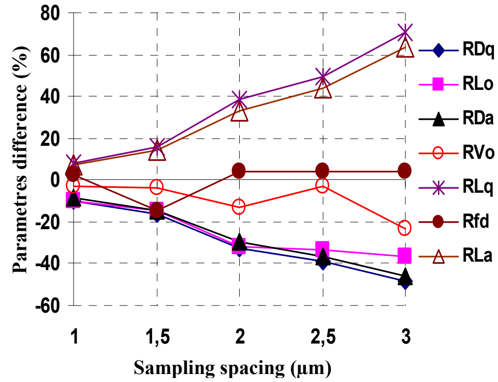


Figure 6. Percentage differences between hybrid parameters for various sampling spacing in terms of original profile with sampling spacing of 0.5 μm. Original profile is stochastic (grinded etalon surface), measured with stylus of 5 μm.

A change of slope till 50% from original profile slope is noticed in performed researches.

From tables 1, 2, 3 and 4, paritcularly from percentage differences, hybrid parameter grouping can be made in terms of the effect of sampling spacing change. RDa(RΔa), RDq(RΔq), RLo and RVo are in the group where by sampling spacing increase, there values decrease. RLa and RLq are parameters where by sampling spacing increase, there values also increase. Only parameter Rfd shows smallest, insignificant change. Highest percentage change, which can reach even 80%, is noticed on parameter RLq for all profiles. So, RDq(RΔq) is more sensitive to slope change of roughness than RDa(RΔa). Comparison of gained results between stochastic and deterministic surface indicated possible larger influences of change of sampling spacing on stochastic surfaces.

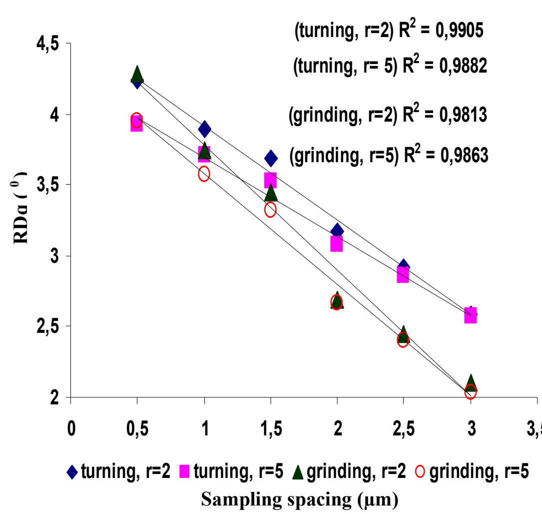


Figure 7. Correlation dependence and value of correlation coefficient between RDq and sampling spacing, for turned and grinded etalon surface with stylus radius of 2 and 5 μm.

The dependence and value of correlation coefficient RDq is shown on Figure 7 as most suitable indicator of roughness slope size change, by sampling spacing change.

Interesting are the considerations of the caused mechanical filtration when measuring profile with bigger stylus radius than recommendations in standards. This mechanical filtration, which has its effect even when gaining the original profile, has effect also in the further research process and is manifested by hybrid parameter difference occurrence. Results gained are somewhat smaller than those gained when measurements were performed with smaller radius.

5. CONCLUSION

Results gained, literature analyzed and own experiences indicate following conclusions:

- It has been determined that parameters that describe slope of roughness profile are significant in two aspects. Hybrid parameters directly effect functional characteristics, while as measurement conditions expressed through sampling spacing, with which same are determined, have direct effect upon hybrid parameter values.

- A significant change of hybrid values occurs by sampling spacing increase. Values of RDa, RDq, RLo and RVo decrease by sampling spacing increase, RLa and RLq increase, while as Rfd has smallest dependence on sampling spacing.

- Maybe in future further researches are necessary that shall provide dependence between Ra, Rq, and RSm and hybrid parameters for same sampling spacing change, all with the purpose of precise determination or at least expansion of recommendations prescribed in ISO 3274-1996 and ISO 4288-1996.

6. REFERENCES

[1]. D. J. Whitehouse. *Handbook of Surface Metrology*. Inst. of Physics, Bristol, 1994.

[2]. Taylor Hobson. *The Parameter Tree of Surface Roughness*. Centre of Excellence. 2000.

[3]. ISO 4287:1997; Geometrical product specifications (GPS) - Surface texture: Profile method – *Terms, defenitions and surface texture parameters*

[4]. JIS B0601 Standard. Explanation of Surface Characteristic, Japan

[5]. Pradeep L. Menezes, Kishore and Satish V. Kailas. *Influence of roughness parameters on coefficient of friction under lubricated conditions*, Sadhana Vol. 33, Part 3, June 2008, pp 181-190.

[6]. Tomov Mite. *Contribution to methods and measurement techniques development for research of influential factors of surface topography identification*. Application for Ph.D. dissertation, Mechanical Engineering Faculty, Skopje, 2008.

[7]. Mikolaj Kuzinovski, Mite Tomov, Piotr Cichosz, Trajčevski Neven, ...: : *Study on possibilities and accuracy of surface layer geometrical structure determination by using contact profilometers.* Scientific-research project, finance by Ministry of Education and Science on Republic of Macedonia. Number: 13-977/3-05, 1.7.2006-30.6.2009.

[8].Tomov M., Kuzinovski M., Cichosz P.: *Effect of sampling spacing on surface roughness parameter values.* XXXII Conference on Production Engineering with foreign participants, Novi Sad, Serbia, 18-20.09. 2008.

[9]. Pawel Pawlus. *An Analysis of slope of surface topography.* Metrology and Measurement System 2005, 12 (3/2005); 299-314.

[10]. Pawel P. Pawlus. *Mechanical filtration of surface profiles.* Measurement 35 (2004); pp 325-341.

[11]. Pawel Swornowski. *The influence of the mechanical filtration of the measuring-pin on the waviness and surface roughness.*Arhives of Mechanical Technology and Automation. Poznan 2006. ISSN 1233-9709, Vol. 26 nr 2. pp 129-137.

[12]. K. J. Stout. *Thre-Dimensional Surface Topography; Measurements, Interpretation and Applications*. Center for Metrology the University of Birmingham, 1994.

[13]. K. J. Stout and L. Blunt. *Tree-Dimensional Surface Topography. Secont edition.* School of Engineering. University of Huddersfield, Penton Pres, London, 1994.

[14].Tomov M., Kuzinovski M., Cichosz P.: Effect *of evaluation length on results of surface roughness measurements*. XXXII Conference on Production Engineering with forign participants, Novi Sad, Serbia, 18-20.09. 2008.

[15]. EAL-G20. *Calibration of Surface Instruments for Measuring Surface Roughness,* 1996.

[16]. ISO 12179: 2000; Geometrical product specifications (GPS) - Surface texture: Profile method - *Calibration of contact (stylus) instruments.*

[17]. ISO 3274:1996; Geometrical Product Specifications (GPS) - Surface texture: Profile method - *Nominal characteristics of contact stylus instruments.*

[18]. ISO 4288:1996; Geometrical product specifications (GPS) - Surface texture: Profile method - *Rules and procedures for the assessment of surface texture.*

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MODEL OF CLASSIFICATION SYSTEM OF TOOL WEAR CONDITION WHILE MACHINING BY TURNING

Abstract: *This work deals with a model of a developed fuzzy system for tool wear classification. The system consists of three modules: module for acquisition and data processing, for tool wear classifying and for decision making. In addition, some of the methods of signal processing used for defining the entering fuzzy classifier vector have been given.*
Key words: *Tool monitoring, Signal processing, Vibration signal, Fuzzy system*

1. INTRODUCTION

The basic requirements for the automation of the process of scraping in modern production conditions are the reliability of the tool monitoring system and the machining process. The shortcoming of the classical systems for tool wear monitoring is the fact that they work within the given boundaries, which often do not meet the requirements in an adequate way. The development of the modern monitoring systems, which work at real time, make the basis for monitoring the tool state and the machining process in an automatic production. Thus, modern diagnostic and managing systems are required to have a level of automation which can make conditions for managing the quality of a product and the production process, which is often called "intelligent" production system.

The machining process contains several different parameters difficult to measure which, combined with the dynamics of the very process, represent a stochastic and non-stationary process. A great number of parameters influence the very course of the machining process, some of them being: the characteristics of the materials processed, the state of the machining system, vibrations occurring during the machining process and a number of unknown but very influential parameters which together make the creation of an adequate processing model harder. This work deals with defining the model of the classification systems for the state of tool wear with special emphasis on the module for gathering and processing vibration acceleration signals by means of applying discrete wavelet transformation (DWT) on signal decomposing. Distinguishing the adequate characteristics of the fuzzy classifier entering vector for the tool wear classifying is one of the most important functions of the system.

2. TOOL WEAR MONITORING PRESENTATION

By developing new technologies and by mutual integration of measuring equipment and other mechatronic elements of a machine, as well as new more flexible managing approaches (open architecture managing system, applying of artificial intelligence algorithms for monitoring and process managing), conditions are met for intelligent processing systems development. [1]

Tool wear is a primary generator of accidental stochastic disturbances with a direct influence on stability, quality and economizing of the machining process. Some estimates show that 20% of the cutting process stoppages belong to the group of those caused by the consequence of the opportune reactions and tool wear discovering.

Getting reliable information about the tool state at real time represents and obligatory condition for identifying the degree of tool wear, which reasonably rises the stability of the machining process quality.

By the mid-80s of the last century several models of wear based on classical mathematical models have been suggested (Bayes` classificatory, the closest neighbors method, linear discriminators, and so on). However, that process was hard to describe by means of classical mathematical models due to its outstanding non - linear and stochastic qualities. Some more intense research on development of tool monitoring systems during the cutting process began in the 90s of the last century by applying a multi sensor approach, i.e. tool wear classifier based on artificial intelligence algorithm, which are in use today as well. The beginning of research in this area assumed that applying of these methods should result in industrially applicable solutions for cutting tools wear monitoring.

Among the most frequently used algorithms are the artificial neural networks (ANN) and fuzzy logics, which are widely applied nowadays and give possibilities for additional research [2].

The reasons for these models being widely applied should be looked for in: the possibility of complex non-linear processes described without sufficient information and burdened with different kinds of disturbance and unwanted noise in signals, usually appearing because of the very stochastic nature of the wearing process and the possibility of brief processing of a larger amount of information at real time. The above mentioned advantages become distinct in problems of the degree of tool wear estimate, where an adequate mathematical wearing model does not exist. In order to increase the quality of the tool wear monitoring system, a number of experimental surveys have been carried out, by using classifying models based on fuzzy logics and recently some hybrid combinations such as Neuro-fuzzy (NF) models and Fuzzy Neural Networks (FNN) appear more often. For this reason distinguishing of a number of different statistical parameters from signals and achieving a group of mutually independent and relevant wearing parameters of satisfactory quality, which are able to fully identify a complex dynamics of cutting tools wear comes as an imperative. The first step is collecting monitoring signals such as forces, vibrations, acoustic emission (AE), temperature and/or engine current etc. The second step is signal processing in order to separate its useful content. The last step is classification, where useful information from the signal are used for current tool state classifying [1].

The vibrating of the cutting tools while machining occurs as a consequence of: chip lamina creating, tools` vibrations, friction on the front and back surface of a tool, wearing of the cutting edge of the tool, the wavy structure of the surface processed and they are also connected to the vibrations caused by conjugated gear action in a kinetic machine chain. Different surveys have shown that tool vibrating occurring during continuous machining is the main reason for the friction between the back surface of a tool and the object being machined. The basic tool vibrating frequency is the resonant system frequency caused by friction on the cutting edge. Vibrations accelerating represent their best measure when appearing at high frequencies. Since the vibrations of cutting tools are the ones of high frequency (over 1 kHz), tool accelerating has been chosen to be a parameter of tool wear monitoring [3].

Applying the value analysis for selecting the identified parameters of the machining process is an important part of parameter adequacy determination. Analyses like this one appear as an adequate response and compensation for following several different and stochastic parameters of the classical systems.

3. BASIC DATA ABOUT THE MODEL

Tool wear monitoring system model can basically be regarded through four segments bound together making a whole, represented in the picture 1.

System modules are the following:

- acquisition and data processing module,
- decision-making data classifying module,
- fuzzy decision-making module.

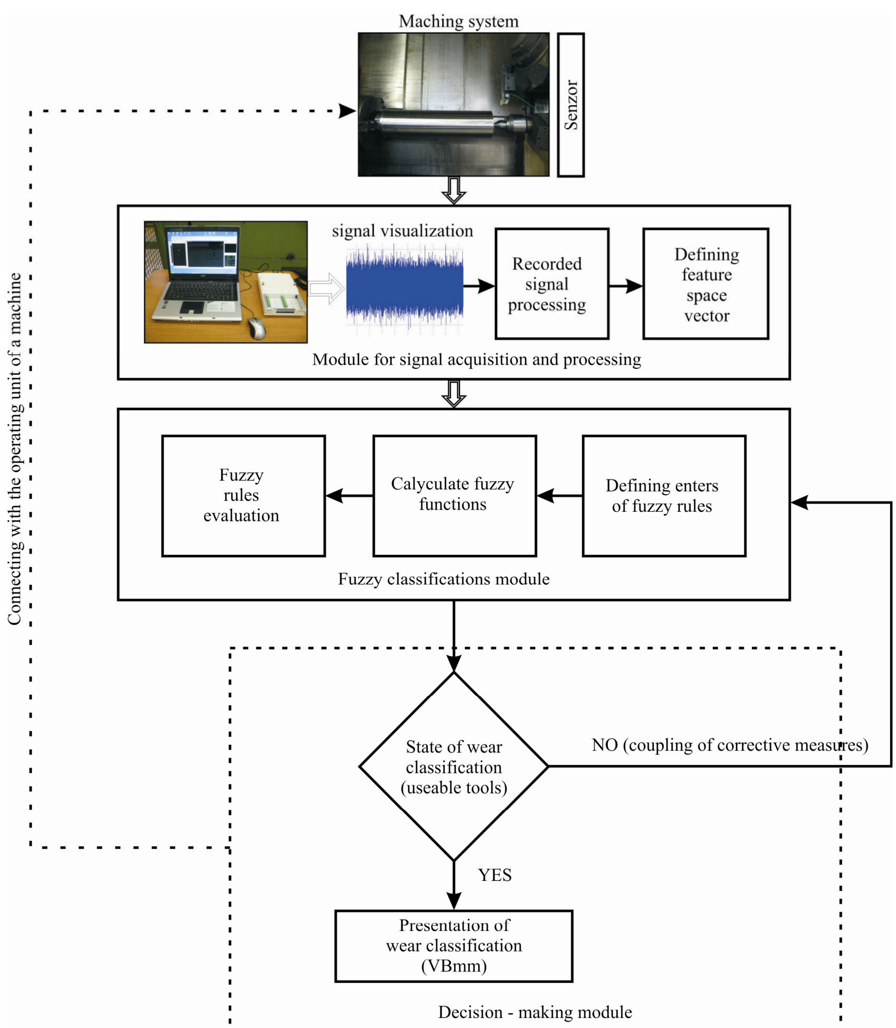

Fig. 1. Presentation of developed system structure for tool wear classification

3.1 Subsystem for data acquisition and processing

Accelerometer measuring vibration accelerations and mounted on the tool handle makes the sensory part of the data collecting module. The part of the module used for data acquisition, processing and analyzing consists of A/D card NI USB 6281 18bit, 625 kS/s, which receives analogous data from the existing sensor, converts them into digital information and sends them to the entering data base. A software system of the Matlab version R2008b has been used for card managing. The system enables the vital working functions to be defined.

By means of the suggested approach the entering data “vectors” are being additionally filtrated in the training data classifying system module, thus acquiring better results at more complex evaluation concerning more complex processing. The structure of the suggested system can be regarded through two phases. In the first phase, the initial model structure establishing phase, the initial structure of the “classifier” is being established, the parameters of structure for a number of combinations of machining parameters (velocity, depth and motion, characteristics of materials and tools etc) and for each wearing parameter respectively, are being determined. In this part of the classifying system, initializing all parameters is equally non-limited. If the testing shows that system responses could be improved at a higher or lower extent, the initial structure can additionally be improved during the phase of secondary learning i.e. structure stabilizing. Data standardization is being done here, as well. It is essential to go through data standardization in order to get more precise data without disturbances that can occur during sampling. Moreover, different mathematical functions for signal processing at real time can be additionally used and then the measuring data can be transformed into other measuring quantities if necessary. The aim of data selecting and standardization is choosing the most influential and accurate data relevant for the process, on the basis of which fuzzy system will be drilled.

The software system has been projected for information collecting and processing as well as managing hardware components, and thus supervising and classifying tool ware on the basis of given restrictions. The remaining tool validity is determined on the basis of wear trend acquired by simultaneous analysis with the calculated wear and the real state.

Selecting the right kind of filter will depend, in the first place, on the kind of the signal followed, tool characteristics, machines, work piece, machining parameter and other machining conditions. As it follows, the filtering procedure is not uniquely defined and it should be carefully determined for each particular case, regarding the individual characteristics of the process. Thus, the suppression of the parts of the signal which carry vital information about the state of cutting tools will be avoided. According to the literature available, it can be concluded that the lowpass and bandpass filters implemented in the measuring equipment and realized by means of computing processing, i.e. program support in the phase of additional signal filtering, are most frequently applied. Filter selecting will depend on its velocity and the quality of the outgoing signal. It should be mentioned that in literature the right kind of used filter is rarely specified, and that in a large number of works it can be noticed that additional filtering is not mentioned at all, although it has been carried out. Within the research the lowpass FIR (Finite Impulse Response) filter has been used for vibration signals.

The above mentioned forms of filtering can be applied in situations when the frequency range of a signal is of interest a priori and completely defined. There are also situations in which it is not always possible to distinguish properly the range with information about the tools state from the ones representing noise [4]. Concrete examples are the high frequencies of vibration signals and the acoustic emission signal, where elastic waves occur due to the effort in the zones of deforming. The waves occur as a consequence of freeing energy produced by separating molecules in a crystal grid of a material. One of the main advantages of using these kinds of signals follow from the fact that their frequencies are considerably higher (ultrasound area) from the vibration frequency of a machine and the surrounding area. In that way unwanted influences can be directly avoided, as well as the occurring of lower frequency spectrum which is not related to the tool wear. However, a problem occurs in cases when it is necessary to isolate more harmonics which appear because of the plastic deformation and breaking of degraded particles, particles-tools collision and all other disturbances for which it is difficult to determine the area of frequency. It turned out that this kind of disturbance is possible to isolate considerably by applying wavelet transformation method. It is a kind of method based on the signal decomposing procedure after which the partial filtering of its segments follows

3.2 Signal processing by means of discreet wavelet transformation

Wavelet transformation is the most frequently used and the most important signal analyzing method in a time-frequent area. Its basic advantage related to methods of frequency area analysis (e.g. Fourier`s transformations) represents a high-quality and simultaneous signal presentation both in a frequency and time areas. In that way, a possibility of signal analysis on the local level is acquired, which is especially important for non-stationary signal processing. This function, while being analyzed, gets a number of different forms related to its width modification. The transformation procedure is based on comparison of wavelet function of a certain width (frequency) defined by a scaling parameter (s) and by parts of signals of the same width in a certain time interval (t – kτ), the scale being inversely defined, considering signal frequency. The record of the continuous wavelet transformation (CWT) in a general form is given in the scheme:

$$\gamma(\tau,s)\frac{1}{\sqrt{|s|}}\int_{-\infty}^{\infty}x(t)\varphi^{*}\left(\frac{t-\tau}{s}\right)dt \tag{1}$$

Where τ is a translation parameter, s scale parameter, x(t) signal being transformed, γ frequency structure of the signal x(t) at a given time interval k$ and with the s scale, and $ the scaled and translated projection of the original wavelet kτ. When analysis of the whole signal is being carried out with the original function of a given scale, the procedure is being repeated for another scale value, i.e. time interval. If the signal contains a spectral component corresponding to the current scale value, multiplying of the wavelet function and the signal located where the component is existing is relatively high. Wavelet moving in time leads to signal localizing in time, while the scale changing produces information of the signal frequencies in each of the analyzed time intervals. In the low-frequency area signal basis (signal approximation) is determined, while the high-frequency area gives more detailed information.

4. WEAR PARAMETERS

4.1 Selecting the tool wear defining parameters

A good selection of the best group of wear parameters, which can classify the degree of tool wear with required accuracy during the process of classification, is the last step of the signal processing procedure. Analysis show that in most cases the aim of the process of parameter selection is selection of the optimal number of parameters and only after that the most suitable parameter group, considering the influence of each parameter separately on the degree of tool wear recognizing.

Although it is better to use a larger number of independent parameters as a rule, too many parameters can cause overnoising, for example when neural frameworks are used (overfitting), which are still used by most of the authors at wear process modeling. Overnoising leads to decrease of the general features of the frameworks and consequently worse quality of the system responding.

It can be noticed that the problem of wear parameter analysis and selection has been treated in literature in several ways. Generally, explanation for their particular selection does not exist. They are followed by works in which the analysis of the influence of recorded signals on the wear dynamics was primarily done. On the basis of these observations wear parameters which describe accurately some segments or appearing of wear process were suggested [5]. A group of methods use the so called parameter sequential selection, which imply their mutual independence when tool wear evaluating, while another group is independent when choosing parameter combinations. Generally speaking, as opposed to the combined approach, when the individual parameter selection is concerned, their growth influences less the increase of the model complexity then the increase of additional data analysis. On the other hand, certain situations show that mutual influences of parameters can result in higher degree of correlation with the wear dynamics than in the case of individual approach. Finally, the last group contains the parameters where the wear parameter selection is done depending on their influence on the classifying results. This approach, as well as the individual analysis of wear parameter influence, has been used in this paper, as well.

5. CONCLUSION

The presented model of tool wear fuzzy classifier uses the processed signal of vibration acceleration from a sensor allocated on the tool in order to evaluate tool wear. This technique provides an acceptable method for the process of fuzzy modeling on the basis of which are calculated the parameters of membership functions which represent the incoming/outgoing data in the best possible way. Once the model is formed, it can evaluate the degree of tool wear for certain cutting parameters (the ones it has been taught). The model is formed rather rapidly and it can evaluate tool wear on-line. The time needed for the model formation depends on the quantity of entering data, while the model accuracy depends on the data selection

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Sick, B., 2002, On-line and Indirect Tool Wear Monitoring in Turning with Artificial Neural Networks, Mechanical Systems and Signal Processing, No 16(4), 487 – 546., ISSN 0888-3270

[2] Antić A., Hodolič, J., Soković, M., 2006, Development of a Neural-Networks Tool-Wear Monitoring System for a Turning Process, Strojniški vjesnik Journal of Mechanical Engineering, 52(11), 763-776, ISSN 0039-2480

[3] Sharma V.S., Sharma S. K., Sharma A. K., 2007, Cutting tool wear estimation for Turning, Journal Intell Manuf, No 19, 99–108.

[4] Antić A., Petrović, B., Zeljković, M., Dinamika obradnog sistema i njene implikacije na indirektno prepoznavanje stanja reznog alata, 32. Savetovanje proizvodnog mašinstva Srbije, Novi Sad: Fakultet tehničkih nauka, 18-20 septembar, 2008, 341- 346, ISBN 978-86-7892-131-5.

[5] Al-Habaibeh, A., & Gindy, N., , 2001, Self-Learning Algorithm for Automated Design of Condition Monitoring Systems for Milling Operations, The International Journal of Advanced Manufacturing Technology, No 18, pp. 448-459., ISSN 0268-3768

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Gostimirovic, M., Kovac, P., Sekulic, M., Savkovic B.

INVERSE TASK SOLUTION OF HEAT CONDUCTION IN GRINDING PROCESS

Abstract: *This paper takes identification of the thermal state of grinding process, using inverse task solution to approximate heat conduction. Based on a temperature measured at any point within a workpiece, this experimental and analytical method allows determination of a complete temperature field in the workpiece surface layer as well as the unknown heat flux on the wheel/workpiece interface. In order to solve the inverse task of heat conduction, a numerical method of finite differences in implicit form was used.*

Key words: *Grinding process, Thermal state, Inverse task solution.*

1. INTRODUCTION

It is evident that grinding process causes the development of large quantities of thermal energy within the cutting zone. The generated thermal energy, located within a relatively narrow area of the cutting zone, causes high cutting temperatures in creep-feed grinding. These increased temperatures instantaneously burst to a maximum, have short duration and exert a pronounced negative effect on wheel surface, workpiece quality and accuracy.

Efficient control of thermal phenomena in grinding requires knowledge of heat development and distribution in grinding, temperature field in the cutting zone and, finally, influence of cutting conditions on grinding temperature. As the research so far has shown, non-stationary and non-linear technical processes involving intensive heat conduction, such as grinding, can be successfully solved using novel approach based on inverse task solution of heat transfer [1]. Inverse task solution of heat transfer allows the closest possible experimental-model approximation of thermal regimes for grinding.

2. GENERAL CASE OF INVERSE TASK

The process of heat transfer between solid bodies or between a system and its environment, of which heat conduction in grinding is also a part, is mostly considered from the standpoint of mutual relations between input and output process parameters. It is widely accepted that such process can be schematized as in Fig. 1.

The first step in the research of any thermal phenomenon is to model the real process. This means development of a model which is valid over a narrow domain limited by boundary conditions. The model, which describes a segment of the real process, correlates input ***u****(t)* and output *z(t)* parameters which define the state of the process at every moment in time ***t***.

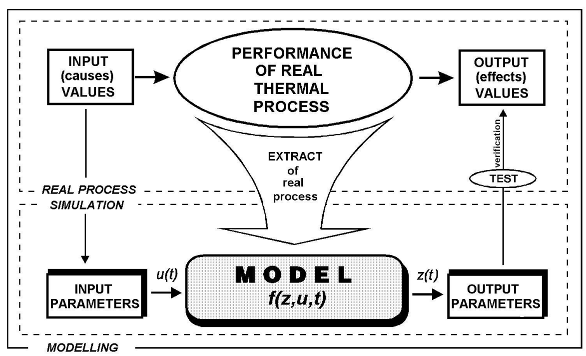

Fig. 1. Diagram of a thermal process

If the input parameters **u**(t) are known and output parameters *z(t)* define process state in time, then the output parameters are a function of input parameters, i.e.:

$$z = f(u,t) \qquad (1)$$

The real thermal process is most often described analytically. The goal is to set up a most adequate analytical model, while, on the other side, keeping its form as simple as possible in order to facilitate solution. Given the right mathematical method, the model thus defined, solves problems quickly and efficiently.

Analytical model of thermal process most often takes form of a system of differential and algebraic equations. Considering the fact that thus modeled task is easily transformed into algorithm and efficiently processed on computer, the differential models are widespread today in the investigation of thermal processes.

If for the adopted thermal model there exist unique conditions, then any particular input parameters of the thermal process shall result in that same or any other thermal state defined by the temperature field of the analyzed object. Determination of the input-output relationship is the direct task of heat conduction. Conversely, the inverse task of heat conduction solves the problem of finding input characteristics of the process for the known temperature field.

If for every unknown parameter ***u*** there is a linear, smooth operator ***A*** which allows determination of output parameter ***z*,** the general case of inverse task is formulated by the following equation:

$$Au = z \qquad (2)$$

If we represent the unknown input parameter of the thermal state with $\boldsymbol{u(t)}$, where $0<\boldsymbol{t}<t_K$, and if $\boldsymbol{z(t_K)}$ denotes the known output parameter of the process, where $0<\boldsymbol{t_K}<t_m$, then the inverse task becomes:

$$Au \equiv \int_0^{t_K} u(t)\theta(t_K,t)dt = z(t_K) \qquad (3)$$

where $\boldsymbol{\theta(t_K,t)}$ is the initial characteristic of the process.

In equation (3), $\boldsymbol{u(t)}$ is the solution, i.e. heat flux or surface temperature of body, while function $\boldsymbol{z(t_K)}$ represents the temperatures measured outside the body at a point ***K***.

3. INVERSE TASK OF THE GRINDING PROCESS

The role of mathematical theory behind thermal phenomena in grinding is to adopt the most adequate model of workpiece, grinding wheel and their inter-relationships. It is well known that, due to lack of continuous cutting edge, irregular geometry of grinding particles and their inconsistent distribution on the grinding wheel, it is very difficult to model the grinding process. Therefore, some simplifications are necessary where the final solution is verified by experiments, fig. 2. Despite simplification, such analytical and experimental model yields reliable results.

One can assume that the elementary heat source on the grinding particle is the result of friction between the grinding particle, workpiece and chip in the workpiece material shear plane. Summing up all the heat sources, i.e. grinding particles in contact with the workpiece, gives the total heat source for the entire cutting zone, ***q***. This total heat source, whose strength varies within a narrow range, acts continuously, shifting across the workpiece surface with constant velocity.

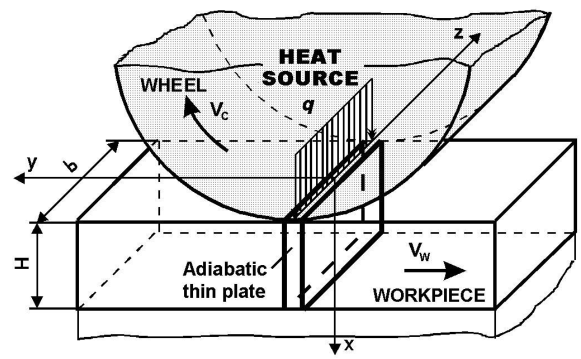

Fig. 2.Model of heat conduction in an elementary workpiece part in surface grinding

Now the analytical form of inverse task solution of heat conduction for surface grinding can be described with the following differential equation of heat conduction (4), in conjunction with the initial, additional and boundary conditions:

$$\rho c(\theta)\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left(\lambda(\theta)\frac{\partial\theta}{\partial x}\right) \qquad \begin{matrix} x\in(0,H) \\ t\in(0,t_m] \end{matrix} \qquad (4)$$

$$\theta(x,t)\big|_{t=0} = \varphi(x) \qquad x\in[0,H]$$

$$\theta(x,t)\big|_{x=K} = \xi(t) \qquad t\in[0,t_m]$$

$$-\lambda(\theta(x,t))\frac{\partial\theta(x,t)}{\partial x}\bigg|_{x=H} = \bar{q}(t) \qquad t\in[0,t_m]$$

The final solution of the inverse task is the heat flux density on wheel/workpiece interface, $\boldsymbol{q(t)}$, and the temperature field $\boldsymbol{\theta}=\theta(x,t)$ throughout entire elementary part of workpiece, $\boldsymbol{D}=\{(x,t): x\in[0,H],\ t\in[0,t_m]\}$.

To solve the partial differential equation (4) an implicit form of the finite differences method was chosen [2]. System of linear algebraic equations (5) are used to calculate the unknown heat flux $\boldsymbol{q}^{n+1}$ on workpiece surface and the temperature field of the workpiece surface layer $\boldsymbol{\theta}_h^{n+1}$ (h=0,1,...,K-1,K+1,...,H) as follows:

$$[\mathbf{R}]\cdot\{\mathbf{\Theta}\}=\{\mathbf{B}\} \qquad (5)$$

Solving the matrix system (5) requires the initial task to be divided into two parts. Direct task of heat conduction within the area $\boldsymbol{D}_2=\{(x,t): x\in[K,H],\ t\in[0,t_m]\}$ and problem of inverse heat conduction in the area of $\boldsymbol{D}_1=\{(x,t): x\in[0,K],\ t\in[0,t_m]\}$.

4. THE RESULTS USING INVERSE METHOD

As the proposed system uses experiment and analytical model to control the heat loading of wokrpiece surface layer in grinding, it requires distribution of temperatures to be determined experimentally at a point within the workpiece.

In this case of verification - to calculate the workpiece heat loading by inverse heat conduction - the known temperature distribution at depth z = 1 mm was taken for additional boundary condition, fig. 3. Furthermore, the contact temperature was not allowed to exceed the critical tempering temperature, which was experimentally esatblished at 550 °C for the selected high-speed steel.

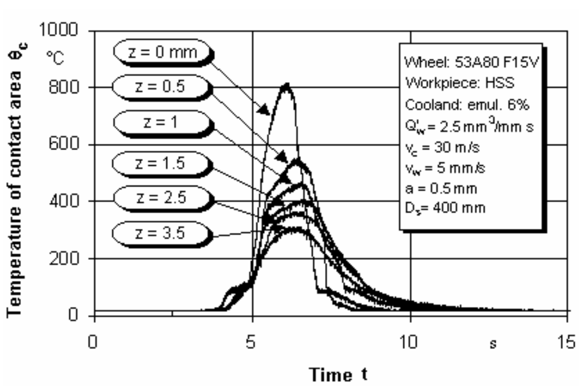

Fig. 3. Temperature distribution in time within the workpiece surface layer

Based on the previous experimental results [3], and considering the process boundary conditions and thermal/physical characteristics of grinding, the total temperature field in workpiece surface layer was obtained by computation, as well as the heat flux density in the wheel/workpiece interface.

The computed time- and depth-related change of temperature in the interface zone of the workpiece surface layer, shows high degree of conformity with the experimentally obtained results. Shown in fig. 4 is the change of interface temperature obtained both analytically and experimentally.

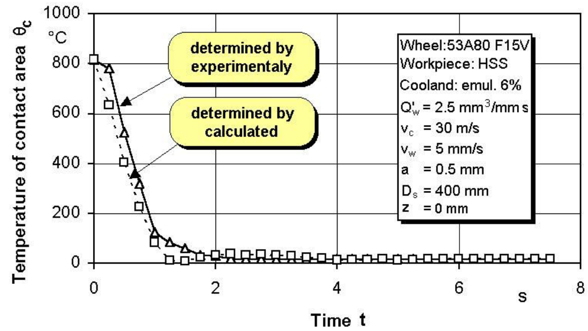

Fig. 4. Temperature change in the interface zone of the workpiece surface layer

5. CONCLUSIONS

- Analytical inverse heat conduction allows approximation of the temperature field in the surface layer of workpiece material and determination of heat flux density distribution in the wheel/workpiece interface zone;
- The inverse task was solved using method of finite differences in implicit form;
- Analytically obtained temperature field in the workpiece surface layer largely agrees with experimental results.

6. REFERENCES

[1] Alifanov O.M.: *Inverse problems of heat transfer: theory and practice*, V Minsk international heat and mass transfer forum, Minsk, 2004.

[2] Özisik N.M.: *Basic Heat Transfer*. Mc Grow-Hill Book Company, New York, 1977.

[3] Gostimirovic M., Milikic D.: *Control of the thermal effects in the grinding process (in Serbia),* Monograph, Faculty of Engineering, Novi Sad, 2002.

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Kovac, P., Savkovic, B., Mijic, A., Sekulic, M.

MODELING OF CUTTING FORCES IN FACE MILLING

Abstract: *This paper presents experimentally obtained results of cutting forces during face milling. Measurement of cutting forces and showing of these results are done by data acquisition system. Virtual instrument used for measuring the force for face milling was developed using graphical programming software. Results are presented in graphical forms and mathematical model for cutting forces components as function of cutting condition was determined.*
Key words: *Milling, Cutting forces, Data acquisition, Virtual instrumentation.*

1. INTRODUCTION

Cutting force (resistance) and their moments have great significance in engineering technology and general in the theory of material machining. They represent the basic categories of cutting mechanics, which means that the cutting force expresses one of the basic characteristics of the state and conduct of the process [1]

Researches in the field of metal processing technology, chip removal, in most of his works, were focused on machinability of material. Machinability of material defining features of tool life, cutting forces, surface quality, cutting temperature and chip form. Knowing these features, as well as important technological characteristics of the material, it is important to both the classical and the design of technology for automated cutting process. In accordance with that is to create a database of machinability and optimization of cutting parameters.

The importance of knowledge of cutting force, as one of the most important machinability functions is large, which is why this issue is constantly attracted the attention of researchers in this field. Knowing the value of cutting force provides to: determine the energy balance of machine tools, perform the calculation and dimensioning kinematics elements of machine tools, perform the calculation and dimensioning of cutting tools and auxiliary equipment, perform optimization of machining processes (based on calculation of optimal values of the elements of the regime and equations whose description of the cutting force), adaptive control machining systems and others. Since the face - milling head is one of the most efficient and, in the field of machining is with relatively high productivity, it is logical that the largest number of papers and related research is dedicated for this process. Cutting forces in milling are intensively studied both analytically and experimentally [2]. In Figure 1 are shown the orthogonal cutting forces in face milling process.

Face milling process particularity like multi tooth that simultaneously cutting and difference in chip cross section that one tooth cut influenced development of variety of models for cutting force calculation. Variation in chip cross section gives difference in intensity of cutting forces and thermal load of single tooth.

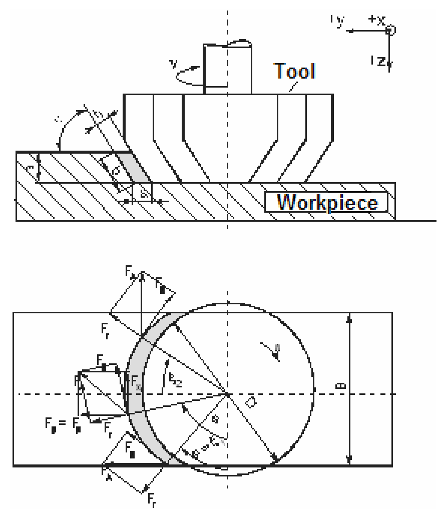

Fig. 1. Plan of cutting forces during face milling

Force F_a changes in direction and intensity during a tooth cutting, so its components F_x and F_y are different intensity according the angle change from 0°÷180. The position $\varphi = \xi_1$ component $F_x = 0$, and the F_a has the feed motion direction, and $F_a = F_p$, where F_p is feed force. If the direction of F_a is perpendicular to the feed then $F_y = 0$ ($\varphi = \pi/2 + \xi_2$). If components F_x and F_y is known it can be calculated on the basis of their force F_a .

Two other components that may decompound the force F_a are the forces in tangential and radial direction. These are the main cutting force F_g and the (passive) penetration cutting force F_r.

If are considered two positions of milling teeth in cut, so the first position is for $\varphi<\pi/2$, in the second is for $\varphi>\pi/2$. The equations that connect these forces are:

Position I:

$$F_x = -F_g \cdot \sin\varphi + F_r \cdot \cos\varphi \tag{1}$$

$$F_y = F_g \cdot \cos\varphi + F_r \cdot \sin\varphi \tag{2}$$

$$F_z = F_a \qquad (3)$$

Solving the system of equations (1) (2) and (3) we get:

$$F_g = -F_x \cdot \sin\varphi + F_y \cdot \cos\varphi \qquad (4)$$

$$F_r = F_x \cdot \cos\varphi + F_y \cdot \sin\varphi \qquad (5)$$

$$F_a = F_z \qquad (6)$$

Feed force in the direction offeed motion F_p at any time is equal to the force F_y, respectively:

$$F_p = F_g \cdot \cos\varphi + F_r \cdot \sin\varphi = F_y \qquad (7)$$

Position II:

$$F_x = -F_g \cdot \cos\left(\varphi - \frac{\pi}{2}\right) - F_r \cdot \sin\left(\varphi - \frac{\pi}{2}\right) \qquad (8)$$

$$F_y = -F_g \cdot \sin\left(\varphi - \frac{\pi}{2}\right) + F_r \cdot \cos\left(\varphi - \frac{\pi}{2}\right) \qquad (9)$$

$$F_z = F_a \qquad (10)$$

Taking into account the addition formula:

$$\sin\left(\varphi - \frac{\pi}{2}\right) = \sin\varphi \cdot \cos\frac{\pi}{2} - \cos\varphi \cdot \sin\frac{\pi}{2} = -\cos\varphi \qquad (11)$$

$$\cos\left(\varphi - \frac{\pi}{2}\right) = \cos\varphi \cdot \cos\frac{\pi}{2} + \sin\varphi \cdot \sin\frac{\pi}{2} = \sin\varphi \qquad (12)$$

equations (8) (9) and (10) are reduced to equations (4) (5) and (6), whose solution has already been shown.

2. EXPERIMENTAL INVESTIGATION

In this work, using the developed system for monitoring, acquisition and measurement of cutting forces in milling process, by use of virtual instrumentation (VI) was performed measurements of milling forces. The aim of the task was to make the analysis of the influence of machining elements on the value of cutting force components. Calculation of the measured cutting force components in the main cutting force, the force of penetration and force extra motion in time domain duration of a tool revolution will be made as well.

Additionaly was performed a comparison of relationships between the main cutting force for two different steel (Č.1530 and Č.4732) at the same machining conditions.

3. MEASURING ACQUISITION SYSTEM FOR THE FORCE DURING FACE MILLING

3.1. Characteristics used acquisition system

Measuring acquisition system must meet the following requirements [2]:

- High efficiency and accuracy of results;
- Involvement of existing laboratory resources and their compatibility;
- Rational use of time and laboratory resources, with very little consumption of workpiece materials, cutting tools and time;
- To be suitable for serial testing in a large number of materials for the formation of computer databases on machinability material cutting;
- Good portability and compatibility;
- To enable the display of results and monitoring processes in real time;
- And finally, to enable the acquisition, storage and processing of data.

Figure 2 shows the measuring acquisition system scheme for the cutting force during face milling.

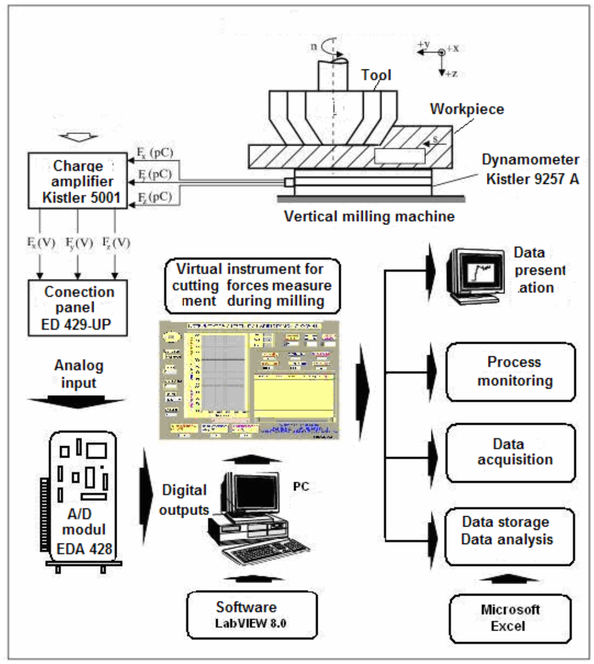

Fig. 2. Model for measuring acquisition system for measuring the cutting force in face milling [3]

From Figure 2 we can see that the system consists of the following components:

- Machine Tool (vertical milling machines - “Prvomajska” FAS-GVK-3)
- Tools (milling head with interchangeable cutting plates)
- Sensor measurement system (three component piezoelectric dynamometer - "Kistler"-9257A)
- amplifier measurement system (capacitate-amplifier "Kistler" - CA 500)
- Dial-up panel for connecting the module with the actual acquisition process (ED429-UP)
- Acquisition Module - A / D converter - ED428
- Computer System
- Program (software) support system
- VI for acquisition, display in real time, storing and processing data

3.2. Virtual instrument

Virtual instrument used for measuring the force in face milling was developed using graphical programming software Lab VIEW 8.0. VI is designed to allow easy reading voltage with dynamometer, which correspond to the forces of cutting during face milling F_x, F_y and F_z, view, change the values in the form of diagrams and tables, and display the maximal values of in a single measurement.

VI contains three components:

- The front panel (front panel) - serves as a graphical user interface
- Block diagram (block diagram) - contains graphic VI source code, which defines its functionality.
- Connector and icon (icon and connector panel) - identifies the VI so that it can be used in another VI. VI in another VI is called SubVI. SubVI corresponds to subroutine in text-oriented programming languages.

4. EXPERIMENTAL TESTING

Using the system shown (Fig. 2) measurements were performed and acquisitions orthogonal cutting force in milling cutter.

During the experimental tests measured were the orthogonal cutting forces F_x, F_y, F_z, and based on them were obtained through the computational power F_g, F_r, F_p and F_a according equations (1) to (10). Figure 3 shows the change of cutting force during face milling with milling cutter diameter D = 125 [mm], with one tooth (insert of TM). Experimental testing was provided with new and worn tool. Workpiece material was a steel Č1530 and Č.473. The diagram on Fig 3 presents the cutting forces measurements versus tooth position for the following cutting regimes: v=177 [m/min] a=1,5 [mm], s_z=0,223 [mm/z].

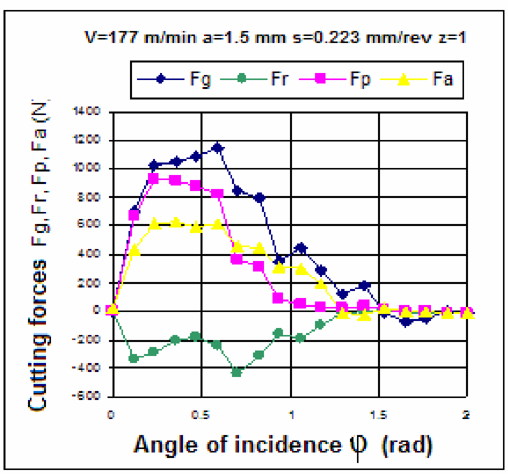

Fig. 3. Change cutting forces versus the position angle of the tool when cutting with a new tool

In the second experiment (Figure 4.) processing is performed with the same cutting regime and the same workpiece material, but this time was used worn cutting insert (Figure 5). Flank wear land on the surface was 0.4 [mm], but there was concentrated tool wear at the top of the insert with the maximum amount of 2 [mm], Figure 5.

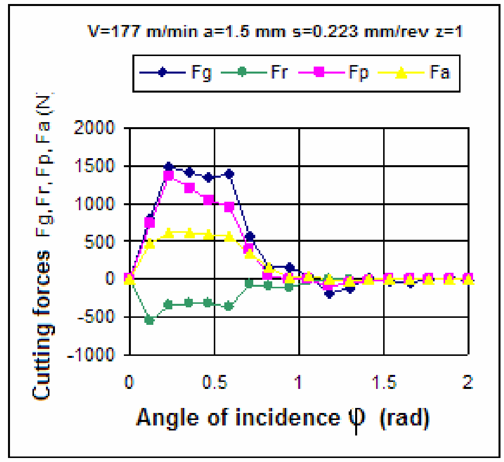

Fig. 4. Change cutting forces versus the position angle of the tool when cutting with a worn tool

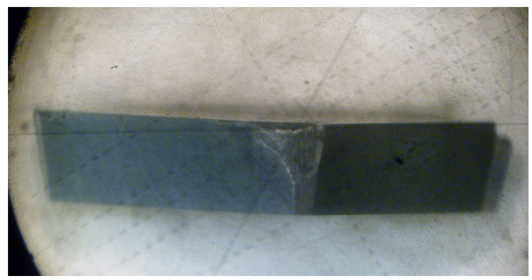

Fig. 5. The appearance of worn insert

Analyze of diagrams in Figure 3 and 4, shows that the machining with worn cutting insert increases the value of cutting force in relation to the case when the cutting was done with new insert.

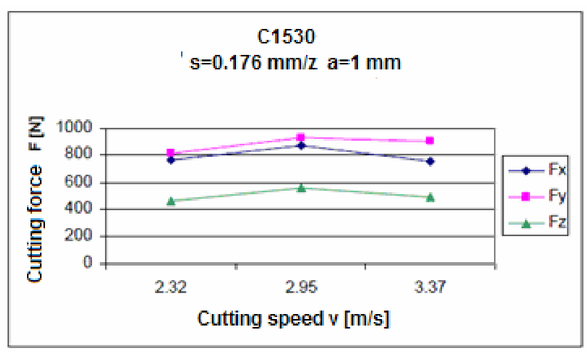

Fig. 6. Change orthogonal cutting force for constant cutting depth and cutting feed, and different speeds with worn cutting tool

In further processing of results was examined dependence on changes in the orthogonal cutting force constant depth a = 1 [mm] and the cutting speed v = 2.32 [m/s], and different feed s_z in interval of (0,178 [mm/z], 0,223 [mm/z], 0,280 [mm/z]) (Figure 6). Also was varied depth, with constant cutting speed and feed (Figure 7). In this case the value of cutting depth a_1=1[mm], a_2=1,5[mm] and a_3=2,25[mm]. The value of cutting speed for this case was constant v = 2.32 [m/s], and feed s_z=0,178 [mm/z].

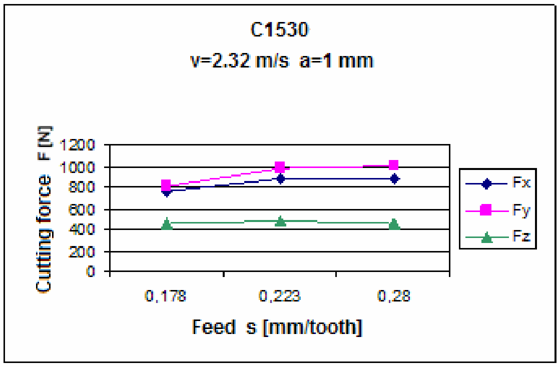

Fig. 6. Change of orthogonal cutting force for constant cutting depth and cutting speed, and different feeds with worn cutting tool

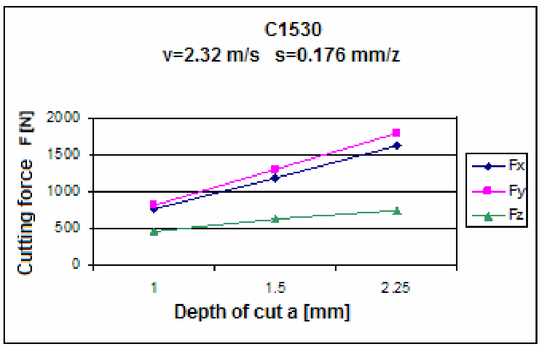

Fig. 7. Change of orthogonal cutting force for constant cutting speed and feed and for different depths of cut with worn cutting tool

The analysis of the diagram in Figure 6, shows that with increasing values of feed and depth of cut the cutting force increase. Change of cutting speed has no great influence on the change of cutting force The largest increase in cutting force is according the variation of depth of cut (Figure 7).

At the end analyzed was relationships for the major cutting force for Č.1530 and Č.4732 for the same machining conditions.

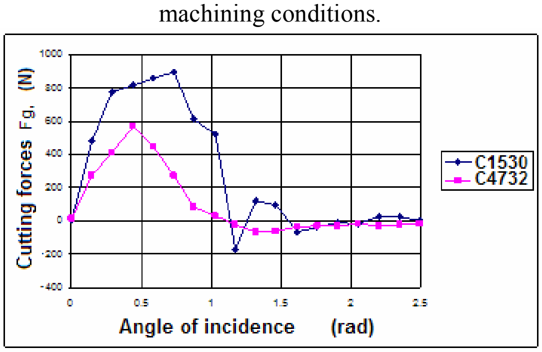

Fig. 8.Cutting forces for different machined materials (Č.1530 and Č.4732) and same cutting conditions

From Figure 8 can be seen that the steels with lower sulfur content (Č.1530) is difficult to machining (more major powers) versus the steel with higher sulfur content (Č.4732). This can be explained by the fact that the increased content of sulfur allows the creation of a larger number of MnS particles, which can plastically deform during the cutting process, unlike the tiles in perlite cementite that break. Besides the presence of MnS particles reduces the length of contact on the surface rake face of tools. Shorter length of contact, with cutting tool resulting in thinner chips and smaller cutting force [2].

5. CONCLUSION

Investigation of cutting forces is a key part in the development of cutting technology itself. They are one of the main criteria for evaluating machinability of material and as such attract the attention of many researchers in this field. Exact knowledge of the characteristics and values of cutting force in the face milling is needed to study the dynamics of cutting process in interaction with the dynamics behavior of the structure of machine tools. Analysis of cutting force in milling is very complex due to the influence of a number of different phenomena.

The work indicates the complexity of the processes that take place during cutting. A large number of factors affect the results, and deviation from the experimental results obtained literature values often. It is the deviation of the results show the importance of such tests, which are the basis for the development of machine tools, tools and optimization of the processing.

6. REFERENCES

[1] P. Kovač, D. Milikić, Metal Cutting, (in Serbian) Novi Sad, February, 1998.
[2] M. Sekulić, Development of base for calculation of cutting forces, master thesis, FTN, Novi Sad, October, 1998.
[3] Lazić B., Development of measurement acquisition system for cutting force during milling with virtual instrumentation (in Serbian) Master work, FTN, Novi Sad, 2009.
[4] A. Mijić: Cutting forces modelling in face Milling, (in Serbian) Master work, FTN, Novi Sad, 2009

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COMPUTER ANALYSIS OF CUTTING FORCE ACTION ON CUTTING TOOL DURING TURNING

Abstract: *Finite element method, as a method of simulation of the cutting phenomenon during machining process allows obtaining information relevant for further computational analysis of tool wear, cutting temperature and cutting forces. These are the most important factors that influence the accuracy of processing and combined with other factors they affect deformation of cutting tools. The paper presents computer analysis of tool deformation during the turning process using finite element method in ANSYS software package.*
Keywords: *Turning, finite element method, load control*

1. INTRODUCTION

Cutting process is one of the most important and most common production processes in the metal machining industry. Production economy in the metal machining industry is achieved primarily by optimal choice of all the factors that influence the cutting process.

Application of computers brought revolutionary changes in the domain of various engineering and scientific disciplines, and one of the first was the area of solid mechanics.

We generally use the terms modeling and simulation interchangeably in manufacturing research literature. In the case of cutting, there are many phenomena that are not easily observed or not subject to direct experimentation so the models are developed so that the influence of a number of process parameters can be simulated using this model. Common models used are based on Eulerian or Lagrangian finite element techniques. Four primary categories of methodologies for modeling of cutting are evident over the past several decades.

- *Analytical modeling* (determining the relationship between the forces in cutting based on cutting geometry and including experimentally determined values of shear angle, friction conditions and chip flow angle; for example, Ernst and Merchant's early work)
- *Slip line modeling* (predicts mechanical response and temperature distributions based on assumptions about slip line field geometry in the shear zone and around the tool)
- *Mechanistic modeling* (predicts cutting forces for a wide range of complex machining processes based on the assumption that cutting forces are the product of the uncut chip area and specific cutting energy where specific cutting energy is empirically derived from workpiece material, cutting parameters, and cutting geometry; for example the work of Tlusty)
- *Finite element modeling* (FEM techniques use small mesh representations of the material and tooling as the basis for determining material stress and strain conditions and, ultimately, flow of material based on assumptions of continuity between adjacent elements)

The application of these modeling techniques covers the range of cutting processes and interests including cutting forces (static and dynamic), power, tool wear and life, chip flow angle/curl/form, built up edge, temperatures, workpiece surface conditions and integrity, tool geometry, coating and design influences, burr formation, part distortion and accuracy, tool deflection, dynamic stability limits and thermal damage. Processes modeled range from orthogonal cutting to multi-tooth milling, hard-turning and drilling. The predominance of the work, as evidenced by research publications, is in turning (plane face tools), face milling, drilling (twist drills) and end milling and slotting.

A number of application areas that have been motivated by increasing cutting performance where modeling has been shown to be effective (cutting hard materials, burr formation, chip formation, temperature and tool wear in cutting) are described here. The increase of computer processor power has enabled a significant improvement in a relationship between the cost of the system and its performance, which resulted in increased number of users in industry, who integrated FEM (Finite Element Method) systems into the process design and product development.

Starting from a number of possibilities which, the application of finite element method and system software ANSYS version 11 and its module, ANSYS Workbench provide, this work carried out computer analysis of the effects of forces that occur during the cutting process on the cutting tool using finite element method in the mentioned module.

2. BASICS OF CUTTING

The process of cutting occurs when a wedge of cutting tool (1) penetrates the material (2) with speed V. Penetration of the tool wedge, under the influence of external forces (cutting force F), transforms the material of thickness a (depth of cut) in the chip thickness (3) a_s.

Under the influence of cutting force F cutting tools are deformed. Under the influence of static and dynamic loading geometry of cutting tools differs in comparison to the previously defined position of the tool without load. In addition to the appearance of deformation of tool geometry stresses occur within the tool.

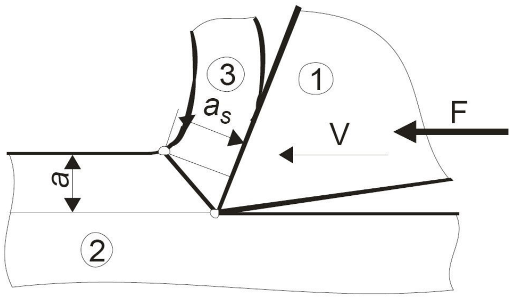

Fig. 1. Basics of cutting process

2.1 The mechanics of cutting - cutting resistance

Cutting resistance forces oppose penetration of the cutting tool wedge in the work piece (Fig. 2.).

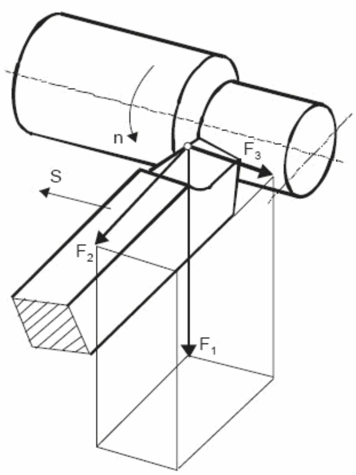

Fig. 2. Components of resultant cutting force in turning

In orthogonal cutting the resulting cutting force F_r can be resolved to:

- F_1 - main cutting force
- F_2 - radial (passive) force
- F_3 - feed force

3. FINITE ELEMENT METHOD

By definition, the finite element method is a method for approximate solution of so called field problems. The FEM is a well established method for the computational analysis of problems in mechanics, fluid dynamics and thermodynamics. In manufacturing, especially in the area of metal forming, the FEM has proven to be an indispensable tool in research as well as industrial applications.

The basic principle of the FEM is the division of the continuum into a finite number of sub domains, the so called finite elements. Thereby, the initially complex, continuous problem is divided into a finite number of discrete and interdependent problems [4].

3.1 ANSYS software

ANSYS is a general-purpose software package designed for analysis using finite elements. The software contains equations that govern the behavior of finite elements, solve them and gives a comprehensive explanation of the functioning of the system as a whole. These results can be presented in tabular or graphical form [4].

Steps in solving problems using ANSYS software:

- *Build geometry*
- *Defining material properties*
- *Generate mesh*
- *Apply loads*
- *Obtain solution*
- *Present the results*

4. THE FINITE ELEMENT METHOD ANALYSIS OF FORCE EFFECTS DURING TURNING

Computer analysis of the effects of cutting force in turning was realized using the *ANSYS Workbench v11* software system and its module for structural analysis. The computer simulated analysis for the processing time of 1 and 2 seconds.

4.1 Build geometry

In the first phase closed 2D contour is modeled using the *Design Modeler* and its module *Sketcher*. Using 3D modeling command *Extrude*, model tools and workpiece are given a third dimension. 3D model is then introduced into the *ANSYS Workbench's* module *Simulation* for further analysis where the meshing of the model is performed (Fig. 3.).

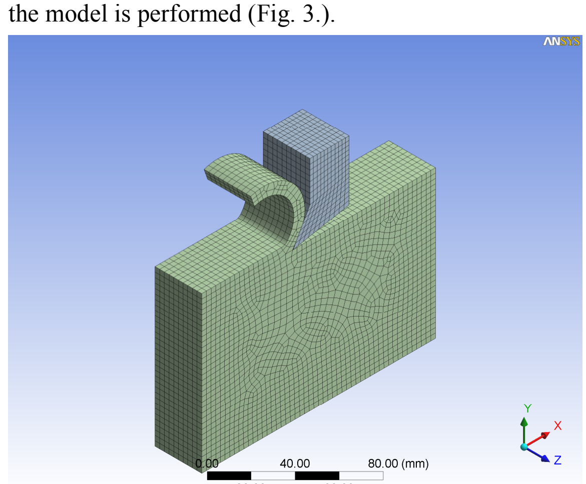

Fig. 3. Mesh of 3D model

4.2 Defining material properties

After the phase of generating discrete 3D model, mechanical and thermal properties of tool material [5] (Table 1.) are entered in *Engineering Data* window.

Characteristic	Tool material
Elastic modulus [N/m^2]	$4{,}15\cdot10^{11}$
Specific Density [kg/m^3]	14300
Poasan coefficient	0,2
Thermal conductivity [W/m°C]	55
Specific heat [J/kg°C]	560

Table 1. Characteristics of tool material

4.3 Defining the type of analysis and boundary conditions

Flexible Dynamic (dynamic load variable over time) analysis is selected. It allows analysis of deformation caused by the action of forces that occur during cutting.

It is necessary to constrain the tool, to take away its degrees of movement freedom in the direction of X, Y and Z-axis (*Fixed Support*).

4.4 Defining loads

For defining of boundary conditions and input data of the cutting forces data from the literature is used [5]. The following experimental data for the force (*Load*) Fr = 2410N (X = 880N, Y = -2200N, Z = -440N) is used. The value of cutting force was obtained on the universal lathe "Galeb-Pobeda" Novi Sad. During machining the following cutting conditions were used feed = 0.426 [mm/rev], cutting speed = 2 [m/s], rpm = 530 [rpm], depth of cut = 2 [mm] machining diameter = 72 [mm] tool material HM P25 and workpiece material steel Č.1730.

4.5 Solving the mathematical model

Since all the necessary elements for a specific analysis were defined, next step in solving the problem was using a command *SOLVE*.

After solving a problem *ANSYS Workbench* provides a graphical display of the results obtained in the form of images and/or animation.

Chosen output result parameters were:

- Directional Deformation X
- Directional Deformation Y
- Directional Deformation Z
- Total Deformation
- Equivalent Elastic Strain
- Strain Energy
- Total Acceleration
- Total Velocity
- Vector Principal Elastic Strain

5. ANALYSIS AND OUTLINE OF RESULTS

The analysis results are shown in Table 2. which contains data about tool deformation in individual axes and the overall deformation.

	Minimum [mm/mm]	Maximum [mm/mm]
Equivalent Elastic Strain	7,4402e-016	8,879e-004
Directional Deformation X	-3,4122e-003	2,4002e-003
Directional Deformation Y	-8,3198e-003	8,8709e-005
Directional Deformation Z	-2,682e-003	5,9462e-005
Total Deformation	0	9,2854e-003

Table 2. Results of finite element analysis

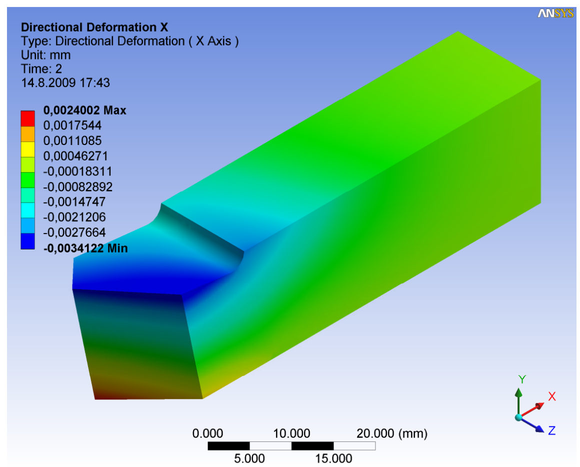

Fig. 5. Directional deformation X-axis

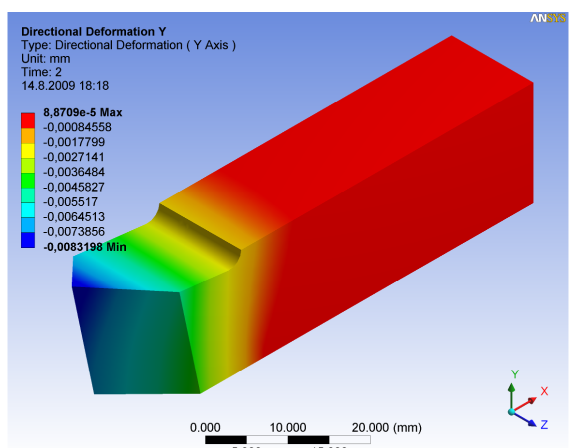

Fig. 6. Directional deformation Y-axis

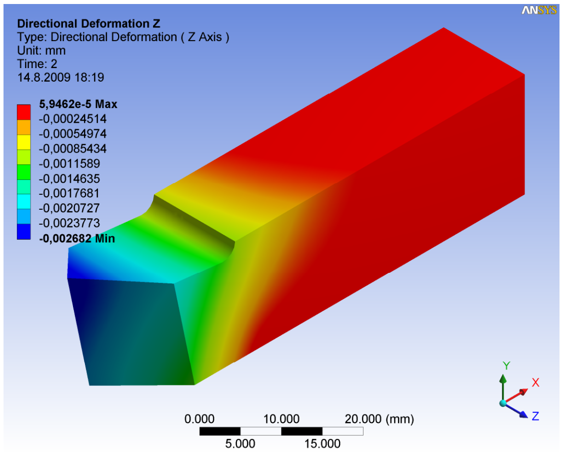

Fig. 7. Directional deformation Z-axis

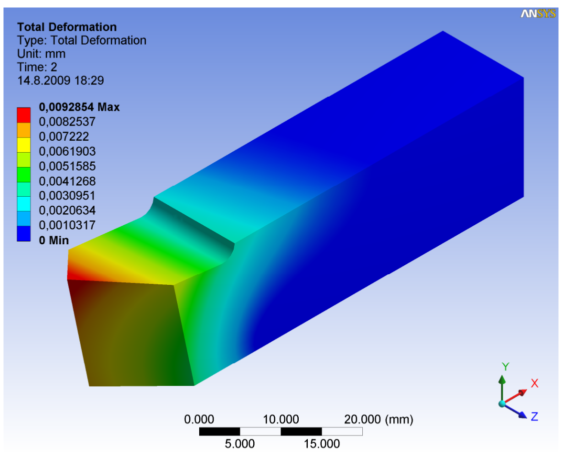

Fig. 8. Total Deformation

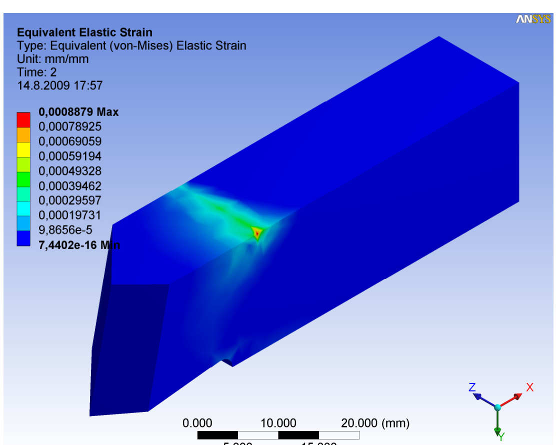

Fig. 9. Equivalent Elastic Strain

6. CONCLUSION

Analysis of the occurrence of tools deformation in cutting metal, simulating the effects of cutting forces in three-dimensional model of the tool by use of the finite element method, gave satisfactory results. The result of the total deformation, due to the effects of force, after one second is 0.0054038 mm, and after two seconds 0.009285 millimeters.

Finite element method as a method of simulation of the cutting phenomena in good measure allows obtaining of information relevant for further computational analysis, tool life assessment as one of the most important factors for testing the accuracy of processing in which, among other factors certainly affect deformation cutting tools.

9. REFERENCES

[1] Armarego, E., Arsecularatne, J., Mathew, P., Verezub, S., 2001, A CIRP survey on the available predictive performance models of machining operations – report on preliminary findings, Proc. 4th CIRP International Workshop on Modeling of Machining Operations, August 2001, Delft: 71-83.

[2] Ernst, H., Merchant, M., 1941, Chip formation, friction and high quality machined surfaces, Surface Treatment of Metals, 29:299.

[3] Messner, G.: Modeling metal cutting process under consideration of elastic material properites, Dissertation aus dem Werkzeugmaschinenlabor, Düsseldorf, 2007.

[4] About ANSYS, Department of Mechanical Engineering at Carnegie Mellon. http://www.me.cmu.edu/academics/courses/NSF_Edu_Proj/ThFlEngr_ANSYS/about_ansys.htm

[5] Kovač, P., Milikić, D. (1998), Rezanje metala, Univerzitet u Novom Sadu, FTN, Novi Sad.

[6] Arsecularatne, J., A. (2003), On prediction of tool life and tool deformation conditions in machining with restricted contact tools, International Journal of Machine Tools & Manufacture Vol. 43.

[7] Ozel, T., Zeren, E. (2004), Determination of work material flow stress and friction for FEA of machining using orthogonal cutting tests, Journal of Materials Processing Technology.

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Krsljak, B.

SURFACE GRINDING OF FLAT WOOD SURFACES AND WOODEN MATERIALS WITH GRINDING BELTS, STATE CHARACTERISTICS AND PROCESS OPTIMIZATION

ABSTRACT: *Surface grinding of flat wooden surfaces and wooden materials is one operational method of doing wood by grinding. It is performed during the treatment of massive wood and all type of wood veneers in the primary and final treatment by cutting, with the purpose to remove all unevennesses that have resulted from previous works or to reduce the height of the workpiece to a determined value. By removing the unevennesses from the surface of the workpiece, it is being prepared for the surface treatment of painting or varnishing. The separation of the material (shaving) is achieved by the simultaneous action of a larger number of abrasive grains bound together with an adhesive*

The paper analyzes the indicators for evaluation and the characteristics of the states during treatment and shows the mathematical approach to process optimization by taking the total cost of treatment as the indicator.
Key words: *Surface grinding, grinding belts, optimization*

1. INTRODUCTION

The operational method of doing wood by cutting has the goal of obtaining details with the requested qualities (precision of shape and dimensions, surface coarseness). Due to the previous, the regime of cutting must be based on the physical – technological possibilities of the method, established by theory and experimenting.

The regime of cutting, as a set of conditions of the working method is defined by: geometrical parameters of the tools (shape and dimensions, condition of the edges etc.) and endurance of the tools (tool materials, edge wear-out), the mutual position of the tool and workpiece and the kinematical parameters of the process (cutting speed, auxiliary motion speed).

In the production of the details a very important parameter is the price of the technological operation, due to which the cutting regime must be economically optimal.

Minimal expenses, next to maximum productivity and maximum reliability are one of the optimizing criteria if the goal is the economics of the method expressed in the price of the finished products. This is the essence of this paper.

2. STATE CHARACTERISTICS

Grinding of flat wooden surfaces and materials (surface grinding) with a grinding belt can be with a belt press and a contact roller.

Surface grinding (fig. 1a) with a belt press is done with the tool (narrow grinding belt) 1 by pressing the tool to the workpiece with the pressurizer 3 by force Q. The main linear motion is done by the tool at speed v and the workpiece 2 performs the auxiliary motion with the speed u.

Surface grinding with a contact roller (fig. 1b) is done by the tool 1 (wide grinding belt) which performs a linear vertical motion with speed v, while the workpiece 2 moves linearly with speed u [1].

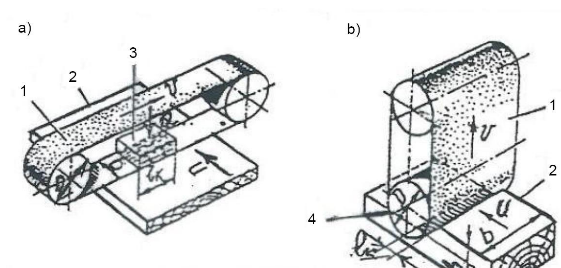

Fig 1. Surface grinding with grinding belts: a– with a belt press, b- with a contact roller, 1-grinding belt (tool), 2- workpiece, 3- pressurizer, 4- contact roller

For evaluating surface grinding the following basic indicators (characteristics) are used: technical (exactness of shape and workpiece dimensions), treatment quality (surface coarseness) and economical indicators (productivity, treatment expenses, etc.).

Besides the basic indicators for evaluating the grinding treatment method, to track the process (and evaluate it) the state characteristics are used: the power that is used for cutting, the resistances to cutting, the wear-out and service life of the tool as well as disturbances (e.g. vibrations during cutting).

The evaluation indicators and the state characteristics of the grinding treatment method depend on a number of influential factors which relate to the characteristics of the treatment system and conditions.

The dependency of the indicators (A_i) for process evaluation (or process state characteristics) to the treatment conditions can be expressed in the following general form:

$$A_i = f(K_1, K_2, \ldots K_n, l, b, v, u, a, t), \quad (1)$$

where : K_1, K_2,...K_n – are the coefficients that relate to the impacting characteristics of the machine (grinder), workpiece and tool. The parameters l, b are the length and width of the workpiece and the width of the grinding belt. The parameters v, u and a are the elements of the cutting regime and t is the duration of the treatment.

The dependencies of form (1) are very complex structures which can be defined only experimentally, researching the grinding process and using the adequate testing methodologies and measuring equipment.

The basic elements of the cutting regime are the main and auxiliary motion speeds and the grinding depth [1] , [4].

The speed of cutting as a kinematical parameter of the process usually doesn't change in cutting machines, because this factor affects the productivity of the process, the tool service life and costs of the treatment..

The grinding speed $\vec{v}$ represents the vector sum of the belt speed $\vec{v}_t$ and the auxiliary motion speed $\vec{u}$:

$$\vec{v} = \vec{v}_t + \vec{u} \,. \quad (2)$$

The auxiliary motion speed (shifting speed) is a very important factor and the path to determining it leads to the complete utilization of the power of the cutting machine, securing the required coarseness of the treated surface, working ability of the tool and strength or hardness of the cutting tool elements or the tool in whole. The shifting speed has to be within the kinematical possibilities of the machine $u_{min} \le u \le u_{max}$, where $u_{max} \div u_{min}$ is the auxiliary motion span of the machine according to catalogue.

The auxiliary motion speed (shifting speed) is $u \ll v_t$, so practically the cutting (grinding) speed can be considered equal to the belt speed:

$$v = v_t = \pi D n \ \text{[m/s]}, \quad (3)$$

where: D – the diameter of the wheel for narrow belts (fig. 1a), i.e. the diameter of the contact roller for wide belts (fig.1b), n- is the rpm of the wheel (roller) [s $^{-1}$].

The auxiliary motion speed u with belt tools (fig.1a,b) can be determined by the following:

$$u = \frac{A_b v l_k}{h\rho} \quad \text{[m/s]}, \quad (4)$$

where : A_b – specific productivity of the tool [kg/m^3],

v – cutting speed [m/s],

l_k – contact line length between the tool and workpiece [m]

h – thickness of the grinded (removed) layer [m],

ρ – density of the wood [kg/m^3].

While grinding with grinding belts and pressurizer (narrow belts) (fig.1a), it is important to determine the optimal contact length of the belt with wood l_k, which is measured in the direction of the cutting speed v. It is determined from the condition that with the belt grains only such an amount of shavings could be cut and removed from the workpiece that can fit in the free space between the grains. The optimal contact length does not depend on the cutting speed, depends partially on the specific pressure and type of wood, but mostly depends on the granularity of the grinding belt. For grinding belts of granularity 32, 16 and 10, the optimal contact lengths l_k are 125 mm, 100 mm and 65 mm.

While grinding with wide grinding belts (fig.1b) the contact line length l_k is determined by calculating according to figure 2 [4]. From the triangle ABO we derive the following:

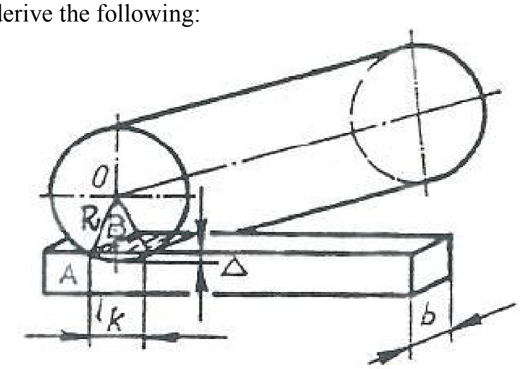

Fig. 2: Contact surface schematics for wide grinding belts

$$\frac{l_k^{\,2}}{4} = R^2 - (R-\Delta)^2 \quad \text{where} \quad l_k = 2\sqrt{2R\Delta - \Delta^2}$$

[m]. The deformation size Δ in comparison to the roller radius R is much smaller, so Δ^2 can practically be neglected and we have:

$$l_k = 2\sqrt{D\Delta} \ \text{[m]}, \quad (5)$$

and the contact area is:

$$A_k = 2b\sqrt{D\Delta} \ [\text{m}^2]. \quad (6)$$

The grinding force depends on the grinding coefficient k, specific pressure q and the contact area between the tool and workpiece A_k and can be calculated by the formula:

$$F = kqA_k \quad \text{[N]}. \quad (7)$$

Under the effect of the pressing force the tool is deformed and the contact area is represented by:

$$A_k = l_k \, b \quad [\text{m}^2], \quad (8)$$

where b – width of the contact between the tool and workpiece (fig.2). By replacing equation (6) into equation (7) we obtain the expression for the cutting force:

$$F = 2kqb\sqrt{D\Delta} \ \text{[N]}. \quad (9)$$

The specific pressure $q = (0{,}5 - 2{,}0)10^5$ [N/m^2] for coarse grinding and $q = (0{,}2 - 0{,}5)10^5$ [N/m^2] for fine grinding.

Determining the specific pressure q and measuring the deformation during operation is very difficult, so practically the force per meter roller length is calculated [1] as:

$$F_1 = q \, l_k \quad \text{[N/m]}. \quad (10)$$

The cutting power is determined by the formula:

$$P = k \, F_1 \, b \, v \quad \text{[W]}. \quad (11)$$

The cutting power can be determined in the general case with the help of the volume equation:

$$P_r = K(A\frac{u}{60}) \text{ [W]}, \quad (12)$$

where K [J/cm^3]- is the specific work of the cutting process in the given treatment conditions,
A [mm^2] – cross section area of the removed material (removed add-on) and
u [mm/min] – auxiliary motion speed.
The expression in equation (12) within the brackets represents the volume of the material removed from the workpiece during one second [cm^3/s].
The cutting power can also be determined by the formula for total cutting machine power utilization:

$$P_r = P_p \eta\,, \quad (13)$$

where:
P_p – propulsion power of the grinding machine
η – utilization coefficient of the propulsion mechanism of the grinding machine

3. PROCESS OPTIMIZATION

For the optimization of process of grinding it is possible to adopt as the criteria one of the process indicators (surface coarseness, maximum productivity, minimum treatment costs).

The assumption for process optimization is knowing the mathematical dependencies of the mentioned process indicators and the treatment regime elements. In surface grinding for the greatest number of cases we can use the dependency of the basic characteristics of the process as a function of the effects of surface grinding V_S (removed volume of material in unit time), because its value is directly reliant on the elements of the surface grinding regime, and when it changes the following also change: surface grinding resistance, surface quality, tool service life and grinding time (on account of which the costs and productivity also vary) [2], [3], [5].

The treatment costs can be expressed as a function of the grinding effects while using the appropriate expressions for service life and tool wear-out also as a function of the grinding effects. The optimization criteria will be minimal costs.

The costs per piece can be displayed as the sum of workplace costs $T_{r\,(r\,m)}$ and tool costs $T_{r\,(a)}$:

$$T_r = T_{r\,(r\,m)} + T_{r\,(a)}\,. \quad (14)$$

Workplace costs are equal to the product of the hourly norm $C_{n\check{c}}$ and required time per piece t_k, where the required time per piece consists of the main time t_g and part of the auxiliary time used for tool cleaning (reduced to per piece), i.e. $t_k = t_g + t_{\check{c}a} / z$. By expressing the main time as the ratio of the material volume removed per piece V_1 and the grinding effects V_S; $t_g = \frac{V_1}{V_S}$ and using the dependency of the tool service life T and grinding effects V_S in the form of a power level function $T = \frac{C_T}{V_S^n}$ we derive the expression for the number of pieces treated during the tool service life $z = \frac{T}{t_g} = \frac{C_T V_S}{V_S^n V_1} = \frac{C_T}{V_1} V_S^{(1-n)}$, so the expression for workplace costs has the following form:

$$T_{r\,(r\,m)} = \frac{C_{n\check{c}}}{60}(V_1 V_s^{-1} + \frac{t_{\check{c}a}}{C_T} V_1 V_s^{(n-1)})\,. \quad (15)$$

Tool costs consist of costs due to the tool wear-out and can be expressed as the product of the cost of the tool unit volume C_a and the volume of the tool wear-out reduced to one workpiece $V_{a\,(1)}$, i.e. $T_{r\,(a)} = C_a V_{a\,(1)}$. By using the dependency of the tool's specific effect (ratio of the removed wood volume to the tool wear-out volume) $V_a = V_1 / V_{a\,(1)}$, in relation to the grinding effects in the form of a power level function $V_a = \frac{C_V}{V_S^{n_1}}$ the volume of the tool wear-out per workpiece can be expressed as $V_{a(1)} = \frac{V_1}{C_V} V_S^{n_1}$; and resulting in the tool costs as:

$$T_{r(a)} = C_a V_{a(1)} = C_a \frac{V_1}{C_V} V_S^{n_1}\,. \quad (16)$$

By replacing equations (15) and (16) in (14) we obtain the total expression for surface grinding costs:

$$T_r = \frac{C_{n\check{c}}}{60} V_1 (V_S^{-1} + \frac{t_{\check{c}a}}{C_T} V_S^{(n-1)}) + C_a \frac{V_1}{C_V} V_S^{n_1}\,, \quad (17)$$

which can be separated into three constituents: $T_r = T_{r1} + T_{r2} + T_{r3}$. Where T_{r1} – costs that depend on the main time and which are reduced with the increase of the grinding effects, T_{r2} – tool cleaning costs and T_{r3} – costs due to tool wear-out. The costs T_{r1} decrease with the increase of V_S while T_{r2} and T_{r3} increase, so the total costs of surface grinding have a distinct minimum as shown on figure 3.

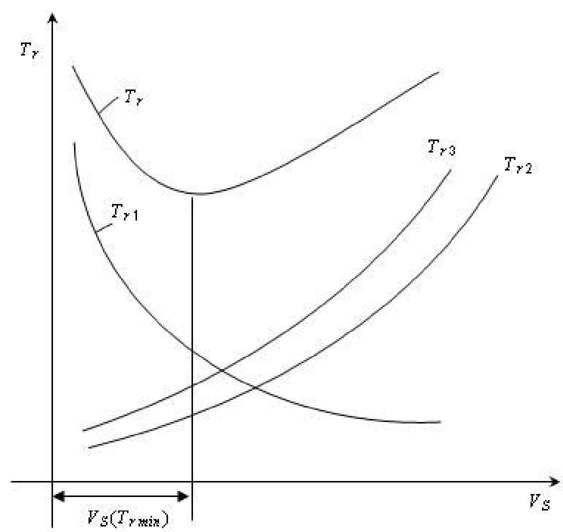

Fig. 3. Variation of total costs in relation to the grinding effects

Differentiating the expression for total costs in relation to the grinding effects and solving the obtained first derivative for zero ($dT_r / dV_S = 0$), we obtain the value of the grinding effects for which the surface grinding costs are minimal.

$$\frac{dT_r}{dV_S}=\frac{C_{n\check{c}}}{60}V_1\left(-\frac{1}{V_S^{\,2}}+\frac{t_{\check{c}a}}{C_T}(n-1)V_S^{\,(n-2)}\right)+C_a\frac{V_1 n_1 V_S^{\,(n_1-1)}}{C_V}=0$$

that is $-\frac{C_{n\check{c}}}{60V_S^{\,2}}+\frac{C_{n\check{c}}t_{\check{c}a}}{60C_T}(n-1)V_S^{\,(n-2)})+\frac{C_a}{C_V}n_1V_S^{\,(n_1-1)}=0\cdot$

When the process enfolds with tool hebetation, then the tool costs can be neglected ($T_{r3}=0$), and we have

$\frac{C_{n\check{c}}}{60}(-1+\frac{t_{\check{c}a}}{C_T}(n-1)V_S^{\,n})=0$, which brings us to

$$V_{S(T_r\min)}=\sqrt[n]{\frac{C_T}{(n-1)t_{\check{c}a}}}\,. \tag{18}$$

From equation (18) we see that the position of the minimum of the curve T_r depends on the values for C_T, $t_{\check{c}a}$ and n.

When the tool operates in self-sharpening conditions then the tool cleaning costs are also disregarded ($T_{r2}=0$), so we have :

$$-\frac{C_{n\check{c}}V_1}{60V_S^{\,2}}+\frac{C_aV_1}{C_V}n_1V_S^{\,(n_1-1)}=0$$

$\frac{n_1V_S^{\,(n_1-1)}C_a}{C_V}=\frac{C_{n\check{c}}}{60V_S^{\,2}}$, and if $n_1=2$ it will be

$$V_{S(T_r\min)}=\sqrt[3]{\frac{C_{n\check{c}}C_V}{120C_a}}\,, \tag{19}$$

where C_V – the coefficient that expresses the wear-out of the tool during surface grinding. From equation (19) we can see that the curve T_r minimum does not depend on the tool service life but rather from the hourly norm, tool price and the coefficient C_V.

4. CONCLUSION

Using equation (12), i.e. the volume equation and equation (13), the total cutting machine power utilization equation, we can calculate the auxiliary motion speed at total cutting machine power utilization.

The grinding effects :

$V_S=b\,u\,a$ [mm³/s], (20)

is a combined variable of surface grinding regime elements during flat surface grinding with grinding belts and is used for optimizing the cutting regime. Using equations (19) and (20) for a certain grinding belt width b and adopted grinding depth a we can define (calculate) the auxiliary motion speed u at which the treatment costs are minimal.

5. REFERENCES:

[1] Beršadskij L.A., Cvetkova I.N., *Rezanie drevesini, izdateljstvo* „ Višejšaja škola ”, Minsk, 1975.

[2] Jovičić M., *Osvrt na pitanja upravljanja i optimizacije procesa obrade brušenjem*, Seminar Technological optimization – TEHNOP, January 1977.

[3] Jovičić M., Kršljak B., Vukasojević R., Drobnjak V., *Obrada brušenjem, Identifikacija karakteristika stanja i optimizacija procesa*, Faculty of mechanical engineering - Belgrade University, Jupiter community, Belgrade, 1986.

[4] Kršljak B., *Mašine i alati za obradu drveta II*, Uljarice – publik, Belgrade 2002.

[5] Kršljak B., *Obrada drveta rezanjem sa obrazovanjem strugotine, Klasifikacija i opšti pojmovi*, XXXI Conference of Production Engineering of Serbia and Montenegro, Kragujevac 2006.

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INVESTIGATION OF CUTTING FORCES DURING MACHINING PROCESS BY HIGH SPEED TURNING

Abstract: *This paper presents the obtained mathematical models of cutting forces during machining process by high speed turning as a function of processing parameters* v, f, a *and* r_ε. *The machining process by turning is performed on NC lathe using ceramic cutting tool inserts and the workpiece material is* ***C*** *1630 (DIN C 55). Processing parameters are varied in range between* v *=300 and 700 m/min* , f *=0,16-0,32 mm/rev*, *a=0,5-1,6 mm and* r_ε*=1,2-2,0 mm. Cutting forces measurement is done at the Institute of Production Engineering and Automation of the Wroclaw University of Technology, Poland using computerized experimental setup with three component piezoelektric dynamometer type Kistler. Experiments are realized acording first order four factorial experimental plan. Mathematical processing is performed at the Faculty of Mechanical Engineering in Skopje using the program CADEX combined with MATLAB.*
Key words: *Machining by turning, cutting forces, mathematical models, factorial experiments*

1. INTRODUCTION

Knowing the magnitude of the cutting forces in the turning process as function of the parameters and conditions of treatment is necessary for determining of cutting tool strength, cutting edge wearing, limit of the maximum load of the cutting machine and forecasting the expected results of the processing. In particular, during machining with high cutting speed, using modern materials and modern cutting machines imposes the necessity of studying physical phenomena in the cutting process and their mathematical modeling. Moreover, analysis of physical phenomena has shown that conditions are created for processing by material removal, in substantially different conditions, primarily due to the use of larger cutting speeds [1]. In such circumstances the creation of possibilities for identification of physical phenomena in the cutting process allows: the creation of the basis for selection of optimal processing parameters, forecasting the process of wear of the cutting edge, determination of time to change the cutting tools, quality management of workpiece surface layer, optimization of cutting tool stereometry, chip shape and removal conducting, upgrading the technology of production of cutting tool inserts and their properties. During intensive machining conditions, monitoring of the cutting forces is possible only with the use of computer aided research systems [2]. Experiences show that the determination of cutting forces in an analytical way not fully reflect the real situation [3]. Basis of mathematical models for cutting forces obtained in an analytical way are spreadsheet data obtained in surveys, conducted in certain treatment conditions that can be changed. From here emerges the justification for carrying out research activities for the determination of mathematical models to describe the change of cutting forces as a function of processing parameters.

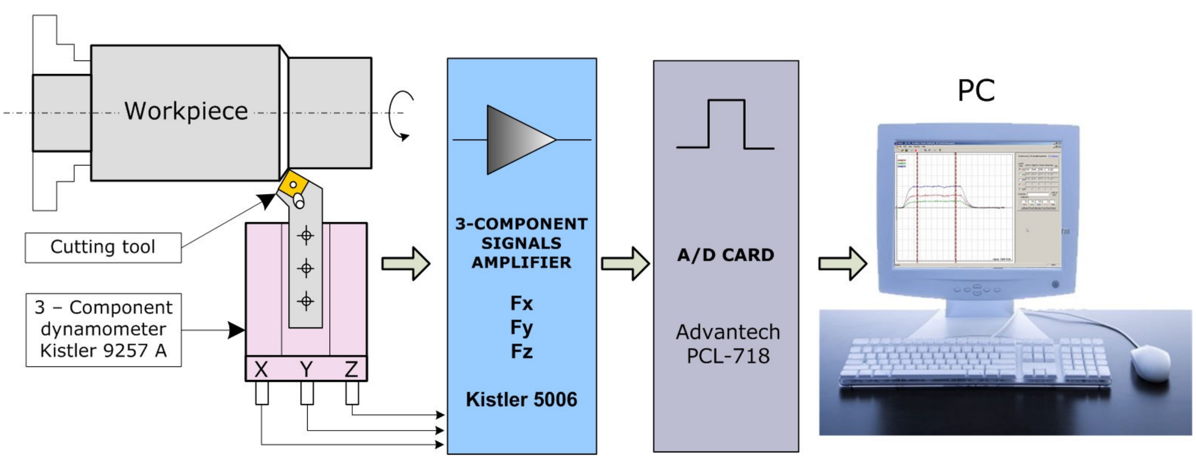

Fig. 1. Schematic view of the research experimental setup

2. EXPERIMENTAL CONDITIONS

2.1 Cutting tool

The processing is performed by use of ceramic cutting tool inserts type SNGN 120712- 120716-120720 made of zircon-oxide ceramics AC 5 (Al_2O_3 +10% ZrO_2) and cutting tool holder type CSRNR 25x25 M12H3, manufactured by HERTEL. Cutting tool stereometry is:

$$\chi = 75°,\ \chi_1 = 15°,\ \gamma = -6°,\ \alpha = 6°,\ \lambda = -6°,$$

$$\gamma_f = -20°,\ b_f = 0{,}2\,\mathrm{mm}$$

2.2 Workpiece

Material C 1630 (DIN C 55), normalized to the hardness of 200 HB.

2.3 Metal cutting machine

NC lathe TUR 50 SN-DC, with power P = 18,5 kW with the area of continuous change in the numbers of revolutions n=50-2250 rev/min.

2.4 Cutting parameters

Cutting speed v = 300-700 m/min, feed f=0,16-0,32 mm/rev, depth a=0,5-1,6 mm, cutting tool insert top radius r_ε=1,2-1,6-2,0 mm.

2.5 Experimental plan

It is used first-order full four factorial plan of experiments (2^4 + 4), presented in Table 1. Power function is accepted for the mathematical model to describe the changes of cutting forces [1, 6]. Mathematical processing is performed at the Faculty of Mechanical Engineering in Skopje with the application of program CADEX in connection with *Model-Based Calibration (MBC) Toolbox Version 1.1,* contained in the *Matlab* software package, which is intended for design of experiments and statistical modeling. Using the advanced features of *Matlab* and *MBC* provides significant advantages in the realization of experimental studies, with an option for graphic interpretation of results.

2.6 Research equipment

Monitoring of cutting forces *Fa*, *Fr* and *Ft* in the cutting process is done with computer aided research experimental setup, presented in Fig. 1. Part of the research setup is three-component piezoelectric dynamometer type Kistler 9257 A. Measurements are done at the Institute of Production Engineering and Automation of the Wroclaw University of Technology, Poland. The software FORTMON does graphical presentation of the measurement data, shown on Fig. 2, [4].

3. RESEARCH RESULTS ANALYSIS

The changes on cutting forces *Fa*, *Fr* and *Ft* were monitored in the research. The power function has been adopted for describing these changes:

$$F_a, F_r, F_t = \mathrm{C}\, v^x f^y a^z r_\varepsilon^q \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Experiment plan and results are presented in Table 1. Some graphical interpretation of the influence of cutting speed - *v*, feed - *f*, cutting depth - *a*, and

Obs No	Independent variables - Real matrix				Result		
	v [m/min]	f [mm/rev]	a [mm]	r_ε [mm]	F_{aav} [N]	F_{rav} [N]	F_{tav} [N]
1	300,00	0,16	0,50	1,20	140,55	224,37	272,21
2	700,00	0,16	0,50	1,20	105,55	165,75	235,24
3	300,00	0,32	0,50	1,20	156,95	296,94	431,46
4	700,00	0,32	0,50	1,20	110,02	221,01	327,86
5	300,00	0,16	1,60	1,20	468,82	347,80	744,78
6	700,00	0,16	1,60	1,20	395,21	295,06	675,11
7	300,00	0,32	1,60	1,20	638,83	500,41	1241,52
8	700,00	0,32	1,60	1,20	520,05	419,39	1063,80
9	300,00	0,16	0,50	2,00	121,86	248,47	285,39
10	700,00	0,16	0,50	2,00	103,01	206,30	262,47
11	300,00	0,32	0,50	2,00	179,85	382,75	525,69
12	700,00	0,32	0,50	2,00	138,78	304,31	427,61
13	300,00	0,16	1,60	2,00	461,87	442,69	789,79
14	700,00	0,16	1,60	2,00	403,47	392,22	739,88
15	300,00	0,32	1,60	2,00	596,41	642,49	1302,48
16	700,00	0,32	1,60	2,00	489,69	530,27	1146,87
17	458,26	0,23	0,89	1,55	267,85	349,18	563,28
18	458,26	0,23	0,89	1,55	250,31	338,25	546,02
19	458,26	0,23	0,89	1,55	264,66	351,44	571,50
20	458,26	0,23	0,89	1,55	256,86	341,94	556,54

Table 1. First order four factorial experimental plan

cutting tool insert tip radius - r_ε on the changes of axial *Fa*, radial *Fr* and tangential force component *Ft* are shown on Fig. 3.

Processing of obtained results includes analysis of mathematical models with and without mutual effect, determination of 95% confidence interval for analyzed models, evaluation of significance of coded polynomial coefficients, determination of experiment error, check of mathematical model adequacy and determination of multiple regression coefficient. Analysis performed, after the complete computer processing, showed adequacy of obtained mathematical models (2), (3) and (4).

$$F_a = 2355{,}2 \cdot v^{-0{,}26} \cdot f^{0{,}34} \cdot a^{1{,}14} \cdot r_\varepsilon^{-0{,}019} \quad (2)$$

$$F_r = 2714{,}55 \cdot v^{-0{,}25} \cdot f^{0{,}5} \cdot a^{0{,}48} \cdot r_\varepsilon^{0{,}47} \quad (3)$$

$$F_t = 4403{,}58 \cdot v^{-0{,}17} \cdot f^{0{,}68} \cdot a^{0{,}89} \cdot r_\varepsilon^{0{,}22} \quad (4)$$

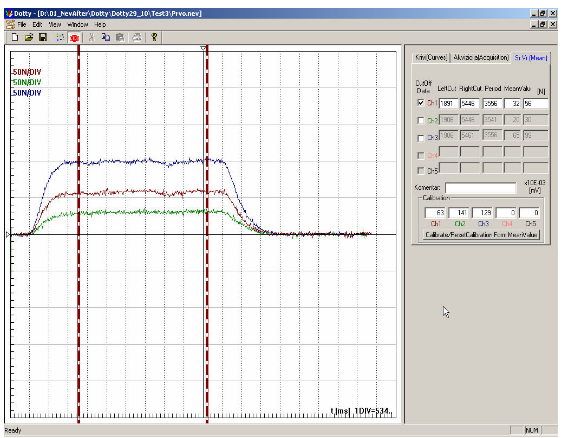

Fig. 2. Graphical presentation of measurements results by using FORTMON software

Researches show dominant influence of feed and cutting depth on cutting force change. This is explained by the fact that by feed increase, contact increase is caused between chip and face surface of cutting wedge as result of increased removed material thickness. Therefore friction between chip and face surface of cutting tool is increased, which alternatively causes higher chip ramming. Actually, a higher plastic deformation is present.

Cutting depth has direct influence on contact length between chip and face surface of cutting wedge. Therefore higher influence of cutting depth outcomes onto axial *Fa*, then on tangential *Ft*, and smallest on radial component *Fr*. It can be concluded that cutting depth has higher influence on force *Fa* and *Ft* than cutting feed. It is vice-versa for the radial component *Fr*, where feed shows higher influence than cutting depth.

The cutting speed influence onto cutting forces change is interesting. At its increase the contact between face surface of cutting wedge and chip decreases, which causes reduction of chip ramming. The last is connected also to reduction of friction coefficient between chip and face surface of cutting tool as a result of increased temperature caused by cutting speed increase. This indicates cutting forces decrease by cutting speed increase.

It can be noticed from equations 2-4 that cutting speed has higher influence onto axial *Fa* and radial *Fr*, while as smaller onto tangential component *Ft*. Such influence order of cutting speed upon cutting components is explained by the occurrence of various temperature conditions.

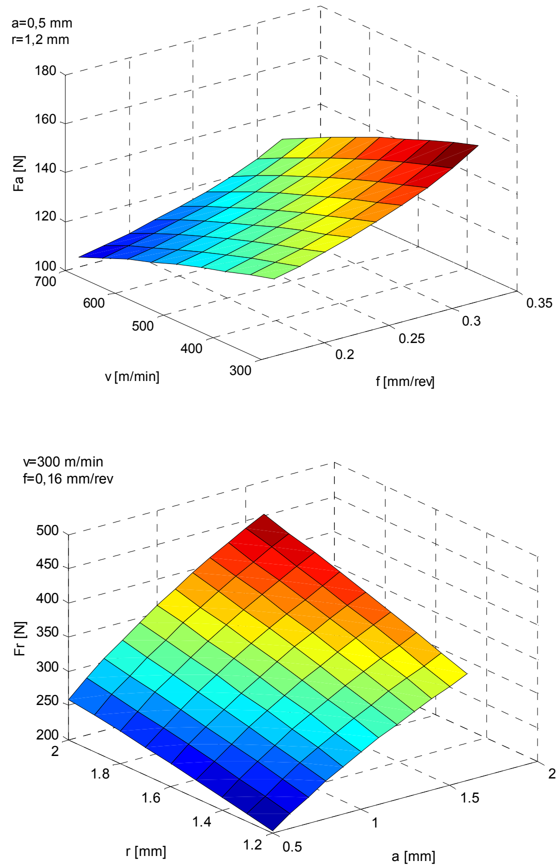

Fig. 3. Graphical interpretation of the influence of cutting speed - *v*, feed - *f*, cutting depth - *a*, and cutting tool insert tip radius - r_ε on the changes of axial *Fa*, radial *Fr* and tangential force component *Ft*

Namely, by cutting speed increase the contact surface in radial direction decreases, where due to higher temperature gradients there is reduction of mechanical characteristics of machined material and significant reduction of friction coefficient between cutting tool insert tip and machined surface. In addition to this is also the fact that cutting speed increase causes temperature and mechanical load change onto cutting blade. Similar is the condition also in direction of force *Fa*, where contact between cutting blade in initial stage is theoretically linear, which causes smaller heat discharge i.e. high temperature occurrence near cutting blade [5].

From this outcomes friction coefficient reduction between rear surface of cutting tool and machined surface. Here, mechanical properties of machined materials are reduced due to high temperature. The condition on face surface of cutting wedge is different, where reduction of tangential component *Ft* is smaller due to larger contact surface between chip and cutting tool. Areas with plastic deformation and abrasive wearing of surface layer of cutting tool insert are noticed here [5]. This indicates existence of various friction coefficients i.e. various terms when chip wears against face surface.

Tip radius of the cutting tool insert r_ε has a different but proportional influence upon change of cutting forces components. Its increase causes contact length increase between cutting blade and machined surface, which indicates a possibility for larger increase of axial force *Fa*. However, axial resistance *Fa* insignificantly increases by increase of r_ε. This is caused by reduction of setting angle of cutting tool χ positioning, by increase of r_ε, which, actually, is different on the circular part against cutting blade length. Radial *Fr* and tangential *Ft* cutting force component increase by increase of r_ε. Then, higher is the influence of r_ε onto the radial component mostly due to larger contact with machined surface.

4. CONCLUSIONS

From the exhaustive experimental researches performed, obtained mathematical models, as well the analysis of results, following remarks and conclusions can be reached:

- The statistical analysis indicated that the describing of changes in cutting forces *Fa, Fr* and *Ft* as function of machining parameters *v, f, a*, and cutting tool insert tip radius r_ε, by means of power function, correctly describes the physics of change of forces as function of machining parameters;

- All factors adopted in models are significant, apart in model (2), and their influence is as follows:

- cutting speed affects cutting forces counter-proportionally, meaning that cutting forces decrease by cutting speed increase;
- feed, as well as cutting depth, have proportional influence on cutting forces change;
- cutting tool insert tip radius r_ε influences cutting forces in a mode where by its increase causes significant increase of forces *Fr* and *Ft*, and insignificant increase of *Fa*;
- cutting depth - *a* and feed - *f* have higher influence, smaller r_ε, and smallest and counter-proportional cutting speed *v* on the change of main cutting force.

- Since small differences of influences are gained and when in a research an influence sign change occurs, justified is to perform more intensified research activities in sense of reducing uncertainty of results that are gained from measurements and determination of the confidential interval onto the influence of separate factors, all with the purpose of reducing or eliminating the negative influence that outcomes from research hardware equipment, the validity of the application of adopted machining parameters, the experiment planning methodology, the mathematical processing of results and applied software solutions.

5. REFERENCES

[1] Pavlovski, V., Kuzinovski, M., Zebrovski, H., Cichosz, P.: *Experimental research of the physical phenomena in turning with ceramic cutting inserts*, Third International Conference on advanced manufacturing systems and technology, AMST '93, Udine, Italy, 1993.

[2] Kuzinovski, M., Trajčevski, N., Cichosz, P., Tomov, M.: *Monitoring system for investigation of the cutting forces in the machining with turning*, 9th International Scientific Conference, MMA 2006, p.p. 19-20, Novi Sad, Srbija i Crna Gora, 15-16, June, 2006.

[3] Stanić, J.: *Metod inžinjeriskih merenja*, Mašinski fakultet, Beograd, 1990.

[4] Trajčevski, N.: *Monitoring system in experimental investigation in machining with turning*, Master thesis, Skopje, February 2008.

[5] Cichosc, P., Zebrowski, H.: Meßung der schnittemperatur beim drehen mit keramischen schneiden, VII Internationale konferenz für werkzeuge und ausstellung. Miskolc (H), 29-31.8.1989.

[6] Jurković, Z., Jurković, M.: *Modeling and simulation of the cutting force using experimental data*, 7-th International Research/Expert Conference "Trends in the Development of Machinery an Associated Technology", TMT 2003, p.p. 81-84, Lloret de Mar, Barcelona, Spain, 15-16 September, 2003.

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DEPENDENCE OF DEFORMATION FROM PARAMETERS OF PROFILING PROCESS

Abstract: *Due to allowed value of deformation of external outline of profile and minimal radius of banding is performed in projecting of technological process. Value of deformation of external outline of profile and minimal radius of banding depend from regime of profiling process. For technological process it may be used derived nomogram, due to dependence of regime of process can define intense of maximal deformation of external fibro of profile. Dependence for determination distribution of intensity of deformation on banding parts of profile is defined.*
Key words: *deformation, profiling process*

1. INTRODUCTION

Preferable factor for projecting technological process for most of materials is plasticity. Correct method for conclusion of appointed question in projecting technological process of profiling is taken in maintaining limit of allowed value of deformation of outer yielding of the fibers on bended parts of profile of limited plastic characteristics of material and determination in these conditions of size of minimal banding radius at profiling. Analysis of deformation on bended parts of profile, basically, gives qualitative mark of influence of parameters of regime of profiling on size of superficial deformation. Complexity of mechanism of deformation of tape at profiling: banding and transversal elongation cause thickening that spreads unevenly on width of bended part of profile.

2. STATISTICAL CANON OF DISTRIBUTION OF INTENSITY OF SUPERFICIAL DEFORMATION

Change of intensity of maximal superficial deformation yielded fibers depends from more factors-parameters of profiling: thickness of tape s_o, widthness of tape b, angle of flexure α, inner radis of baning r and the others. Even at careful lab mesurments of deformation we dont get correct functional dependence: at same conditios of experiment we get different values of deformatios. So size of intesity of deformations gains characters of axdents as variable value.

Nondeterminated value, in this case of deformation, can be correctly described if we determed canon of its grading. Canon of grading can be determed due ti statistical analysis; where intensity of deformation changes from 0,04 to 0,66 with change; thickness of tape from 1 to 4 mm, angle of flexure from 15^o to 90^o, relative radius of banding r/s_o=0,5-14 and relative widthness of tape b/s_o=6-35.

Regression analysis show corelation of intensity of deformation on outer conture of profile from individualistic parameters of profiling process (r/s_o, α, b/s_o). However, in real process of profiling alongtime all parameters of process change.

Insertion of dependence in form,

$$e_{ik} = B\left(\frac{r/}{s_o}\right)^{b_1} \alpha^{b_2} \left(\frac{b}{s_o}\right)^{b_3} \tag{1}$$

After logarithm zing of formula (1) we get,

$$y = b_o + b_1 x_1 + b_2 x_2 + b_3 x_3 \tag{2}$$

where are:

$$y = \ln e_{ik}$$

$$x_1 = \ln\frac{r_o}{s_o}\,;\;\; x_2 = \ln\alpha\,;\;\; x_3 = \ln\frac{b}{s_o}\,,$$

$b_1, b_{2,} b_3$ - formula parameters

Formula (2) is affirmated with experiment of matrix, where is necessary to chose limits of value for every variable, $x_{i\min}$ – inferior level $x_{i\max}$ - superior level that is conditionality with technological process. Cordination of parameters is taken due to formula transformation,

$$x_1 = \frac{2\left[\ln\left(\frac{r}{s_o}\right) - \ln\left(\frac{r}{s_o}\right)_{\max}\right]}{\ln\left(\frac{r}{s_o}\right)_{\max} - \ln\left(\frac{r}{s_o}\right)_{\min}} + 1$$

$$x_1 = \frac{2\left[\ln\alpha - \ln\alpha_{\max}\right]}{\ln\alpha_{\max} - \ln\alpha_{\min}} + 1 \tag{3}$$

$$x_3 = \frac{2\left[\ln\left(\frac{b}{s_o}\right) - \ln\left(\frac{b}{s_o}\right)_{\max}\right]}{\ln\left(\frac{b}{s_o}\right)_{\max} - \ln\left(\frac{b}{s_o}\right)_{\min}} + 1$$

Levels of coding of factors in process are given in table 1.

Table 1. levels of coding of variable factors

Lavel	Parameters					
	r/s_o	α^o	b/s_o	X_1	X_2	X_3
Superior	3.5	90	25	1	1	1
Medial	2.5	60	15	0	0	0
Inferior	1.5	30	5	-1	-1	-1

Coefficient of regression of formula (2) in matrix form

$$b = (X'X)^{-1} X'Y \tag{4}$$

where are:

X –a plan of matrix,

X' - transported matrix

$(X'X)^{-1}$ - inversion matrix, corelation matrix or matrix of defect.

$$X'Y = \begin{vmatrix} \sum x_{oi} & y_i \\ \sum x_{o1} & y_i \\ \sum x_{2i} & y_i \\ . & . \\ \sum x_{ni} & y_i \end{vmatrix}$$

Results of examination and calculation of coefficient of regression are in table 2.

Table 2. Results of two series of examination

Ordinal number	Serie	Paraneters			A plan of matrix				Izlaz	
					Code marks					
		r/s_o	α_o	b/s_o	X_o	X_1	X_2	X_3	e_{iR}	$y=lne_{iR}$
1	I	2.5	60	15	+1	0	0	0	0.161	-1.8264
2		1.5	90	25	+1	-1	+1	+1	0.338	-1.0847
3		3.5	30	25	+1	+1	-1	+1	0.151	-1.8905
4		3.5	90	5	+1	+1	+1	-1	0.171	-1.7661
5		2.5	60	15	+1	0	0	0	0.191	-1.6555
6		1.5	30	5	+1	-1	-1	-1	0.239	-1.4313
7	II	3.5	30	5	+1	+1	-1	-1	0.110	-2.2073
8		3.5	90	25	+1	+1	+1	+1	0.171	-1.7661
9		2.5	60	15	+1	0	0	0	0.211	-1.5559
10		1.5	30	25	+1	-1	-1	+1	0.286	-1.2518
11		2.5	60	15	+1	0	0	0	0.181	-1.7093
12		1.5	90	5	+1	-1	+1	-1	0.303	-1.1940

Coefficient of formula (2) is determined from,

$$b_o = \frac{1}{6}\sum_{1}^{6} y_i \; ; \; b_i = \frac{1}{4}\sum_{1}^{4} x_i y_i \tag{5}$$

This plan is realised on rolling place for profiling of square from material tape Č 0148.

Due to formula (3 i 4) is gained corelation of profiling deformation in relation to parameters of process,

$$\ln e_{iR} = -2.1254 - 07312 \ln\left(\frac{r}{s_o}\right) + + 0.2602 \ln\alpha + 0.0379 \ln\left(\frac{b}{s_o}\right) \tag{6}$$

Results of equasion in formila (6) and their comparison with real values of deformation from first series of examinations are given in table 3. Valuation of dispersia $(y-\hat{y})^2$ for first serie of examinations is 0.04806, that is for two degrees of freedom is 0.02403.

Table 3. Comparison of calculation and examination results of deformation e_{iR}- first serie of examination.

Ordinal number	Real values $y=lne_{iR}$	Calculation values $\hat{y} = \ln \hat{e}$	$(y-\hat{y})$	$(y-\hat{y})^2$	Interval 95%-non limits of reliability	
					$\hat{y} = \ln \hat{e}_{iR}$	$\hat{e}_{iR}$
1	-1.8264	-1.6275	0.1989	0.03956	-1.8985 do -1.3565	0.15-0257
2	-1.0847	-1.1286	0.0439	0.00192	-1.7736 do -0.4836	0.169-0,616
3	-1.9905	-2.0346	0.0441	0.00195	-2.6796 do -1.3896	0.068-0.249
4	-1.7661	-1.8097	0.0436	0.0190	-2.4547 do -1.1647	0.086-0.312
5	-1.6555	-1.6272	0.0280	0.0078	-1.8985 do -1.3565	0.15-0.257
6	-1.4313	-1.4755	0.0442	0.00195	-2.1205 do -0.8305	0.12-0.436
		-9,7034	-	0,04806	-	-

Analysis of examination of dispersion for first serie is given in4.

Table 4. Analysis of examination for first serie

Defect	Suma kvadrata	Degree of freedom	Size of dispersion
Members of zero order	$\left(\sum \hat{y}_i\right)\frac{1}{6} = \frac{94,1559}{6}$	1	15.6976
Members of first order	$4\sum_{1}^{3} b_i^2 = 0.047016$	3	0.15672
Inadequancy of experiment results	$\sum(y-\hat{y})^2 - \sum_{i=1}^{n_o}(y_{oi}-\bar{y}_o)^2$	1	0.00772
Experiment	$S_E = \sum_{i=1}^{n_o}(y_{oi}-\bar{y}_o)^2$	1	0.04034
Residual	$S_R = \sum(y_{oi}-\hat{y}_o)^2$	2	0.02403
Common	$\sum_{1}^{6} \hat{y}^2 = 16.1628$	6	2.69380

Vector degree in matrix are orthogonal, so coefficient of regresion b_0, b_1, b_2, b_3 are determined apart from each other with minimal possible dispersion. Exept that adaptation of methods of least quadric takes minimal dispersion mark $S^2(\hat{y})$ value y gained in formula (1). Method has importance because it rely on empirical values y that are not connected, it is considered that defect of experiment of normal grading and has equally dispersion.

Limit of defects for logharitm intensity of deformation is gained from relation

$$\hat{y} \pm t_{f,\alpha}\sqrt{S^2(\hat{y})} \tag{5a}$$

From relation (5a) interval of reliability for logharitm of deformation,

$$P\left\{\hat{y} - t_{f,\alpha}\sqrt{S^2(\hat{y})} \le \ln \hat{e}_{iR} \le \hat{y} + t_{f,\alpha}\sqrt{S^2(\hat{y})}\right\} = 1-\alpha$$

where are:

$\hat{y}$ - calculation values lne_{iR}, formula (5)

$t_{f,\alpha}$ - grading of Students, at f degree of freedom(1-α) level of probability

$S^2(\hat{y})$- mark of dispersion $\hat{y}$, determined due to matrix $(X'X)^{-1}$ and rest of the dispersion.

Evaluation of the rest of dispersion S^2 is based on summ of quadrats of different values of logharitm deformation. For first examination serie of summ of quadrats lne_{iR} deviation is 0.04806 (table 3). For two deegres of freedom markof the rest of dispersion S^2=0,02403. Mark of dispersion $S^2(\hat{y})\ln e_{iR}$ is taken in analogy with conditions of examination, so for examinations 2,3,4,6 based on matrix $(X'X)^{-1}$,

$$S^2(\hat{y}) = \left(\frac{1}{6}+\frac{1}{4}+\frac{1}{4}+\frac{1}{4}\right)S^2 = \frac{11}{12}S^2$$

and for examinations 1 i 5

$$S^2(\hat{y}) == \frac{1}{6}S^2.$$

Interval of credibility for examinations 2, 3, 4, 6 at 95%-om interval of confidenc and two deegres of freedom (at $t_{2;0.05}$),

$$\hat{y} \pm t_{2;0.05}\sqrt{\frac{11}{12}S^2} = \hat{y} \pm 4{,}3 \cdot 0{,}15 = \hat{y} \pm 0{,}645$$

and for examinations 1 i 5

$$\hat{y} \pm t_{2;0.05}\sqrt{\frac{1}{6}S^2} = \hat{y} \pm 4{,}3 \cdot 0{,}63 = \hat{y} \pm 0{,}271$$

For evaluation of results of first serie of examinations is necessary to determine and to analyse mark of dispersion and to check adequacy of hypothesis of matematical model. For analysis is determined:

1. Basic summ of quadrats $\sum y^2$ consists of summ of quadrats of the rest $\sum(y-\hat{y})^2$ and summ of quadrats of regression $\sum y^2 - \sum(y-\hat{y})^2$

2.Summ of quadrats of regression consists from summ of qudrats conditionaled by model of zero order and summ of quadrats conditionaled by model of first

3.Summ of quadrats consists from summ of quadrats and relative defect of experiment, and summ of quadrats that makes inadequacy of presenting results of experiments

$$\sum(y-\hat{y})^2 - \sum_{1}^{n_o}(y_{oi} - \bar{y}_o)^2$$

Analysis of dispersion mark for first serie of experiments is given in table 4. Comparation of dispersion marks, relative inadequancy of presenting results of experiments, with dispersion mark of experiment defect, is given with Fishers F-grading. For first serie of examination F=0,19; for P=0,95 and $f_1=f_2=1$ F_T=164,4, points that gained matematical model (5) is adequat.

Calculated interval of credibility (table 3) show that is necessary to confirm results of experiments by reapting of experiment, what is obvious, that intervals are wide and does not enable use of gained formula. So, it is necessary to do second serie of experiments (6-12) whose results are given in table 2. Due to this datas next formula is presented

$$\ln e_{iR} = -2.0344 - 0.9005\ln\frac{r}{s_o} + 0.2269\ln\alpha + 0.1189\ln\frac{b}{s_o} \tag{6}$$

Statistic alanalysis of results of second serie of examination is taken analogisally to analysis of firs serie of examination. N requards to all differences beetwen two series, gasined formulas are similar, which makes possible to unite results of first and second serie. Coeficient of united series of examinations can be determed as average value of formula (5) and (6):

$$\ln e_{iR} = -2.0799 - 0.8158\ln\frac{r}{s_o} + 0.2435\ln\alpha + 0.780\ln\frac{b}{s_o} \tag{7}$$

Interval of credibility are:

$\hat{y} \pm 0.1570$ - for examinations 2-4, 6-8, 10, 12 i

$\hat{y} \pm 0.0693$ - for examinations 1, 5, 9, 11.

Common adequacy of model (7), is taken by analysis of dispersion mark (table 5).

Table 5. Analysis of dispersion mark of unated series of examination

Defect	Summ of quadrats	Deegre of freedom	Size of dispersion
Members of zero order	$\left(\sum_{1}^{12} y_i\right)^2 \frac{1}{12} = \frac{372{,}9533}{12}$	1	31,080
Members of first order	$4\sum_{1}^{3} b_i^2 = 0.5664$	3	0.1888
Inadequacy of results of experiments	$\sum(y-\hat{y})^2 \sum_{i=1}^{n_o}(y_{oi}-\bar{y}_o)^2 = 0.024887$	5	0.004977
Experiments	$S_E = \sum_{i=1}^{n_o}(y_{oi}-\bar{y}_o)^2 = 0{,}056971$	1	0.01899
Residual	$S_R = \sum(y-\hat{y})^2 = 0.081858$	8	0.010232
Common	$\sum_{1}^{12}\hat{y}^2 = 32.3572$	12	2.6964

3. CONCLUSION

Formula (7) can be transformated in natural form by transformation from logharitm to numerical parameters

$$e_{iR} = \frac{0.125\alpha^{0.244}\left(\frac{b}{s_o}\right)^{0.078}}{\left(\frac{r}{s_o}\right)^{0.816}} \tag{8}$$

Due to formula (8) is gained nomogram (picture 1) according to dependence from regime of profiling can be determed intensity of maximal logharitm deformation of outer fibers of profile, and intensity of deformation on inner area of profile e_{iR} and maximal stress in profile.

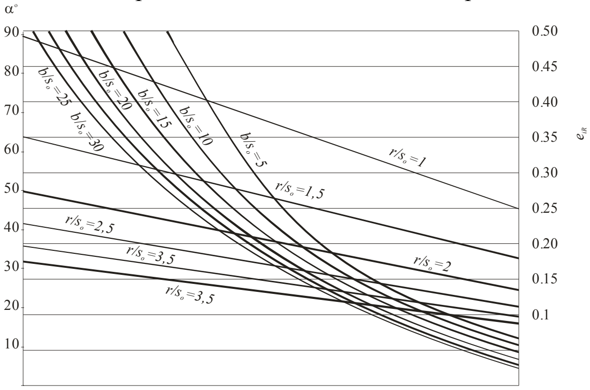
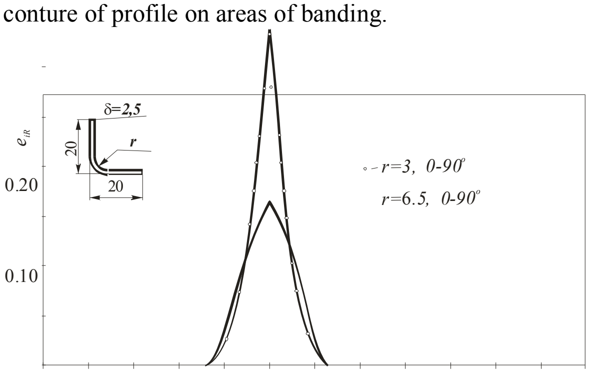
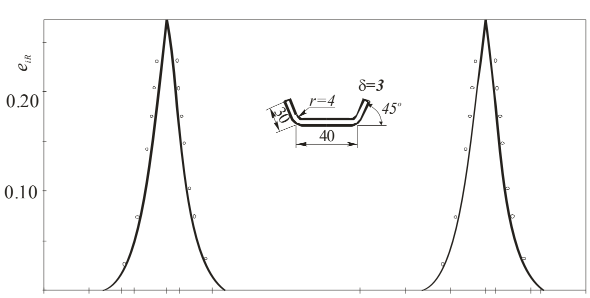


Fig. 1. Nomogram for determination of maximal superficial deformation in relation to parameters of profiling

Intensity of maximal deformation of profile in evert shaped cell, and what is necessary at projecting regime of profiling, based on plastic characteristics of material, is determined from differences of intensity of deformation of profile beetwen last and previous cell. Due to these differences and formula (8) can be determed and minimal allowed radius of banding by profiling (results of examination of materials by extension).

Technological process impose need for determination of distribution of intensity of deformation at cross section of bended part of profile. On picture 2 are given results of experimental research of intensity of deformation at outer conture of profile on areas of banding.





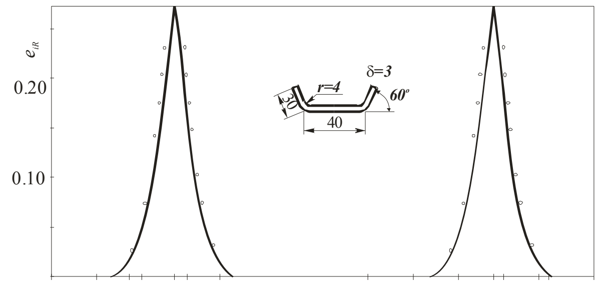


Fig. 2. Distribution of intensity of deformation on bended parts of profile on its inner conture

Analysis of results show that deformation grades in domain of small size of bended parts of profile, approximately on one to two thickness of tape. In common case deformation can be concetrated in domain (α, R).Grading of deformation at banding part (α, R); deformation is the biggest on bisectrix of angle of banding and intensiveky is reductives by deviation from it; value e_{iR} distributs simetricaly in relation to bisektrix so it can be considered only half of bended part (α, R/2).

Due to exposed, disposal of intensity of deformation on bended parts of profile can be presented by dependence,

$$e_{iR} = e_{ir\max} \exp\left(\frac{-6\alpha_x}{\alpha}\right) \tag{9}$$

where are:

α - full angle of banding

α_x - x-ti part of half of bended angle

$e_{iR\max}$ - intensity of maximal deformation, gained from formula(8).

Curves of dispersion of intensity of deformation of outer conture of profile, gained from formula (9), shown on picture 2.

1. LITHERATURE

1. O Miletić; Technology of engineering, Mchanical faculty of University in Banja Luka , 1999., Banja Luka
2. O Miletić; Constitutive relations by process of continuall profiling of composite husk and plate, University u Banjaluci-Mechanical faculty 2002., Banja Luka
3. O Miletić, M. Todić; Carrying structure of machine and equipage, University in Banjaluci-Mechanical faculty 2005., Banja Luka
4. M. Todić, O. MiletiĆ, D. Marić; Thickness in fuction NDS two-layer composite, DEMI 2009., Banjaluka 2009.

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POWER ULTRASOUND IN MACHINING

Abstract: *Ultrasound energy consisted of oscillating mechanical and acoustic energy is often called ultrasound. There are a few fields with usage of ultrasound oscillation in mechanical material machining. One of this ways is physical principle of ultrasound machining by abrasive suspension and the second is intension grinding technique by ultrasound. Paper deals with general information about ultrasound and with his application in machining process.*
Keywords: *technology, ultrasound, intension technique.*

1. INTRODUCTION

One way of the economical development is considered the increasing of the industry production through the slower development of production usage. The way of technological process rationalization is intensification of technological processes by ultrasound.

2. CHARACTERISTIC OF ULTRASOUND

Special properties and influences of ultrasound energy in the conditions of broadening ultrasound oscillation are showed in the research results. Ultrasound energy consisted of oscillation mechanical and acoustic energy is often called ultrasound. Ultrasound falls under to acoustic field with acoustic zone up to audibility of hearing and ultrasound technique delimits this zone above limit 20 kHz with respect to safety aspect. Effect of ultrasonic energy for its dissemination in the environment depends on the size of amplitude. In this regard, ultrasound can distinguish between small amplitude - ultrasonic energy in this case is passive (it does not effect any physical or chemical change) by a large amplitude - active ultrasonic energy is often called macrosound or ultrasound power (the effect of affecting the properties respectively structure subjected to environmental its effects).

3. ULTRASOUND MACHINING AND MACHINING AIDED BY ULTRASOUND

In technical practice, the generally used two terms to express the working material through ultrasound. It is Ultrasonic machining (USM - Ultrasonic Machining / and working with the support of ultrasound. The principle of ultrasonic machining is based on the abrasive effect of the suspension and fine abrasives, circulating between the workpiece and tool. It is a broad-based technology that is used for cutting materials, dredging grooves, deep hole drilling, milling and thread cutting, polishing, lapping and grinding of glass and so forth.
Machining with the support of ultrasound technology is a combination of processes, for example. turning, drilling, grinding with a combination of vibrant tool ultrasonic energy. Grinding with the support of ultrasound is also referred to as rotary ultrasonic machining. / Rotary Ultrasonic Machining - RUM /.

Fundamental differences between the ultrasonic treatment and ultrasonic rotary cultivation are:

- Movement of the tool during operation with the support of ultrasound-RUM is higher axial and axial rotation in the ultrasonic machining-USM only vibrating movement of the tool,
- For grinding with the support of ultrasound - RUM – are used classic diamond tools in the form of conventional grinding wheels,
- For the removal of material used abrasive particles of diamond tool - grinding grains.

In ultrasonic machining USM - tool is used for the transmission of vibration, pressure and flow guide of suspension and the suspension is not in direct contact with the workpiece, on the contrary, in the RUM is in direct contact with the workpiece.

4. ULTRASOUND USAGE IN MACHINING

There are several areas where the use ultrasonic oscillations in the mechanical machining of materials. One of these areas is the physical principle of the ultrasonic machining abrasive suspension. (Fig. 1) This method of ultrasonic machining abdominal suspension and vibrant tool allows producing hard and brittle materials, different aspect holes (blind and transient) of very complex shapes. Allows to carry out such operations, when other methods of machining have been very difficult, would be unreasonable or not performed at all. Vibrant tool to the workpiece is pressed with frequency of approximately 20 000 oscillations per second at a time and retract abrasive grains dispersed in water in the working materials.
These grains with their sharp edges rip small particles from the surface of the material. Together with the abrasive suspension are then removed to the surface, taking the place flows in the new grinding suspension. The whole cycle is repeated continuously.

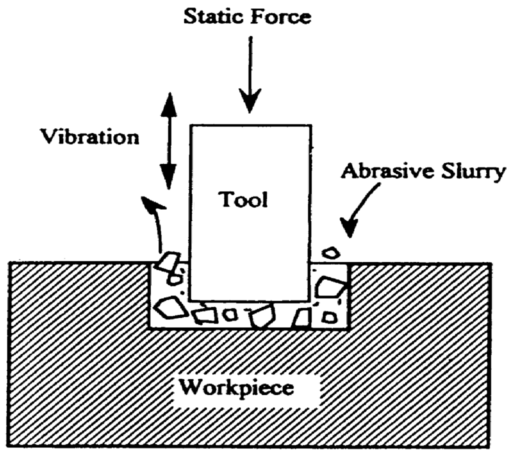

Fig. 1 Ultrasound machining by abrasive slurry

The second is the intensification of grinding methods by ultrasound. Getting to the point of ultrasonic oscillations sharpened substantially affects the entire process to create the conditions for the intensification and increased productivity grinding process.

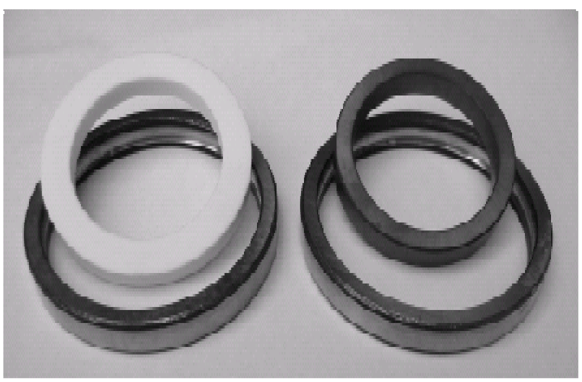
Fig.2 SiSiC and Al_20_3 rings


Fig.3 Diamond grinding tool1A1 D30 T15x2, 5H10 D76 C

In terms of utilization of ultrasound to influence the process grinding to pay attention to these methods and technologies:

- Ultrasonic drilling diamond abrasive tools
- Ultrasonic grinding,
- Ultrasonic honing and superfinishing,
- Ultrasonic cleaning grinding wheels,
- Ultrasonic grinding compensating coil.

Ultrasonic drilling using diamond abrasive tools (Fig. 3) represents a special method of grinding the material in which the diamond tool rotates while axial oscillation.
Abrasive tools have full rotational shape or tubular cross-section. In the space below the abrasive face of diamond bearing material is machined by grinding and coolant floatation on the surface.

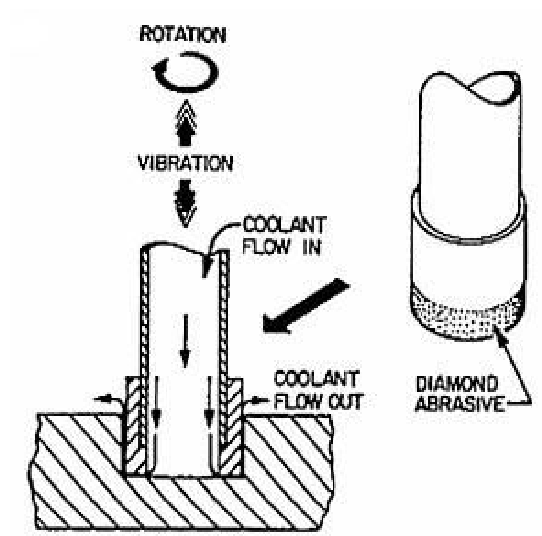

Fig.4 Schematic illustration of rotary ultrasonic machining (RUM) process

Technology (Fig. 4) ultrasonic grinding materials by rotated and ultrasound oscillated abrasive tool allows you to increase productivity and the intensification of the technological process of grinding. The influence of ultrasound arises in the process of continuous renewal sharpened cutting properties of grinding the tool (Fig. 5) which can be described as the "cleaning and self – sharpening" of grinding tools.

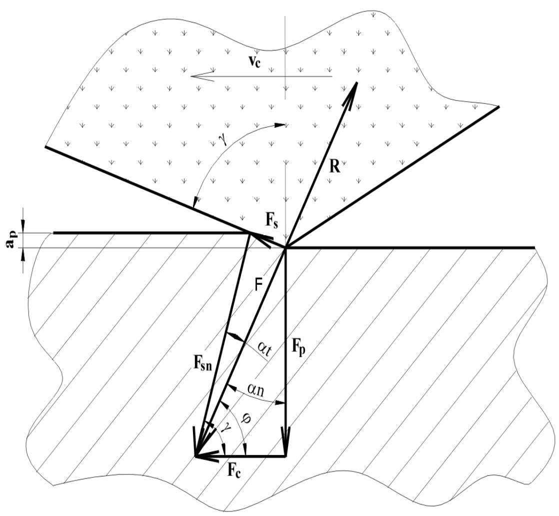

Fig. 5 Resolution of ultrasound grinding forces,
F – final cutting force, F_p – pressed force, F_c – cutting force of grinding wheel, F_s – friction force, F_{sn} – normal force, R – final force charged to a grinding grain, a_p – depth of grinding, γ - rake, φ – angle of feed moving, α_n – friction angle on the workpiece, α_t – angle of friction., v_c – cutting speed

Ultrasonic honing and superfinishing are one of the successful application of ultrasonic methods applied to grinding processes in the finishing operations of precision rotary surfaces. It was found that the process under the influence of ultrasonic grinding, honing and superfinishing permanently continued, without a gradual slowdown and decline in the effect of cutting abrasive grain.
Another area is the intensification of some classical methods of metal machining by vibrant tools such as. turning, milling, drilling, cutting threads.
The effectiveness of the impact of ultrasound on the process of cutting chips depend on several factors: the frequency and amplitude of oscillations, the ratio of the speed of oscillation of circuit speed of machined parts, sectional chips, physic-chemical properties of working material and tool.
Ultrasonic oscillations tool in turning in the direction of cutting speeds directly affect the deformation process of cutting. Separation of chip is made in full cutting speeds. Pressing the chip is smaller, which significantly reduces the cutting force (40 to 50%).
Diminishes the fortifying of the cutting area and

Fig. 6 Ultrasound grinding by Al_2O_3

improves the quality of machined surface area, which takes the mirror shine. To the ultrasound usable field consists the surface strengthening of metal workpieces by suitable finished and oscillated ultrasound tool.
Ultrasound oscillations as intensification factor are effective in surface balling of workpieces of cloudy and no cloudy steel and cast iron.
This method of strengthening surfaces, improving the fatigue properties, reduce roughness, increase wear resistance as well as ultrasonic microhardness can achieve in considerably by smaller static forces balling.
The principle of that method is based on the use of erosion activity of cavitations acting in a suitable fluid containing abrasives.

5. CONCLUSION

The favorable impact of power ultrasound on the process of grinding of hard brittle materials by grinding diamond tools for the use of appropriate types of tools and technology with proper choice of conditions seen in general:

- several cutting increasing rate of speed and feed speed of tool to cut,
- a substantial decrease in the value of specific wear diamond grinding tools,
- the machining of hard and brittle materials with tool of greater depth of cut,
- significantly higher productivity and deepening the process of machining in comparison with ultrasonic free abrasives machining, improving the quality of machined surfaces of hard brittle materials by reducing the surface roughness.

The article describes about field only of power in the ultrasonic machining. Despite the positive laboratory research has failed to implement on a broader scale, these applications of active sonar to practice.
It can be expected that further research in this area could increase the current knowledge and the issue adopts a greater number of qualified specialists, who gradually extended their use in practice.

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6. REFERENCES

[1] Mankova, I.: *Progresívne technológie, Progressive technologies.* Vienala Košice, 2000, 275s, ISBN 80-7099-430-4
[2] Mihalcak, P., Liptak, O., Pis, P.: *Skúmanie vplyvu ultrazvuku na vŕtanie tvrdých krehkých materiálov brúsnymi diamantovými nástrojmi.* Searching of ultrasound influence to drilling to hard brittle materials by grinding diamante tools. Volume of Research Works, Slovakia, SjF STU Bratislava, Vol. 15, 1977, pp 105-122
[3] Svehla, S., Figura, Z.: *Ultrazvuk v technológií, Ultrasound in technology,* Alfa Bratislava, 1984.
[4] Matusova, M., Javorova, A: *Modular clamping fixtures design for unrotary workpieces.* In: Annals of

Faculty of Engineering Hunedoara - Journal of Engineering. - ISSN 1584-2673. - Tom VI, Fasc. 3 (2008), pp. 128-130
[5] Danisova, N.: *Application of intelligent manufacturing system in the flexible assembly cell*, In: Annals of Faculty of Engineering Hunedoara - Journal of Engineering. - ISSN 1584-2673. - Tom V, Fasc. 3 (2007), pp 41-45,
[6] Lipa, Z., Charbulova, M.: *Quality of machined surface at grinding*, In: Proceeding of 9th. International conference TECHNOLÓGIA 2005. Bratislava: STU, 2005, pp. 445 – 450, ISBN 80-227-2264-2
[7] Matusova, M., Oravcova, J., Kostal, P.: *Gripping in robotized workplaces*. - Vega 1/0206/09. In: Machine Design. - ISSN 1821-1259. - 2009: 49th anniversary of the Faculty of technical sciences, Novi Sad. May 18th 2009. - Novi Sad : University of Novi Sad, 2009, pp. 355-358
[8] Ciutrila, G.: *Stand and results of the researches on the processing technology of internal grinding using ultrasonic vibrations.* In: International Symposium MTeM Cluj –Napoca, Romania, 2001

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SUPPLEMENT FOR IMPROVEMENT EXISTING MODEL FOR CALCULATING SPIRALLY FLUTED DRILL

Abstract: *In this paper, starting from total loading tools in processing drilling, scheme which respond really conditions was formed. Then, on the base analytical term elastic line of axis of tool differential equation was set up, and general solution was obtained using starting and boundary conditions. On the base so make relation was formed general mathematical model for calculated sizes which defined deformation-tension picture of tools.*
Key words: *mathematical model, differential equation of second order, processing drilling, axial and radial forces, critical forces of deflection*

1. INTRODUCTION

At the process of treatment metal by boring, the tool is loading with axial (F_x) and radial (F_y) forces, and with rotate moment. This is representative on the Figure 1., [1;8]. Existing models for calculated tools using only axial forces, but in many cases it is not really state, [7].

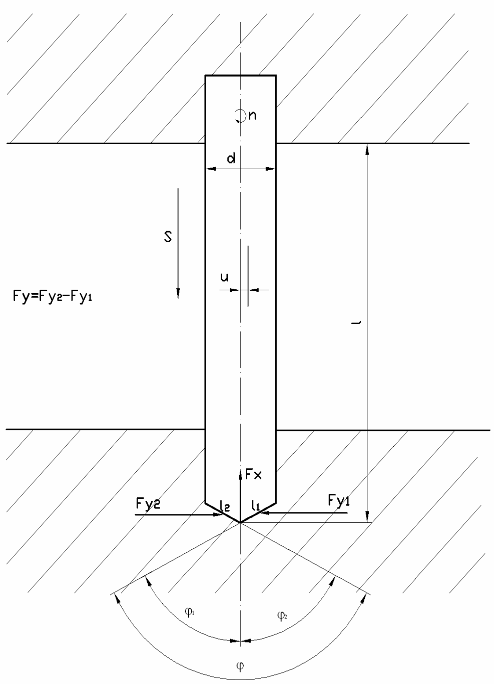

Figure 1. Analyses of forces which operate to tools at the process of treatment by boring

If borer as tool at the treatment by boring not simetric or is irregular sharpen, or is not equal trim nails, we get difference in length of primary hatchet (l_1 and l_2), or in angles of top (φ_1 i φ_2), [7;8].

In this case, radial force is

$$F_y = F_{y2} - F_{y1} \qquad (1)$$

Axial force (F_x) loading tools on pressure, or on deflection.

2. IDENTIFICATION OF CALCULATED SCHEME OF PROBLEM

In according with forces which operating on tools, we will determined calculated scheme of problem as shown on Figure 2, where the length of tools is marking with 1, and the displacement them top u is constant for given condition of treatment.

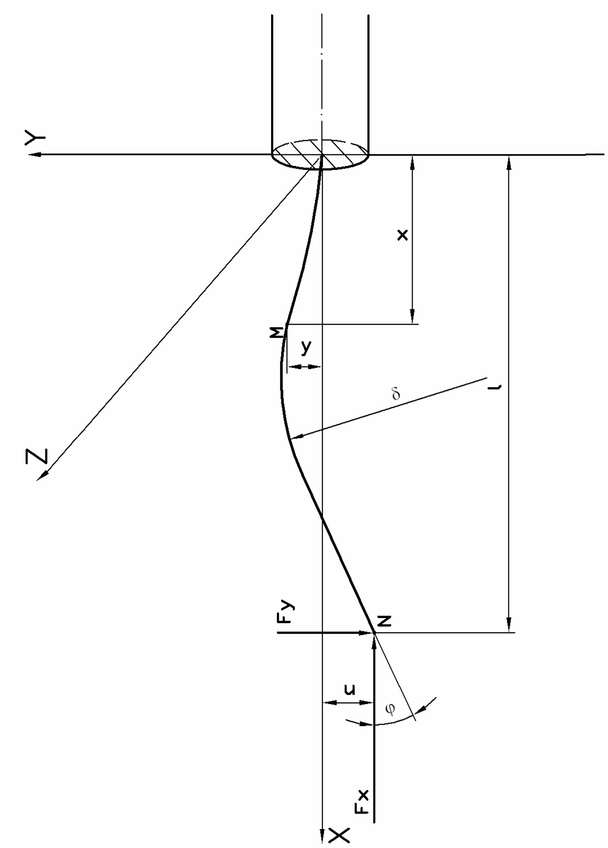

Figure 2. Calculated scheme of problem

3. Differential equation of problem

Equation of elastic line of axis tool, because work forces F_x and F_y, in general case we can show as y=f(x)

Curve for every point M(x,y) of elastic line will be, [4],

$$\frac{1}{\rho}=\frac{y''}{\pm\sqrt{(1+y'^2)^3}} \tag{2}$$

According elastic theory, curve of neutral line can be shown in form , [3],

$$\frac{1}{\rho}=\frac{M}{EI} \tag{3}$$

In relation (3), M is moment twist and EI is inflexibility joist at same tension.

When equation (2) is equal equation (3), we get,

$$\frac{y''}{\pm\sqrt{(1+y'^2)^3}}=\frac{M}{EI} \tag{4}$$

Curves of tangente are little variables, y'^2 is little variable, because y'^2 ‹‹ l, term (4) transform in , [2],

$$y''=-\frac{M}{EI} \tag{5}$$

Term (5) is analytical term of elastic line, where sign depends of orientation coordinate axis. For our case, Fig. 2, elastic line is convex in the direction of positive y- axis, and for every point $y''<0$, [4].

In term(5), $\frac{M}{EI}$ is a positive variable. Under activity forces F_x, F_y stick is twisting and have curve y on the distance x. In this section moment is,

$$M=F_x(u+y)+F_y(l-x) \tag{6}$$

Replacing moment from equation (6) in relation (5), we get,

$$y''=-\frac{F_x(u+y)+F_y(l-x)}{EI} \tag{7}$$

and,

$$y''=-\frac{F_x}{EI}(u+y)-\frac{F_y}{EI}(l-x) \tag{8}$$

Now we introduce parametar k^2,

$$\frac{F_x}{EI}=k^2 \tag{9}$$

And term (8) is transformed in,

$$y''=-k^2(u+y)-\frac{F_y}{EI}(l-x) \tag{10}$$

Differential equation (10), we can write as,

$$y''+k^2y=\frac{F_y}{EI}x-\frac{F_y}{EI}l-k^2u \tag{11}$$

And this relation is linear nonhomogenous second order equation with constant coefficients. Characteristic equation of homogenous part is

$$r^2+k^2=0 \tag{12}$$

Solving of equation (12) are,

$$r_1=k\cdot i \qquad r_2=-k\cdot i$$

Then, homogenous part of equation have form, [5],

$$y_h=C_1\cos kx+C_2\sin kx \tag{13}$$

$$\eta=m+n=0+1=1$$

$$\eta=y_p$$

Particularly solving of equation (11), will be have linear form, [5],

$$y_p=a_1x+a_0 \tag{14}$$

a_1 and a_0 are constants which are not calculated. Differentiating relation(14) and replacing in (11) we got

$$y_p'=a_1 \qquad y_p''=0$$

$$0+k^2(a_1x+a_0)=\frac{F_y}{EI}x-\frac{F_y}{EI}l-k^2u \tag{15}$$

Toward (15) we got

$$k^2a_1=\frac{F_y}{EI} \qquad a_1=\frac{F_y}{k^2EI}=\frac{F_yEI}{F_xEI} \tag{16}$$

$$a_1=\frac{F_y}{F_x} \tag{17}$$

$$k^2a_0=-\frac{F_yl}{EI}-k^2u$$

$$k^2a_0=-\frac{F_yl}{F_x}k^2-k^2u \tag{18}$$

$$a_0=-\frac{F_yl}{F_x}-u \tag{19}$$

Replace constants (17) and (19) in (14), we get particularly solving,

$$y_p=\frac{F_y}{F_x}x-\frac{F_y}{F_x}l-u \tag{20}$$

and,

$$y_p=\frac{F_y}{F_x}(x-l)-u \tag{21}$$

General solving of equation (11) is sum of homogenous and particularly part;

$$y=y_h+y_p \tag{22}$$

Toward (13) and (21), gets,

$$y=C_1\cos kx+C_2\sin kx+\frac{F_y}{F_x}(x-l)-u \tag{23}$$

And it is general solving of equation (11).

We calculate constant C_1 and C_2 using boundary conditions:

$x=0 \quad y=0$

$x=l \quad y=-u$ (24)

Replace conditions (24) in equation (23), we get,

$$0=C_1\cdot\cos 0+C_2\cdot\sin 0+\frac{F_y}{F_x}(0-l)-u \tag{25}$$

$$C_1 = \frac{F_y}{F_x l} + u \quad (26)$$

$$-u = C_1 \cdot \cos kl + C_2 \cdot \sin kl + \frac{F_y}{F_x}(l - l) - u \quad (27)$$

$$C_2 = -(\frac{F_y}{F_x} l + u) \cdot ctgkl \quad (28)$$

Replace constants from terms (26) and (27) in term (23), final solving of equation (11) will be,

$$y = (\frac{F_y}{F_x} l + u)\cos kx - (\frac{F_y}{F_x} l + u) ctgkl \cdot \sin kx + \frac{F_y}{F_x}(x - l) - u \quad (29)$$

and,

$$y = (\frac{F_y}{F_x} l + u) \cdot (\cos kx - ctgkl \cdot \sin kx) + \frac{F_y}{F_x}(x - l) - u \quad (30)$$

Differentiating equation (30), we get

$$y' = (\frac{F_y}{F_x} l + \mathrm{u}) \cdot (-k \sin kx - k\, ctgkl \cdot \cos kx) + \frac{F_y}{F_x} \quad (31)$$

Differentiating equation (31), we get,

$$y'' = (\frac{F_y}{F_x} l + u) \cdot (-k^2 \cos kx + k^2 ctgkl \cdot \sin kx) \quad (32)$$

4. CALCULATED CHARACTERISTICS VARIABLES

On the base equation (30), (31), (32) we can get important relation for calculated tension-deformation picture at description problem.
For

x=0, y'=0 (33)

using (31) will be

$$(\frac{F_y}{F_x} l + \mathrm{u}) \cdot (-k \sin 0 - k\, ctgkl \cdot \cos 0) + \frac{F_y}{F_x} = 0 \quad (34)$$

And then,

$$\mathrm{u} = \frac{F_y}{F_x}(\frac{tgkl}{k} - l) \quad (35)$$

and,

$$\mathrm{u} = \frac{F_y}{F_x k}(tgkl - kl) \quad (36)$$

Term (36) is characteristic equation of observation problem
Combination terms (36) and (30) we have

$$y = \frac{F_y}{kF_x}(tgkl \cdot \cos kx - \sin kx + kx - tgkl) \quad (37)$$

Differentiating equation (37) we get,

$$y' = \frac{F_y}{F_x}(1 - tgkl \cdot \sin kx - \cos kx) \quad (38)$$

and,

$$y'' = \frac{kF_y}{F_x}(\sin kx - tgkl \cdot \cos kx) \quad (39)$$

Replacing,

$x = l \qquad y' = \varphi$ (40)

In term (38), we get

$$\varphi = \frac{F_y}{F_x}(1 - tgkl \cdot \sin kl - \cos kl) \quad (41)$$

Using term (5), moment of twist is

$M = -y'' EI$

Replacing term (39), in above relation for moment we get

$$\mathrm{M} = \frac{kEIF_y}{F_x}(tgkl \cdot \cos kx - \sin kx) \quad (42)$$

$$\mathrm{M} = \frac{F_y}{k}(tgkl \cdot \cos kx - \sin kx) \quad (43)$$

and then for $x=0$,

$$\mathrm{M}_{\max} = \frac{kEIF_y}{F_x} - tgkl \quad (44)$$

and then using term (9),

$$\mathrm{M}_{\max} = \frac{F_y}{k} tgkl \quad (45)$$

and maximal tension because axial pressure and twist will be

$$\sigma_{\max} = \frac{F_x}{A} + \frac{M_{\max}}{W} \quad (46)$$

Horizontal displacement can be calculated if we show fluted drill as console:

$$u = \frac{F_y \cdot l^3}{3EI} \quad (47)$$

If we equalize relation (36) and (47) than can be eliminated *u*:

$$\frac{F_y}{F_x \cdot k}(tgkl - kl) = \frac{F_y \cdot l^3}{3EI} \quad (48)$$

Toward relation (9) axial force will be:

$$F_x = k^2 EI \quad (49)$$

With replacement F_x in relation (48) we obtained:

$$\frac{tgkl - kl}{k^2 EI - k} = \frac{l^3}{3EI} \quad (50)$$

Now, finally there are:

$$tg\,kl = \frac{k^3 l^3}{3} + kl \qquad (51)$$

With introduction:

$$kl = X, \text{ or } k = \frac{X}{l} \qquad (52)$$

relation (51) transformed in:

$$tgX = \frac{X^3}{3} + X \qquad (53)$$

Obtained transcendent equation (53(can be solved with some of numeric mathematical methods. Approximation solving, can be obtained by grafical method using two function in according with fugure 3:

$$y_1 = tgX, \qquad y_2 = \frac{X^3}{3} + X \qquad (54)$$

The smallest positive solving are obtained in the intersection curves (54).

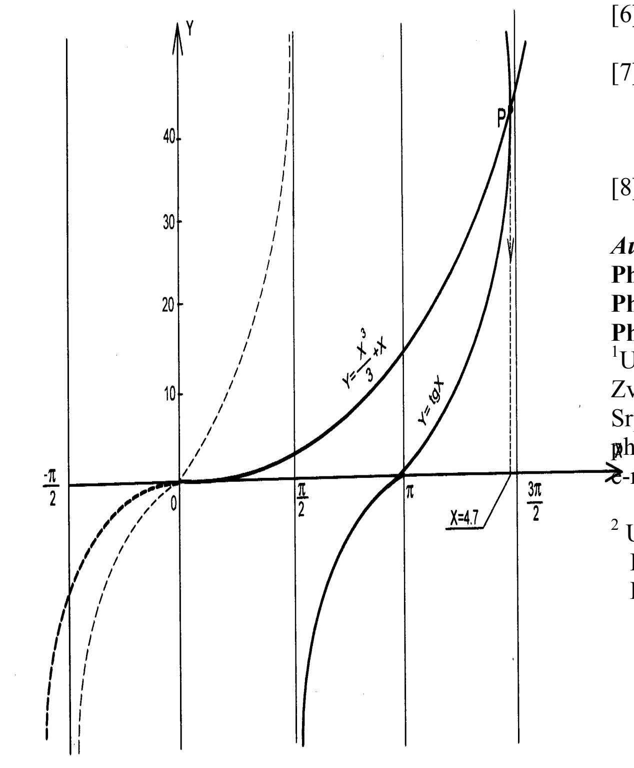

Figure 3.Graphical equation solving

Now, critical force deflection is total defined toward (9) or (52):

$$F_{kr} = \left(\frac{x}{l}\right)^2 EI \qquad (55)$$

5. CONCLUSION

Given mathematical model in comparision by symmetrically load tools, is better for real state because that in real treatment condition there are some irregularity and disturbance.

Model is performed for general case of treatment and make possible determination critical values of load tools, slope and tension in anywhere point of elastic line, as important variables for produce practice. Relation for horizontal disturbance top of tools which is performed on the base characteristic equation problem make possible analysis of important factors to error and precision treatment observation operation, and it can have practical role.

6. REFERENCES

[1] P. Stanković: *Mašinska obrada (I)*, građevinska knjiga, Beograd, 1981.

[2] D. Rašković: *Otpornost materijala*, Naučna knjiga, Beograd, 1982.

[3] S. Timošenko: *Teorija elastičnosti*, Beograd, 1970

[4] D. Mitrinović: *Matematika I i II*, Građevinska knjiga, Beograd, 1951.

[5] D. Mitrinović: *Diferencijalne jednačine*, Naučna knjiga, Beograd, 1951.

[6] D. Kumabe: *Vibracionoe rezanie*, Mašinostroenie, Moskva, 1985.

[7] B. Pejović: *Analiza opterećenja i deformacija pri nesimetričnom opterećenju kod procesa obrade bušenjem,* Savetovanje proizvodnog mašinstva Jugoslavije, Niš, 1998.

[8] E. Trent: *Metal Cutting*, Butterwort, London, 1977.

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CENTERLESS GRINDING AND POLISHING OF CIRCULAR STAINLESS STEEL TUBES

Abstract: *This paper describes the process of grinding and polishing of circular stainless steel tubes carried out by special centerless machines. It is a machine used for grinding and polishing of stainless steel tubes made by complex machine comprising four grinding and three polishing modules. Each of the modules ensures higher quality of the processed surface. The machine consists of four grinding and three polishing modules.*
Key words: *centerless, grinding, tube*

1. INTRODUCTION

Centerless grinding process differs from other cylindrical grinding processes in that the workpiece is not mechanically constrained. On traditional, old design machines, a workpiece is either held between centers or chucked and rotated against the faster spinning grinding wheel by an external motor usually located in a workhead. Parts made using a centreless process do not require center holes, drivers or workhead fixtures. Instead, the workpiece is supported on its own outer diameter by a work rest blade located between a high speed grinding wheel and a slower speed regulating wheel with a smaller diameter. Centerless grinding is proper for grinding cylindrical tubes and bullion.

2.CENTERLESS GRINDING

Grinding is one of the most significant production operations within final processing, for it provides:
- highly accurate proportions
- high quality of the processed surface.

Most commonly, grinding is subsequent to thermal treatment whereby it eliminates any defects caused by thermal deformations during the thermal treatment.

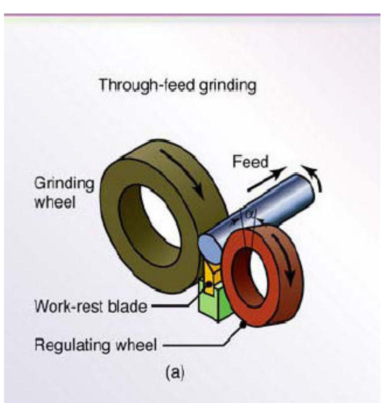

Fig. 1. Schematic view of the mode of operation

The type of abrasive, machine performance and selection of the working parameters are of major importance for the final precision and surface quality of the machined components.

Centerless grinding makes it possible to quickly replace the processed parts with those to be processed. There are three main modes of centerless grinding:

1. Through-feed grinding
2. In-feed grinding
3. End-feed grinding.

Figure 1 shows the schematic view of through-feed grinding.

As the figure shows, grinding and regulating wheel rotate in the same direction, a work-rest blade being in between. When centerless grinding is concerned, regulating wheel is usually rotated for α angle that ranges from 0° to 8°. This provides the occurrence of workpiece horizontal velocity component, therefore the external mechanism for axial motion of the workpiece is needless. Owing to this axial motion, objects processed in such manner can have only circular cross-section which is constant along the whole workpiece.

During the grinding process, number of revolutions of regulating wheel is much smaller than the one of grinding wheel, and this difference regulates the number of revolutions of a workpiece and its axial motion. In order for this mode of operation to be feasible, the machine must be regulated by PLC controller whose role is to adjust both the number of revolutions and the workpiece force on grinding wheel.

During the process of centerless grinding, grinding wheel performs the main rotary motion. Secondary motion is performed by the regulating wheel, it is rotary and it provides longitudinal tube feed. The axis of grinding and regulating wheels can shift from 1 to 10 mm, as related to the axis of the workpiece. The feed of the workpiece can vary according to change in the dip angle α and periferal velocity of the regulating wheel.

$$S_{workpiece} = V_r \cdot \sin\alpha = D_r \cdot \pi \cdot n_r \cdot \sin\alpha \quad [\text{mm/min}],$$

wherein:

$S_{workpiece}$– presents feed of the workpiece
V_r – periferal velocity of regulating wheel
α – dip angle of the regulating wheel in relation to grinding abrasive wheel
D_r – external diametar of the regulating wheel

n_r – number of revolutions of the regulating wheel

According to the diametar of the workpiece, two parameters of the operation mode are accepted: space between the grinding and regulating wheels, and change in the height of longitudinal work-rest blade. During the tube grinding process on the special centerless machine, grinding wheel is wrapped with changeable abrasive belt which is replaced after being worn out.

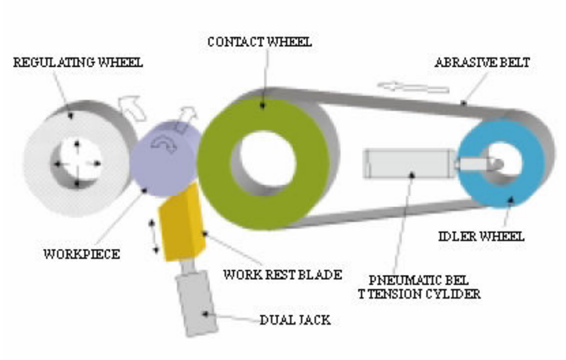

Fig. 2. Centerless grinding process setup

The process of centerless belt grinding is utilized for the outher grinding of cylindrical surfaces. It works after the principle of through-feed of the workpiece. Centerless grinding process setup is shown in figure 2.

Centerless grinding is on the increase because it eliminates the operation of centering both ends of the workpiece. The workpiece is completely supported in the grinding zone. That fact permits a higher efficiency of the grinding process.

2.1. Abrasive belt centerless grinding

During the abrasive belt centerless grinding, removal of material is achived by the grinding head, which consists of the following main components:

- The regulating wheel,
- The contact wheel,
- The idler roll
- The work rest blade and
- Abrasive belt.

The workpiece is supported by an angular rest blade (through-feed support). Work rest blade can be adjusted for different heights, depending on the diameter of the workpiece. The abrasive belt is supported by a serrated rubber or plain-faced contact wheel and an idler wheel. The tension of the abrasive belt is achieved through a pneumatic device. The regulating wheel is placed opposite to the contact wheel. Its role is to ensure the contact between the workpiece and the grinding head. Its position is set under a certain angle to generate an axial feed and workpiece's rotation. The surface speed of the regulating wheel is usually about 1/20 of the contact wheel speed.

The cutting forces exerted by the grinding head hold the workpiece against the rest blade. The workpiece rotates at the same surface speed as the regulating wheel. The rest blade supports the workpiece and can be adjusted at a proper height relative to the contact wheel.

Outlet of the abrasive belt grinding process is workpiece surface roughness. For the best results of the grinding process, working parameters of the process must be properly determined. The most important working parameters on abrasive belt grinding process are cutting speed, feed rate, contact pressure, contact wheel hardness etc.

Abrasive belt centerless grinding technology offers many adventages. The most important are:

- High feed rates can be utilized, commonly up to 20m/min
- Workpiece is supported both by the regulating wheel and the work rest blade. In this way, cutting process is intense, with no distortion of the workpiece
- Because there is no wear of the abrasive belt, the surface speed is constant
- The process is cooler
- Setup time is short

3. MACHINE FOR GRINDING AND POLISHING OF CIRCULAR STAINLESS STEEL TUBES

The main purpose of advanced machine systems is to achieve high productivity in conditions of high accuracy and surface quality for the workpiece. One of the ways to attain this goal is to group more operations, commonly carried out on different machines, on the same machining system. Some resently made tests show a significant improvement in roughness and accuracy of tubes machined on this machine systems.

Fig. 3. The entire machine for grinding and polishing of circular stainless steel tubes

The machine for grinding and polishing of circular stainless steel tubes is a product of the Italian company *Surface Engineering* from Milan, and it is the result of long time experience and cooperation with *Siemens* company. Figure 3 shows the entire machine. The machine for grinding and polishing of stainless steel tubes comprises a set of several minor machines – modules. The total nominal output of the machine is 80kW and it requires constant water supply of 2 bars water pressure for its functioning.

The total machine length is 21m and it functions with the assistance of a crane whose lifting capacity amounts to 10t. It is mounted in a machine hall, and its role is to transfer raw material (unmachined tubes) and ready made products.

The total machine length is 21m and it functions with the assistance of a crane whose lifting capacity amounts to 10t. It is mounted in a machine hall, and its role is to transfer raw material (unmachined tubes) and ready made products.

The machine consists of an infeed, four grinding modules, three polishing modules and a part for authomatic packaging of machined tubes into polyethylene foil. The assembled machine is controled by PLC *Siemens* company. It is the machine construction that enables shutting down some of its parts (according to circumstances or due to a failure/maintenance), which provides maximum working efficiency of the machine.

The infeed is on the tube entrance into the machine, and it provides the entrance of the tubes 100mm – 6000mm long. Most commonly, 6000mm long tubes are utilized. The infeed is completely automatized and its maximum load is 2t, wherein the number of tubes it can receive depends on the diameters and thickness. The diameter of tubes varies between 10mm and 220mm.

The grinding modules ST 220 (Figures 4 and 5) are the first in the technological procedure of pipe grinding and polishing.

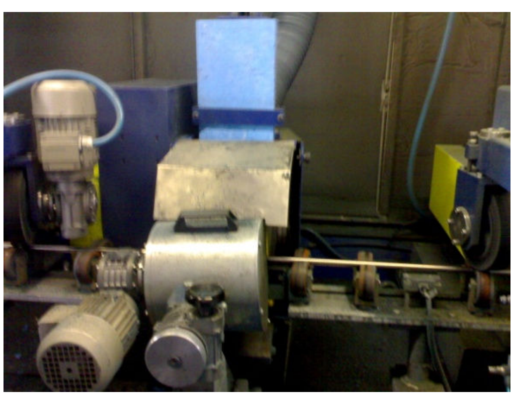

Fig. 4. Interior of the ST220 module

All the grinding modules are identical, however the power within particular modules varies, i.e. 17kW, 13kW, 10kW and 7kW. The first grinding module exerts the greatest power. Each of the modules may vary in the number of revolutions of the grinding wheel, within the range of 1500o/min to 3000o/min, which is governed by the PLC.

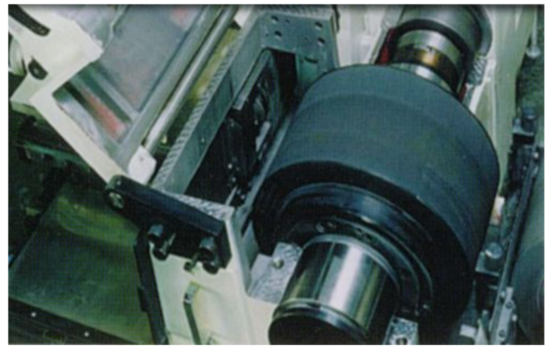

Fig.5. Grinding wheel inside the grinding module

The fineness of the abrasive bands of the grinding wheels also varies among modules. The fineness of the abrasive band of the first module is the lowest (400), and it grows with bands that follow, i.e. 600, 800 and 1000.

Artificial materials, such as aluminium oxide, silicon carbide, cubic boron nitride and diamond are most commonly used for the production of grinding (abrasive) bands. For the different purposes, the ST 220 uses CBN (cubic boron nitride) and PCD (artificial diamond)-based bands produced by *Klingspor*.

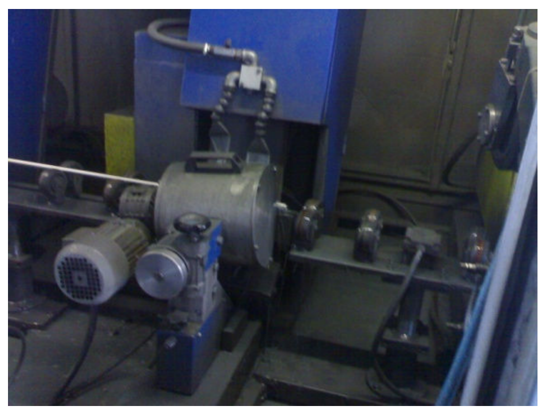

Fig.6. Interior of the PT 150 module

Having being worked in grinding modules, tubes enter the polishing modules, the PT 150 type (Fig. 6). All the modules are identical, nonetheless they exhibit different power, i.e. 7kW, 5kW and 3kW.

Fig.7.Polishing brushes

Within each module, polishing brushes (Fig. 7) can have different number of revolutions (100 o/min – 300 o/min), which is regulated by the PLC.

The fineness of the polish paste in each of the modules is 1200, 1400 and 1600. Brushes and pastes are combined, depending on quality requirements (high, moderate or low tube finish).

Subsequent to the above phase, tubes are automatically placed into a special carrier. They are then transferred by an automatic packaging machine into the 70µm thick polyethylene foil, whereupon these are considered as final products. The entire process of tube engineering can include finishing of maxiumum 25 tubes per hour, whereby the actual speed is approximately 10 tubes per hour, since the speed of the process depends on quality requirements. The materials used in the process (grinding bands, polishing brushes and polish pastes) are produced by the *Klingspor* and *3M*.

4.CONSLUSION

The paper presents the process of abrasive belt centerless grinding and polishing of 6000 mm long stainless steel tubes worked on a special machine produced by the company *Surface Engineering* from Milan. This process is carried out on a complex machine comprising four grinding and three polishing modules. Each of the modules ensures higher quality of the processed surface. Depending on quality requirements, some of the modules can be excluded.

This is the latest method of tube processing. It is highly productive, and it ensures high quality and accuracy of the processed surface. Multiple modules systems prove ability to obtain required specifications in a single pass.

5. BIBLIOGRAPHY

[1] Koepfer C.:*Centerless Grinding :Not Magic*, MODERN MACHINE SHOP Magazine, 2007.

[2] Kim K.:*Modeling of the centerless through-feed grinding process*, Journal of Mechanical Science and Technology**,** Volume 17, Number 7 / July, 2003

[3] Surface Engineering Operational Manual, Milano, Italy, 2007.

[4] Quality Centerless Grinding, Middlefield, USA, 2000.

[5] Intercity Centerless Grinding, Fountain Valley, USA, 2003.

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THE THRUST FORCE STRUCTURE IN DRILLING

Abstract: *The purpose of this work is to present investigation of the thrust force generated during drilling process. The thrust force acting on drill is the sum of three components: the cutting component, the thrust force attributed to ploughing at the chisel edge and the thrust force resulting from friction at the margin. The thrust force structure is determined by experimental decomposition of the drilling process. The result of the simulation study has shown a very good agreement between the theoretical predictions and experimental evidence.*
Key words: *drilling, thrust force*

1. INTRODUCTION

Drilling is the most commonly used machining operation. However, it is also one of the most complex cutting processes. The fact the great majority of hole diameters are within the 10 to 20 mm range cannot be efficiency produced by any other way, clearly shows how important the drilling operation is in the field of modern metal cutting.The basic principles of drilling are now well understood. The typical cutting process of a twist drill is threedimensional and oblique. Cutting speed, inclination angl and rake angle vary depending on the radius r along the cutting lip of the drill. Cutting characteristics of the drilling process are fundamentally nonlinear because of the complex physical phenomena of built-up edges, temperature variations, strain hardening and tool wear. The thrust force depends on the geometry of the drill (diameter, point angle, lip length, evolution of the cutting angles along the edges,etc.) as well as on the cutting conditions (cutting speed, feed rate, lubrication, etc.) and on the material's properties.

It is known that a drill consists of two cutting edges: the chisel edge and the main cutting edges. The point of the drill is generally formed by a chisel edge, which has a highly negative rake angle and very low cutting speeds because of its small radius. The cutting speed of the chisel edge is, in fact, zero at the drill center. The main feature that distinguishes it from other processes is the fact that cutting is combined with extrusion in the centre of the drill, at the chisel edge. The chisel edge extrudes into the workpiece material and hence, contributes substantially to the thrust force but little to the torque. Also, it is rather difficult to explain its cutting action on a theoretical basis, as there is an oblique cutting action combined with an extrusion process which produces two distinct types of chips, as shown in Figure 1.

The experimental investigation by Oxford showed that during cutting there were three identifiable zones of interest at the drill point, namely, the main cutting edges (or lips), the secondary cutting edges on the chisel edge, and an indentation zone about the drill centre, Figure 2. Outside indentation zone, the chisel edge produces an orthogonal cut with a negative rake angle, Figure 3. The rake angle is negative in the middle area and becomes gradually positive in the peripheral region. Means during drilling, the material is indented, extruded and machined by orthogonal cutting on the chisel edge and machined by oblique cutting on the main cutting edges.

In drilling, the thrust force does not contain only components of the main cutting edges, also it contains some of additional loads, which is present in drilling like:

- Friction force on drill edge between facet and machined hole,
- Extrusion force of the chisel edge.

Fig. 1. Two types of chips that are produced by extrusion and cutting actions in the drilling process [1]

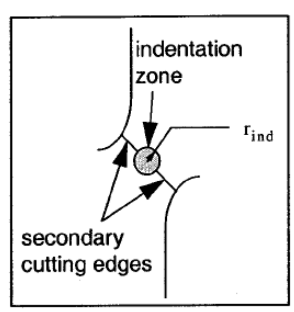

Fig. 2. Regions of the chisel edge [1]

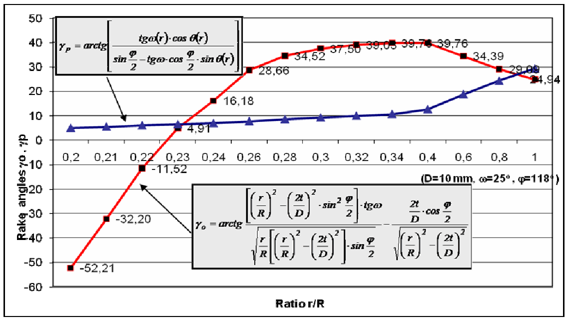

Fig. 3. Variation face rake angle γ_p and normal rake angle γ_o across the cutting lip [2]

In this paper, experimental decomposition of drilling process is applied to determination of structure the thrust force in drilling.

2. THE CUTTING FORCE MODEL

By analyzing the plan of cutting forces in drilling (Fig. 4) it is possible to conclude that the twist drill is affected by the following loads: torque, which is the result of the two main cutting forces F_v, and thrust force as the sum of the two feed forces F_{s1}. The sum of penetration forces F_p is zero, only if two main cutting lips are identical and are symmetrical upon the drill axis.

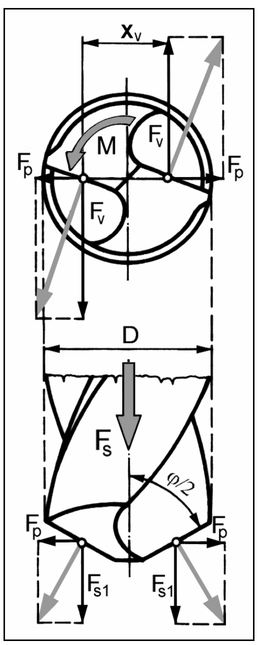

Fig. 4. A plan of cutting forces in drilling [2]

The model that will be studied in this work is based on the assumption that there are three distinct cutting edges on a typical drill: the main cutting edges, the chisel edge and the margin cutting edges. Various investigators have studied contribution of these cutting edges to the thrust force. Their results are very different. This is somewhat understandable. Thrust force, which derived from the main cutting edges and thrust forces that derived from chisel edge are not independent of each other. There are a lot of mutual relations between their mechanisms of emergence.

The contribution of the main cutting edges to the thrust force is approximately 40% (Oxford), 50% (Preger), 54,5% (König), 40% (Williams), 50% (Kaczmarek) [2]. The chisel edge contributes about 57% (Oxford), 46% (Preger), 22,5% (König), 60% (Williams) and 40% (Kaczmarek) [2]. The margin cutting edge has not been studied extensively, but its contribution is belived to be insignificant for a sharp drill. The friction between the margin cutting edge and hole walls has been reported to be 3% (Oxford), 4% (Preger), 10% (Kaczmarek) and 23% (König) [2].

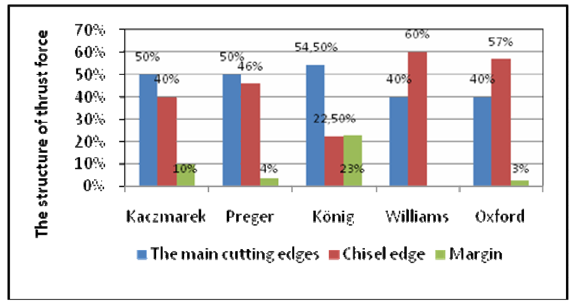

Fig. 5. The thrust force structure in drilling

In the investigated model, the thrust force in drilling is composed of three elements: the force generated by the main cutting edges, the force generated by the chisel edge and the force generated by margin cutting edges.

3. DETERMINATION OF THRUST FORCE

In order to determine the values of partial thrust force, special experimental decomposition was develop which is based on breaking down the drilling process into basic phases. An experiment was prepared which consisted of four sub-experiments, as shown in Figure 6 [2]. This approach was chosen to analyze the different cutting mechanisms acting on the main cutting edges, chisel edge and margins separately.

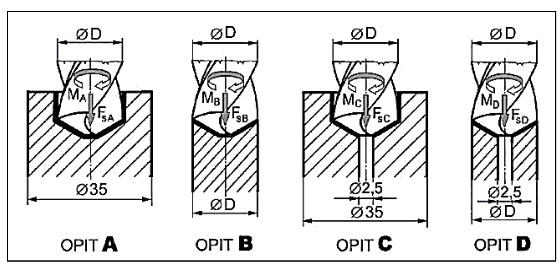

Fig. 6. Experiment plan with four sub-experiments

Friction thrust force can be determined by experiments A and B, using $F_{sT} = F_A - F_B$, the real cutting thrust force is given by experiment D so it is: $F_{sR} = F_D$, and finally the thrust force from chisel edge was obtained from experiments A and C like: $F_{sJ} = F_A - F_C$.

The total thrust force will be the sum of the partial values generated by the margin cutting edges, the main cutting edges and the chisel edge:

$$F_s = F_{sT} + F_{sR} + F_{sJ} \qquad (1)$$

3. EXPERIMENTAL PROCEDURE

The drilling tests were conducted on Index GU600 machine tool. The experiment conditions are summarized in Table 1. HSS drill bits with different diameters have been used for drilling the steel workpiece under different cutting conditions (six different feed rates were used; spindle speed was kept constant at 21-22 m/min). During the experiments, the thrust force was measured using Kistler dynamometer and sampled using a PC based data acquisition system with LabVIEW software, Figure 7. Component values were obtained by taking allowed average of the signal at the ¼ and the ¾ stage of each drilling phase.This technique allowed the signal components that correspond to the entry and exit of the drill.

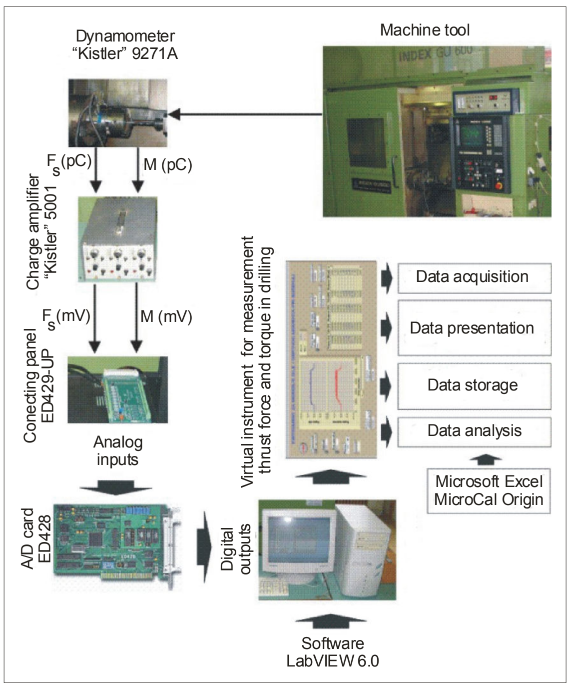

Fig. 7. Block diagram for the measuring system

	Diameter: 10 mm, 12 mm, 15 mm
Workpiece	Material: Č1220 (C15)
Machine tool	Type: Index GU600
Cutting conditions	Speed: 450-710 rpm; Feed: 0,056-0,179 mm/rev ; Coolant: Without

Table 1. The cutter, workpiece and cutting conditions

4. EXPERIMENTAL RESULTS

The typical thrust force signal is shown in figure 8. During the drilling process, the chisel edge penetrates into workpiece first, but the actual cutting action occurs at the cutting edges of the tool. As the drill feeds into workpiece,the area of cutting continually increases until all of the cutting edges are engaged. In the begining, the thrust force is close to zero and then it gradually increases and finally reaches steady state as shown in Figure 8. At the completion of drilling, the drill bit is extracted from the workpiece material and the thrust force goes to the zero at the exit part of cycle.

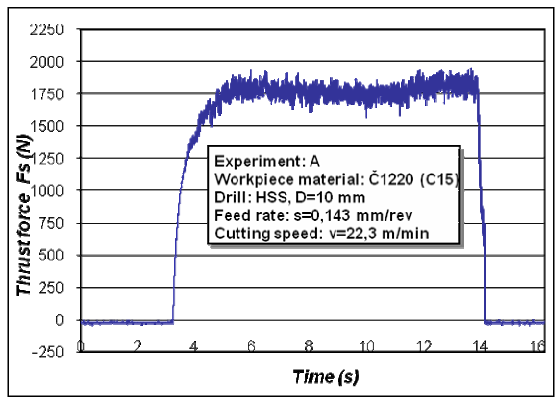

Fig. 8. Typical thrust force signal in drilling

The experimental results are summarized in Table 2, Table 3 and Table 4.

Cutter	Type: twist drill; Material: HSS								
Feed s, mm/o	MARGINS		„REAL“ CUTTING		CHISEL EDGE		THRUST FORCE		
	$F_{sT}=F_A-F_B$		$F_{sR}=F_D$		$F_{sJ}=F_A-F_C$		$\Sigma F_s = F_{sT}+F_{sR}+F_{sJ}$	$F_{s.measured}$	E
	N	$\%\Sigma F_s$	N	$\% \Sigma F_s$	N	$\% \Sigma F_s$	N	N	%
0,056	71	6,43	400	36,23	633	57,33	1104	969	13,93
0,071	57	4,26	494	36,97	785	58,75	1336	1162	14,97
0,089	65	4,36	559	37,56	864	58,06	1488	1312	13,41
0,112	77	4,47	680	39,51	964	56,01	1721	1488	15,65
0,143	114	5,68	765	38,15	1126	56,15	2005	1776	12,89
0,179	197	7,18	954	34,80	1590	58,00	2741	2362	16,04
	average ▸	5,40	average ▸	37,20	average ▸	57,38		average ▸	14,48

Table 2. Partial thrust forces: ∅10 mm; v=22,3 m/min

Feed s, mm/o	MARGINS		„REAL“ CUTTING		CHISEL EDGE		THRUST FORCE		
	$F_{sT}=F_A-F_B$		$F_{sR}=F_D$		$F_{sJ}=F_A-F_C$		$\sum F_s = F_{sT}+F_{sR}+F_{sJ}$	$F_{s.measured}$	E
	N	$\%\sum F_s$	N	$\% \sum F_s$	N	$\% \sum F_s$	N	N	%
0,056	88	5,99	440	29,95	941	64,05	1469	1287	14,14
0,071	95	5,54	529	30,89	1088	63,55	1712	1501	14,05
0,089	198	10,37	548	28,70	1163	60,92	1909	1646	15,98
0,1125	120	5,61	700	32,77	1316	61,61	2136	1900	12,42
0,143	267	10,94	713	29,12	1460	59,83	2440	2164	12,75
0,179	250	9,16	841	30,82	1637	60,00	2728	2477	10,13
	average ▸	7,94	average ▸	30,39	average ▸	61,66		average ▸	13,24

Table 3. Partial thrust forces: ∅12 mm; v=21,1 m/min

Feed s, mm/o	MARGINS		„REAL“ CUTTING		CHISEL EDGE		THRUST FORCE		
	$F_{sT}=F_A-F_B$		$F_{sR}=F_D$		$F_{sJ}=F_A-F_C$		$\sum F_s = F_{sT}+F_{sR}+F_{sJ}$	$F_{s.measured}$	E
	N	$\%\sum F_s$	N	$\% \sum F_s$	N	$\% \sum F_s$	N	N	%
0,056	101	6,85	497	33,90	868	59,24	1465	1457	0,60
0,071	110	6,22	605	34,21	1054	59,57	1770	1720	2,90
0,089	244	11,43	669	31,35	1221	57,22	2133	2014	5,90
0,1125	166	6,73	873	35,38	1429	57,88	2469	2374	4,00
0,143	348	11,91	924	31,60	1651	56,48	2923	2808	4,10
0,179	361	10,60	1114	32,66	1935	56,74	3410	3285	3,80
	average ▸	8,95	average ▸	33,18	average ▸	57,86		average ▸	3,55

Table 4. Partial thrust forces: ∅15 mm; v=21,2 m/min

A quantitative comparasion between the predicated and experimental thrust force is expressed as:

$$E = \frac{F_{s.calculated} - F_{s.measured}}{F_{s.measured}} \cdot 100\% \qquad (2)$$

The thrust force structure determined from experiments (A, B, C, D) is summarized in Table 5.

	The contribution of the margin cutting edges			The contribution of the main cutting edges			The contribution of the chisel edge		
	D, mm	%∑M	Average %	D, mm	%∑M	Average %	D, mm	%∑M	Average %
Thrust force	10	18,62	**18,79**	10	70,96	**73,18**	10	10,40	**8,00**
	12	18,40		12	74,75		12	6,81	
	15	19,35		15	73,85		15	6,80	

Table 5. The thrust force structure in drilling

5. CONCLUSION

The metod used for determination of thrust force structure in drilling has shown that it depends on chisel edge, the main cutting edges and margins. The results have confirmed some previous studies (Fig. 5.) and showed that chisel edge has certainly the greatest influence on the thrust force because of his characteristics. Experiments have shown that the influence of friction between the drill margins and machined surface on value of thrust force cannot be ignored.

6. REFERENCES

[1] Oxford, C. J.: *On the Drilling of Metals 1-Basic Mechanics of the Process*, Transactions of the ASME, The American Society of Mechanical Engineers, Vol. 77, pp.103-114, 1955.

[2] Sekulić, M.: *Determination of cutting forces in drilling*, PhD Dissertation, University of Novi Sad, Faculty of Technical Sciences, 2007.

[3] Sekulić, M., Gostimirović, M., Puzović, R.: *Modelling of drilling –predicting main cutting force*, 12th International Research/Expert Conference ”Trends in the Development of Machinery and Associated Technology” TMT 2008, Istanbul, Turkey, 26-30 August, 2008., pp. 101-104.

[4] Milikić, D., Sekulić, M., Gostimirović, M., Uzelac, S.: *Structure of cutting forces in drilling*, 7th International Conference Technology 2001, Bratislava, Slovakia, 2001., pp. 421-425.

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Sekulic, S.

ONE METHODOLOGY FOR DETERMINATION WEIBULL'S DISTRIBUTION FUNCTIONS BY MEDIAL RANKS FOR WHICHEVER SIZE SAMPLE

Abstract: *Data colection of failures is responsible and often, last work. Meanwhile, data processing is also lasting and request knowing of Statistics and data processing. For varnish data processing, unical methodological approach, with three variants, dependent of size sample, is expozed. First two related on unreprezentative sample N $\leq$ 50 and thred on reprezentative and N> 50 i N>>50. For determination of distribution functions of failure all variants are based on medial ranks. First variant related on sample 5 $\leq$ N $\leq$ 10 and medial ranks we must determine for all failures of sapple, while second we use for samples 11 $\leq$ N $\leq$ 50 (unreprezentative sample) and threed for N>50 (repezentae sample). For variantes time to failure grouping in intervals. Proposed racional, uniform, methodology, based on medial ranks, for whichever sample size, using by tham medial ranks smaller than N = Z <15, can be applicated.*

Keywords: *reliability, distrbution function, medial rank,*

1. INTRODUCTION

Data collection of failures is responsible and often, last work. Meanwhile, data processing is also lasting and request knowing of Statistics and data processing. For varnish data processing, unical methodological approach, with three variants, dependent of size sample, is expozed. First two related on unreprezentative sample $N \leq 50$ and third on reprezentative and $N > 50$ *i* $N >> 50$.

For determination of distribution functions of failure all variants are based on medial ranks.

First variant related on sample $5 \leq N \leq 10$ and medial ranks we must determine for all failures of sample, while second we use for samples $11 \leq N \leq 50$ (unreprezentative sample) and third for N>50 (reprezentative sample). For last two variantes time to failure grouping in intervals. How is known number of intervals we can determine by next terms [1]:

$$z = 1 + 3{,}3 \log N \qquad (1)$$

and

$$z = 5 \log N \qquad (2)$$

In *Table T.1* the numerical values of interval z dependent of sample size N. On the basis from *Table T.1.,* the number of intervals z are recomanded, for second variant $5 \leq N \leq 8$ and for thrird $8 \leq z \leq 12$.

N	50	80	120	200	500	800	1200	10000
(1)	6,6	7,3	7,9	8,6	9,9	10,6	11,2	14,2
(2)	8,5	9,5	10,4	11,5	13,5	14,5	15,4	20,0

Table T.1.

For all variants beside determination of distribution function parameters of failures $F(t)$, reliability $R(t)$, frequence $f(t)$, idensity of failure $\lambda(t)$ and confidence interval bounderies, by d_α*-test* Kolmogorov-Smirnov, dependent of sample size N and adopted risk α, can be determined. On the end mean time to failure T_m using distribution function parameters via gamma Γ *function,* is determined. [1-7].

Investigation today pointed that, for technical systems, *Weibull's distribution function* can be used.

$$F(t) = 1 - \exp[-(t/\eta)]^{\beta} \qquad (3)$$

How is before notised, basis for distribution function parameters determination, indpendent of sample size, are medial ranks, which can be determined from knowing tables from literature, or determined by terms

$$MR = (j - 0{,}3)/(N + 0{,}4) \qquad (4)$$

for unreprezentative and

$$MR = j/(N + 1) \qquad (5)$$

for reprezentative samples

When the medial ranks are known, for particular time values to failures, *Weibull's distribution function* are determined by the smpple size.

The correlation coefficient is

$$r = \beta\,(\sigma_x / \sigma_y) \qquad (6)$$

where the variance of x-value

$$\sigma_x^2 = (1/N)\ \Sigma x_i^2 - x^2 \qquad (7)$$

and variance of y-value

$$\sigma_y^2 = (1/N)\ \Sigma y_i^2 - y^2 \qquad (8)$$

Mean of x-values

$$x\square = (1/N)\ \Sigma x_i = A_2/B_2 = B_1/B_2 \qquad (9)$$

and mean of y-value

$$\square = (1/N)\ \Sigma y_i = C_2/B_2 \qquad (10)$$

If the correlation coefficient is near one, the correlation between variables is stronger.

The distribution function parameters can be done by pure graphical method by entering experimental points of time to failure and his corresponcing medial ranks in *Weibull-s* probability paper from which we can read out values of shape parameter β (on scale) and position η on t axes (for medial rank $MR = 0,632$).

The reliability as acomplement is

$$R(t) = 1 - F(t) = exp[-(t/\eta)]\, n^{\beta} \qquad (11)$$

frequence

$$f(t) = dR(t) /dt = \beta / \eta (t/\eta)]^{\beta\text{-}1} exp[-(t/\eta)]^{\beta} \qquad (12)$$

idensity of failures

$$\lambda(t) = f(t) /R(t) = \beta / \eta (t/\eta)]^{\beta\text{-}1\lambda} \qquad (13)$$

The mean time to failures, on the basis of distribution function parameters, via Γ *(gamma)* functions is

$$T_m = \eta\, \Gamma (1/\beta + 1) \qquad (14)$$

Hipotesis testig can be performed by confidence interval borders using d_{α}- test of Kolmogorov-Smirnov, dependent of size sample N and adopted value of risk α [8]. For unreprezentative samples (N < determines the formα50) the size of the critical value d unreprezentative is

$$N \leq 50 \;\Rightarrow\; d_{\alpha} = 1,388\ \alpha^{-0,120}\ N^{-0,464} \qquad (15)$$

and

$$N > 50 \Rightarrow\; d_{\alpha} = 1,654\ \alpha^{-0,138}\ N^{-0,5} \qquad (16)$$

2. EXAMPLES

In continue, by examles, data processing, for all three variantes, dependent of sample size, wil be presented.

2.1 Unrepresentative samples N $\leq$ 50

2.1.1 Unrepresentative samples 5 $\leq N \leq$ 10

In ths cases for all values of T_{im}, to failures, medial ranks must determine i.e for all failures $j = 1, ...N,$ from tables or calcule:by term

$$MR = (j\text{-- } 0,3)/(N + 0,4) \qquad (3)$$

Critical value for testing is

$$d_{\alpha} = 1,388\ \alpha^{-0,120}\ N^{-0,464} \qquad (15)$$

Example 1.

The investigation of the cutting-tool reliability was caried out for a flexible production line which was containin circular sawing machineg (Forte), machine for face alignment an drill in (Duap, ZS 30n AK), copyng lathe No 1 (Dubied, 517S-rd/500), and copyng lathe No 2 (Dubied, 517S-rd/500). Interconection of the machine tools was by flexible transporting system. The lathe No 1 as saplied with one tool and it was used to process one side of the work piece in one pass. The lathe No. 2 was saplied with two tools, and the other side of the work piece was processesd with two tools in two passes after its rotation for 180^0. The investigation cutting-tool reliability was caried out on the both of lathes, but as the spase is limited, only the results obtained for the lathe No 1 The work piece were steel Č.4171 stepped shafts of basic dimenssions Ø 28 x 317 mm.The cutting-tool as cutter with mechanical clamped carbide *KNUX* 160405 (cutting edge angle $\kappa = 55^0$, and corner radius r = 2,0 mm). Cutting condition: cutting speed $v = 3,48\ m/s\ (n = 2360\ min^{-1})$ and feed $s = 0,3$ *mm* (depth of cut variable, $\delta_{max} = 2,2\ mm$).

The times to failures t_i and tham correspondig medial ranks *MR* in *Table T.2,* are clasified.

t_{im}	11,83	12,09	13,51	14,19	14,67	1,49
MR	10,9	26,4	42,1	7,9	73,6	89,1

Table T.2

For graphoanalitical data processing, on the basis data from *Table T.2* . the table *T.3.* is filed.

i	T_i	x_i	$F(t)$	$1 - (Ft)$	$1/1\text{-}F(t)$	y_i	x_i^2	x_i^2
1	11,88	2,475	0,109	0,891	1,122	-2,159	6,126	- 5,344
2	12,09	2,492	0,264	0,736	1,358	-1,182	6,210	-2,945
3	13,51	2,603	0,421	0,579	1,727	-0,604	6,776	-1,573
4	14,19	2,653	0,579	0,421	2,375	-0,145	7,038	-0,384
5	14,67	2,686	0,264	0.264	3,788	0,287	7,215	0,770
6	15,49	2,740	0,891	0.109	9,174	0,796	7,508	2,181
Σ		15,649					40,872	7,297
$B_2 = N$		$A_2 = B_1$				C_2	A_1	C_1

Table T.3

Output dates from *Table T.3*, for Weibull's funkction parameters

$$\beta = 9,6081043$$

and

$$\eta = 14,291413$$

Varijances of x and y values are

$$\sigma_x^2 = 0,0096281$$

$$\sigma_y^2 = 0,9406216$$

men values of x and y

x□ $= 2,6074974$

$$\bar{y} = -0,5011731$$

and standard deviations are

$$(St.Dev)_x = 0,1074880$$

$$(St.Dev)_y = 1,624245$$

Correlation coefficient is

$$r = 0,9720741$$

Crtical value for determination confidence interval must be determined from equation (15) (for risk $\alpha = 5\%$ and $N = 6$) is

$$d_{\alpha} = 1,388\ 5^{-0,120}\ 6^{-0,464} = 0,492$$

Sutituting values for β i η in term (3) and terms from (11) till (14) for distribution function, reliability, frequence idensity and mean time to failure, we have

$$F(t) = 1 - exp\ [-(t/14,291413)^{9,6081043}]$$

$$R(t) = exp\ [-(t/14,291413)^{9,6081043}]$$

$$f(t) = (1/1,4765)(t/14,291413)\ exp\ [-(t/14,291413)^{9,6081043}]$$

$$\lambda\ (t) = (1/1,487433)\ (t/14,291413)^{8,6810413}$$

and meantime to failure

$$T_m = 14,291413\ \Gamma (1/9,6081043 + 1) = 15,8\ min.$$

In order to drawn the relationships (3) from (11) till (13) it is necesary to devide the time period Δt, in wich the failures are expected into time intervals δt. For adopted number of intervals *k,* for each value of time, which devide particular intervals, values by terms from (11) till (13), must be determined. The calculation, in *Table T.4* is provided. Values from the table are used for drawing diagrams.

i	ti (1)	ti/η (2)	R(ti) (3)	F(ti) (4)=1-(3)	λ(ti) (5)	f(ti) (6)=(3)(5)
1	6	0,41969	0,99978	0,00022	0,00036	0,00036
2	8	0,55958	0,99639	0,00361	0,00438	0,00436
3	10	0,69948	0,96909	0,03091	0,03041	0,02947
4	12	0,83937	0,93235	0,16765	0,14807	0,12325
5	14	0,98149	0,43409	0,56591	0,57587	0,24998
6	16	1,11916	0,05107	0,94893	1,80014	0,09193
7	18	1,25906	0,00009	0,99991	5,00581	0,00045
8	20	1,39895	0,00000	1,00000	12,49588	0,00000
9	22	1,53885	0,00000	1,00000	28,58826	0,00000
10	24	1,67874	0,00000	1,00000	1,67874	0,00000

Table T.4

2.1.2 Unrepesentative samples $11 \leq N \leq 50$

When we have unrepresentative samples $11 \leq N \leq 50$ all time of failures expected in order that $t_{im-1} < t_{im}$ and after that in intervals, by tham number of intervals are $5 \leq z \leq 8$, and after, for every interval, medial renks from table or calcule by term

$$MR = (z_i - 0,3)/(N + 0,4) \qquad (4')$$

where $j = z_i$ i $N = Z$.

Critical value can be determined by equation (14)

$$d_\alpha = 1,388\ \alpha^{-0,120}\ N^{-0,464} \qquad (15)$$

Example 2

Determining mean time of cutting tools failures by external Longitudinal turnig of Steel Č.7680. Cutting conditions: cutting speed $v = 1,5$ m/s $(n = 1400\ min^{-1})$, depth of cut $\delta_{max} = 1,5$ mm , feed $s = 0,2$ mm. The failures of 28 cutters was adventured after:

18,3 19,4 21,8 23,2 25,3 25,9 27,0 28,0 28,6 29,7 30,2 30,4 30,7 32,4 32,9 33,4 33,8 34,0 34,9 35,1 35,6 36,1 36,7 37,23 37,8 i 38,9.

Diapason in which we have failures Δt $(t_{max} - t_{min})$ need to be devided on equal intervals $\delta t = \Delta t / Z$ (where Z is number of intervals). In this exampe is $\Delta t = (t_{max} - t_{min}) = 18,0 \div 39$ min. $\Delta t = 21$, $Z = 7$, $\delta t = 21/7 = 3$ min.

For adopted nuber of interval $Z = 7$ next values of mean time to failures for particular intervals t_{im} and tham corresponding values of medial ranks MR, are given.

t_{im}	18,25	22,00	26,07	28,77	31,78	34,78	37,34
MR	0,094428	0,22849	0,36412	0,50000	0,63588	0,77151	0,90572.

Values in previous series represent input values for data processing as shown in *Example 1*.

Upper values are output values for data processing like in *example 1*.

So we have for

$$\beta = 4,2154556$$

and

$$\eta = 31,223406$$

Variance of x and y values amounts

$$\sigma_x^2 = 0,056660239$$

$$\sigma_y^2 = 1,0011664$$

mean values of x and y

$$\bar{x} = 3,3204673$$

$$\bar{y} = 0,5088083$$

and standard deviation

$$(St.Dev)_x = 0,26585$$

$$(St.Dev)_y = 1,08077532$$

Correlation coefficient

$$r = 0,9971905$$

Crtical value for determination confidence interval must be determined from equation (15) (for risk $\alpha = 5\%$ and $N = 28$) is

$$d_\alpha = 1,388\ 5^{-0,120} 28^{-0464,} = 0,244069$$

Sutituting values for β i η in term (3) and terms from (11) till (14) for distribution function, reliability, frequence, idensity and mean time to failure, we have

$$F(t) = 1 - exp\ [-(t/31,223106)^{4,215456}]$$

$$R(t) = exp\ [-(t/31,223106)^{9,6081043}]$$

$$f(t)=(1/7,4068165)(t/14,,291431)exp[-t/31,223106)^{4,214556}]$$

$$\lambda\ (t) = (1/7,4068165)\ (t/31,223106)^{3,213456}$$

$$T_m=3,223106\Gamma(1/4,2156+1)=3,223106.\ 0,90852=28,367\ min$$

Procedure farder is equal like in *Example 1*.

2.2 Representative samples N > 50.

Za For representative sample, is also, how is peresented in 2.12, all failures was clasified in intervals $(8 \leq z \leq 12)$, and after that equal procedure is used, but the critical value is determined by term

$$d_\alpha = 1,654\ \alpha^{-0,138}\ N^{-0,5} \qquad (16)$$

Example 3

The cutting of the grooves of sealing piston rings by automatic flow line processing as investigated in order to determine the cutting-tool reliability. The material of piston is alloy AlSi12CuNiMg. Piston diameter Ø 62,2 mm, width of channel 4,0 and 2,0 mm, (tplerances of channels 0,015 mm, and cutting tools 0,013 till 0,015 mm. Set for cut in as previously set upped cutting-tool "block" with cemented carbide inserts K10 (rake angle $\gamma = 20^0$ and back angle $\alpha = 10^0$. Cutting condition: cutting speed $v = 3,58$ m/s $(n = 1100\ min^{-1})$, and feed $s = 0,06$ mm.

The failures of cutting tools was observed in douration of three and half monts. The failures was advantured after:

45,5 82,5 82,5 91,5 91,5 91,5 96,0 100,5 100,5 110,0 110,0 110 121,0 121,0 121,0 127,0 148,0 153,5 153,5 153,5 160,0 164,0 164,0 164,0 164,0 168,5 168,5 168,5 168,5 168,5 168,5 176,0 176,0 176,0 176,0 176,0 183,0 183,5 183,5 183,5 183,5 183,5 191,0 191,0 191,0 191,0 191,0 200,0 200,0 200,0 200, 205,5 205,5 210,0 210,0 219,0 225,0.

In this case Δt $(t_{max} - t_{min}) = 225 – 45 = 180$; $Z = 9$; $\delta t = 180 / 9 = 20$

For adopted nuber of interval $Z = 9$ next values of mean time to failures for particular intervals t_{im} and them corresponding values of medial ranks MR, are given.

t_{im}	45,50	82,50	95,25	115,50	127,00	158,28	175,98	195,00	217,50
MR	0,07412	0,17962	0,28862	0,39308	0,50000	0,60691	0,71376	0,82038	0,92587.

So we have for

$$\beta = 2,2274804$$

$$\eta = 154,62398$$

Variance of x and y values amounts

$$\sigma_x^2 = 0,2164252$$

$$\sigma_y^2 = 1,0894668$$

Mean values of x and

$$\bar{x} = 0,2164252$$

$$\bar{y} = 1,0894668$$

and standard deviation

$$(St.Dev)_x = 0,4931353$$

$$(St.Dev)_y = 1,1070908$$

Correlation coefficient

$$r = 0,9927978$$

Crtical value for determination confidence interval must be determined from equation (16) (for risk $\alpha = 5\%$ and $N = 57$) is

$$d_\alpha = 1,654\ 5^{-0,138}\ 57^{-0,5} = 0,274$$

Substituting values for β i η in term (3) and terms from (11) till (14) for distribution function, reliability, frequence idensity and mean time to failure, we have

$$F(t) = 1 - exp\ [-(t/154,63298)^{2,2274804}]$$

$$R(t) = exp\ [-(t/154,63298)^{2,2274804}]$$

$$f(t)=(1/7,4068165)(t/154,63298)exp[(t/154,63298)^{2.2274804}]$$

$$\lambda\ (t) = (1/7,4068165)\ (t/154,63298)^{1,2274804}$$

and mean time to failure

$$T_m=154,62358\Gamma(1/2,2274804+1)=154,62358.0,88565=136,943\ min$$

Procedure further is equal like in *Example 1*.

3. CONCLUSION

On the basis of the following conclusion could be drawn:

- Proposed racional, uniform, methodology, based on medial ranks, for whichever sample size, using by tham medial ranks smaller than $N = Z = 15$, can be applicated

4. REFERENCES

[1] Stanivuković, D., Ivanović, G., Efektivnost tehničkih sistema – Zbirka zadataka -, Fakultet tehničkih nauka, Novi Sad, 1978., 261 (in Serbian)

[2] Sekulić, S., Određivanje pouzdanosti reznog alata u radioničkim uslovima, Zbornik radova Prvog naučnog skupa EFTES '75, Novi Sad, 1975. (in Serbian)

[3] Sekulić, S., Statistical Formulation of a Cutting Tool Reliability in a Working Conditions, Reports of the 21st Conference of the European Organization for Quality Control - EOQC, Varna, 1977.

[4] Sekulić, S., Određivanje pouzdanosti reznog alata u radioničkim uslovima, Održavanje mašina i opreme - OMO, Beograd, 1975, IV, 6. (in Serbian).

[5] Sekulić, S., Methodologies for Determination of Cutting-tool Reliability, Drugie miedzynarodowe sympozium NARŽEDZIA 84, Krakow - Janovice – Tarno, Poland, 1984.

[6] Sekuić, S., Determination of Cutting-tool Reliability on Flexible Automatic Flow Lines, Toward the Factory of the Future, Proceedings of the 8th International Cohference on Production Research ICPR 85, Stutgard, 1985, Springer-Verlag, Berlin-Heidelberg-New York-Tokio, 1985.

[7] Sekulić, S., Grafical Procedure for Prognosis of the Cuutig-tool Reliability on Flexible Automatc Lines, Proccedings of International Conference INTERTECHNO 90, Budapest, Hungary, 1990.

[8] Sekulić, S., Estimation of the Cutting Tools Based on Probability Approach, University Days, Proceedings of International Scientific Conference, TG-JIU, Romania, 2002.

[9] Sekulić, S., Approach Complex Evaluation of the Cutting Tools Based on Probability, Proceedings of International Conference on Manufacturing Engineering - ICMEN, Kasandra, Halkidiki, Greece, 2002, pp 215-223.

[10] Sekulić, S., Metodologije za određivanje pouzdanosti reznog alata, Zbornik radova Fakulteta tehničkih nauka Univerziteta u Novom Sadu, br. 14, 1983, Novi Sad (in Serbian).

[11] Sekulić, S., Grafoanalitički i grafički postupak obrade podataka pri određivanju pouzdanosti alata, Zbornik radova Fakulteta tehničkih nauka Univerziteta u Novom Sadu, br. 16, 1984, Novi Sad (in Serbian).

[12] Sekulić, S., Grafički postupak za određivanje pouzdanosti reznog alata zasnovan na broju obradaka obrađenih pojedinim alatima, Zbornik radova XIX Savetovanja proizvodnog mašinstva Jugoslavije, Sept., 1985, Kragujevac, 1985. (in Serbian).

[13] S., Sekulić, Određivanje pouzdanosti reznog alata na fleksibilnim proizvodnim sistemima, Zbornik radova VIII Seminara BIAM '86, Zagreb, jun, 1986, Zagreb, 1986. (in Serbian)

[14] Sekulić, S., Bogičević, S. Metodologije za određivanje pouzdanosti reznog alata podržane računarom, tribologija u Industriji, god. XVII, br. 3, 1995, pp 86-91. (in Serbian).

[15] Sekulić, S., Regresione jednačine d_α-testa Kolmogorov-Smirnova, Zbornik radova Sedme jugoslovenske konferencije o tribologiji sa međunarodnim učešćem - YUTRIB '01, okt., 2001, Beograd, Jugoslovensko društvo za Tribologiju, 2001. pp 3-5 - 3-8. (in Serbian)

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GENERAL EFFECT OF TOTAL DATA POINTS NUMBER ON MATERIAL RATIO CHANGE OF THE ROUGHNESS PROFILE

Abstract: *The study presents results gained from analysis of the effect of total data points change upon material ratio change of the roughness profile for constant evaluation length. Etalons were analyzed, representatives of the deterministic (turned) and stochastic (grinded) surface. Measurements were made by means of a stylus instrument Surtronic 3+, while as the analysis was performed by means of a professional software TalyProfile. The change of the amount of sampling spacing was provided by the program Microsoft Office Excel. Research was performed with sampling spacing in amount of 0,5; 1,0; 1,5; 2.0; 2.5 and 3.0 μm. The change of material ratio curve shape and material ratio for both deterministic and stochastic surface on depth 0,25Rt, 0,5Rt and 0,75Rt are analyzed.*
Key words: *Roughness profile, material ratio of the roughness profile, sampling spacing, contact (stylus) profilometer*

1. INTRODUCTION

Desired characteristics of mechanical parts' surface topography are more often stated as criteria for production quality evaluation. Large amount of functional characteristics that parts have to meet in exploitation depend precisely upon surface topography condition. Table 1 presents the dependence between functional characteristics and parameters that describe surface topography [1,2]. It is pointed out then that values of amplitude and functional parameters are decisive for correct part function.

Material ratio of the roughness profile [3,4,5], Figure 1, falls within functional parameters i.e. curve parameters [3]. Against ASME B46.1-2002 the material ratio is denote as t_p (denote also used in ISO 4287-1984 to 1997) and as Rmr(c) according to ISO 4287-1997. The value change of Rmr(c) is reviewed initiating from highest point of roughness profile peak above mean line till lowest point of roughness profile valley below mean line within sampling length, Figure 1, and is basis for surface bearing analysis.

Surface bearing is introduced as a term by Abbott and represents the size of overlapping of subject surface with nominal surface upon which certain force acts, when also the surface unleveled deviations are taken into account [6]. Change of Rmr(c) value against roughness profile depth within frames of Rt value is defined the material ratio curve of the roughness profile or Abbott-Firestone curve, Figure 1. Material ratio curve shape of the roughness profile can be proportional, digressive, progressive and combined as digressive-progressive and progressive-digressive.

Prompted by the high significance of roughness parameter values in parts function, as well as large differences gained in roughness parameter measurement processes [7], often researchers try to analyze and determine the effects of measurement conditions upon precision of roughness profile measured values. Results of such researches are presented in [8,9,10,11,12,13,14,15] and refer to analysis on sampling spacing change, stylus geometry, filtering, evaluation length, mean line determination mode, etc. Most expanded is the interest in research of the effect of sampling spacing change upon roughness parameters. Therefore, in [8] is determined the effect of sampling spacing change upon peak, direct measurable and average parameter values. In [9] is determined how sampling spacing change effect of value of average slope of modeleded random profile.

Function	PARAMETERS				
	Amplitude	*Distribution*	*Spacing*	*Hybrid*	*Functional(Rk)*
Bearings	↑	↑	↖	↖	↑
Seals	↑	↑	↖	↑	↑
Friction	↑	↑	↑	↑	↑
Slideways	↑	↑	↑	↖	↑
Wear	↑	↑	↑	↑	↑
Fitigue	↑	↖		←	↑
Stress and fracture	↑	←	↖		↑

Key: ↑-much evidence ↖-some evidence
← little or circumstantial evidence

Table 1.

It is clear that for unchanged evaluation length or surface, sampling spacing against x- or z-axis and total number of data points, which profile is described with, surface roughness in 2 and 3D are in direct mutual dependence. Namely, larger sampling spacing means smaller number of data points and vice-versa.

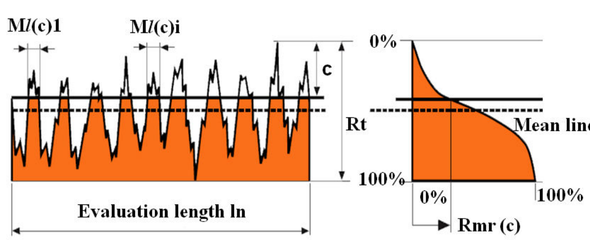

Figure 1. Material ratio curve of the roughness profile [4].

Measurement of machine parts surface topography, especially in 3D, includes several thousands of points [1, 2]. All these points pass through sampling process, transfer, A/D conversion, statistical processing and graphical presentation. Even though a very powerful digital technique is used nowadays for measurements, still particular time [16] is needed. If this is supplemented by the need of repeating measurements several times all with the purpose of gaining satisfactory statistical comparison of results, then the factor time is certainly worth paying more attention to.

Prompted by such fact, authors of this study decided to analyze the general influence of data points change upon material ratio change of the roughness profile for constant evaluation length and on several levels of vertical profile sections. Additional motive for such research was the large dependence of functional characteristics from material ratio curve (which determines the Rk parameters), which can be evidenced in Table 1, and the absence of dependence in international standards (ISO) between the measuring conditions and the Rk parameters.

Particularly vital is to review the intensity of coefficient change and material ratio curve for various profiles with various number of data points for deterministic and stochastic surface. Presented results were gained as a result of researches performed within frames of the international project [15], while as are also basis for defining scientific thesis in applied doctor's dissertation [14]. Based on the analysis of till today published studies in this field, as well as based on experiences gained, it can be concluded that sampling spacing change directly affects values of peak parameters and shape of roughness profile, which directly determines the coefficient and shape of material ratio curve. Precisely this conclusion for existence of a double dependence does not allow free theoretical interpretations of the behaviour of material ratio size and material ratio curve shape for various sampling spacing.

2. MEASUREMENT CONDITIONS AND MEASURING EQUIPMENT

Researches of such type require utilization of computer equipment for roughness measurements that provides access to measured profile coordinates. For the purpose, coordinates of original roughness profiles were gained by means of software TapyProfile connected to contact profilometer Surtronic 3+, with which measurements were taken, Figure 2. Various etalon surfaces were used in the research, representatives of deterministic surface (machined by turning, Figure 3, with nominal Ra = 0,2 µm) and stochastic surface (machined by grinding, Figure 4, with nominal R=0,2 µm). Measurements are in compliance with recommendations prescribed in ISO 3274-1996 and ISO 4288-1996. Measuring equipment verification was performed by means of calibration, applying etalon of type C with value for Ra of 6 µm in compliance with [17,18]. Vertical resolution of unit roughness measurement is 10 µm, while as horizontal resolution amounts 0,5 or 1 µm for evaluation lengths smaller or equal to or larger than 8 µm, appropriately. Pick-up: TYPE 112-2672 (DCN 001) with stylus radius of 2 µm and skid radius of 8.7 mm move with speed of 1 mm/s against measured surface. In the research also a stylus with radius of 5 µm is used for measured etalons with Ra = 0,2 µm, which is not in conformance with ISO 3274-1996 and 4288-1996.

Figure 2. Computer equipment for roughness measurements

A deliberate omission is in question for the purpose of defining also the affect of the mechanical filtering of roughness profile caused by stylus radius in terms of defining this affect upon further research process with sampling spacing change.

Evaluation length (ln) contains five sampling lengths (lr) with size of 0.8 mm.

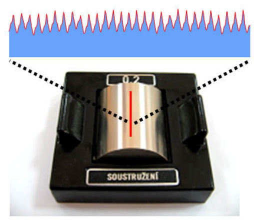

Figure 3. Deterministic etalon surface (machined by turning)

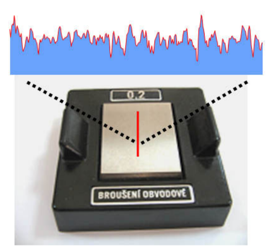

Figure 4. Stochastic etalon surface (machined by grinding)

3. EXPERIMENTAL RESEARCH

Applied professional software TalyProfile has ability to record measured (original) profiles in TXT-Ascii Profiless format, thereby providing opportunity for undertaking coordinates against x- and z-axis and there further processing.

Data points number change is provided by change of sampling spacing for constant evaluation length. So, original profiles with deterministic and incidental character were gained with sampling spacing of 0,5 µm and contain 8000 points with evaluation length of 3,9995 mm. Profiles with sampling spacing of 1 µm contain 4000 with evaluation length of 3,9995 mm.2667 points are contained in profiles with sampling spacing 1,5 µm at length of 3,999. At length of 3,998 mm match 2000 data points for sampling spacing of 2 µm. Profiles with sampling spacing of 2,5 µm contains 1600 points at length of 3,9975 mm an on length of 3,999 mm for sampling spacing of 3 µm match 1334 data points. Various size of sampling spacing for one same recorded profile was gained by using program Microsoft Office Excel since applied measuring equipment did not allow sampling spacing change thereby also data points number change.

By omission of one, two, three, four or five points on original profile the change of total number of data points is simulated, however always initiating from one same starting point. In that way, roughness profiles with sampling spacing of 1,0; 1,5; 2,0; 2,5 and 3,0 µm are gained. However, profile evaluation length suffers insignificant change due to the omission of points from original profile, which always initiates from same starting point. Largest deviation on evaluation length of 2 µm is noticed on profiles with sampling spacing of 2,5 µm.

The purpose of data points number change is to provide analysis of the influence of number of data points that define roughness profile upon the change of material ratio. Investigation include diferent section level of roughness profile, namely 0,25Rt; 0,5Rt and 0,75Rt. Also analysis was performed on the change of shape of material ratio curve by calculation of Rk parameters. Rk parameters are standardized in ISO 13565-2:1996 and presented on Figure 5. Each change of material ratio curve shape directly influences values of parameters: Rk, Rpk, Rvk, MR1, MR2, A1 and A2.

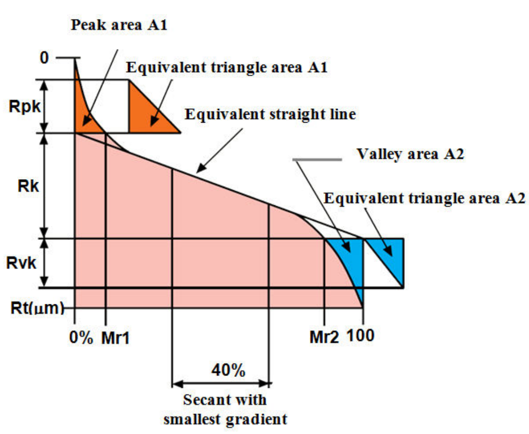

Figure 5. Rk parameters [4]

4. PRESENTATION AND ANALYSIS OF RESULTS GAINED

Values of material ratio of the roughness profile on section (depth) level of 0,25Rt, 0,5 Rt and 0,75Rt, as well as the percentage differences gained for profiles with various data points, for deterministic and stochastic surface and for original profiles measured with stylus radius of 2 and 5 µm, are presented in table 2, 3, 4 and 5. The minus prior ratio difference determines that gained values are smaller than values of original profile.

Rk parameter values for different profiles with mutual ratio differences are systematized in tables 6, 7, 8 and 9, with following units of measurement Rk (µm), Rpk (µm), Rvk (µm), MR1 (%), MR2 (%), A1 (μm^2 /mm) and A2 (μm^2 /mm).

Values gained for material ratio of profiles with various number of data points for section level of 0,25Rt, 0,5Rt and 0,75Rt confirmed the assumptions that coefficient change, even theoretically, is hard to be foreseen in sense of determining the change trend. Results in table 2 show material ratio coefficient change by change of number of data points and this change is reduced by depth increase of analyzed cross-section. It can be maybe herein concluded that some dependence exists between material ratio and number of data points for all levels of analyzed depth, which theoretical explanations exist for, which indicate that by omission of profile data points possible reduction of most protruded peak occurs, thereof moving of depth level towards the mean line, but also that by omission of data points from roughness irregularity slopes are reduced and cross-section surface increases i.e. surface material ratio.

Section level	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
0.25 Rt (%)	6,2	6,26	6,96	6,96	9,1	9,82
0.5 Rt (%)	29,1	29,3	31,2	32,4	37,1	38,6
0.75 Rt (%)	79,3	79,2	81,2	81,9	84,9	85,3
Difference (%)						
0.25 Rt		0,97	12,26	12,26	46,77	58,39
0.5 Rt		0,69	7,22	11,34	27,49	32,65
0.75 Rt		-0,13	2,40	3,28	7,06	7,57

Table 2. Material ratio of turned etalon surface for various number of data points, measured with stylus of 2 µm.

Section level	Number of profile data points					
	8000	4000	2667	2000	1600	1334
0.25 Rt (%)	12,7	12,9	12,8	12,8	12,2	12,3
0.5 Rt (%)	31,1	31,6	31,6	32,3	32	33,4
0.75 Rt (%)	80	79,8	79,5	79	76,9	76,4
Difference (%)						
0.25 Rt		1,57	0,79	0,79	-3,94	-3,15
0.5 Rt		1,61	1,61	3,86	2,89	7,40
0.75 Rt		-0,25	-0,63	-1,25	-3,87	-4,50

Table 3. Material ratio of turned etalon surface for various numbers of data points, measured with stylus of 5 µm

Section level	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
0.25 Rt (%)	57,2	56,7	54,3	51	50,4	52,6
0.5 Rt (%)	98,8	98,8	98,7	98,3	98,2	98,7
0.75 Rt (%)	99,7	99,7	99,7	99,7	99,7	99,6
Difference (%)						
0.25 Rt		-0,87	-5,07	-10,84	-11,89	-8,04
0.5 Rt		0,00	-0,10	-0,51	-0,61	-0,10
0.75 Rt		0,00	0,00	0,00	0,00	-0,10

Table 4. Material ratio of grinded etalon surface for various numbers of data points, measured with stylus of 2 µm.

Use of inappropriate stylus significantly increased the material ratio at section level of 0,25 Rt, which indicates possibility of mechanical filtration and peak shortening, table 3. Possible mechanical filtration of stylus provided gaining results contrary to previously stated ones in Table 2.

Section level	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
0.25 Rt (%)	6,49	6,99	6,94	9,22	9,9	11,5
0.5 Rt (%)	60,4	62	61,5	65,4	66,7	68,2
0.75 Rt (%)	97,1	97,4	97,1	97,8	97,8	97,7
Difference (%)						
0.25 Rt		7,70	6,93	42,06	52,54	77,20
0.5 Rt		2,65	1,82	8,28	10,43	12,91
0.75 Rt		0,31	0,00	0,72	0,72	0,62

Table 5. Material ratio of grinded etalon surface for various numbers of data points, measured with stylus of 5 µm.

Param- eters	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
Rk	0,673	0,675	0,669	0,665	0,674	0,666
Rpk	0,319	0,306	0,308	0,295	0,274	0,257
Rvk	0,138	0,129	0,131	0,121	0,131	0,121
MR1	14,8	14,9	14,8	15,4	14,1	14,4
MR2	92,3	91,9	92	92,9	93,8	93,8
A1	23,6	22,8	22,8	22,7	19,3	18,5
A2	5,32	5,22	5,25	4,28	4,09	3,78
Difference (%)						
Rk		0,30	-0,59	-1,19	0,15	-1,04
Rpk		-4,08	-3,45	-7,52	-14,11	-19,44
Rvk		-6,52	-5,07	-12,32	-5,07	-12,32
MR1		0,68	0,00	4,05	-4,73	-2,70
MR2		-0,43	-0,33	0,65	1,63	1,63
A1		-3,39	-3,39	-3,81	-18,22	-21,61
A2		-1,88	-1,32	-19,55	-23,12	-28,95

Table 6. Rk parameters of turned etalon surface with various number of data points, measures with stylus of 2 µm.

Stochastic roughness profile has larger number of unit peaks and valley on unit length in comparison with deterministic one.

This fact leads us to an assumption that change of material ratio shall not vary much by change of number of data points, which theoretically would be explainable by matching the nature of change of material ratio coefficient with the change of data point number by accidental distribution of roughness profile ordinates. This assumption was confirmed in Table 4. At section level of 0,5 Rt and 0,75 Rt there isn't even any difference in the material ratio for various profiles. Stylus of 5 µm has fully changed the shape of stochastic roughness profile, thereof also of the material ratio gained, which can be evidenced in Table 5.

Material ratio curve shape for all reviewed profiles does not suffer any significant change by the change of data point number. Confirmation of this conclusion are the values of Rk parameters, particularly the Rk parameter. Its maximum change does not overcome more than 8% of all reviewed profiles, which gives us the right to conclude that central part of material ratio curve, which is defined with Rk (Figure 4) does not suffer changes in shape.

Param- eters	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
Rk	0,545	0,549	0,553	0,559	0,572	0,585
Rpk	0,378	0,369	0,354	0,335	0,296	0,271
Rvk	0,108	0,107	0,113	0,101	0,0992	0,0855
MR1	18,6	18,6	17,9	18,6	18	18,4
MR2	87,5	87,9	87,8	90,5	91,3	93,8
A1	35,1	34,3	31,7	31,2	26,6	25
A2	6,75	6,46	6,93	4,8	4,32	2,66
Difference (%)						
Rk		0,73	1,47	2,57	4,95	7,34
Rpk		-2,38	-6,35	-11,38	-21,69	-28,31
Rvk		-0,93	4,63	-6,48	-8,15	-20,83
MR1		0,00	-3,76	0,00	-3,23	-1,08
MR2		0,46	0,34	3,43	4,34	7,20
A1		-2,28	-9,69	-11,11	-24,22	-28,77
A2		-4,30	2,67	-28,89	-36,00	-60,59

Table 7. Rk parameters of turned etalon surface with various number of data points, measures with stylus of 5 µm.

Param- eters	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
Rk	0,649	0,645	0,647	0,638	0,625	0,608
Rpk	0,167	0,167	0,167	0,163	0,158	0,162
Rvk	0,39	0,386	0,386	0,37	0,352	0,36
MR1	7,16	7,07	7	7,53	7,54	7,19
MR2	89,7	89,6	89,8	90,2	89,4	89,3
A1	5,97	5,9	5,85	6,13	5,94	5,82
A2	20,1	20,1	19,6	18,1	18,6	19,3
Difference (%)						
Rk		-0,62	-0,31	-1,69	-3,70	-6,32
Rpk		0,00	0,00	-2,40	-5,39	-2,99
Rvk		-1,03	-1,03	-5,13	-9,74	-7,69
MR1		-1,26	-2,23	5,17	5,31	0,42
MR2		-0,11	0,11	0,56	-0,33	-0,45
A1		-1,17	-2,01	2,68	-0,50	-2,51
A2		0,00	-2,49	-9,95	-7,46	-3,98

Table 8. Rk parameters of grinded etalon surface with various number of data points, measures with stylus of 2 µm.

Param-eters	Namber of profile data points					
	8000	4000	2667	2000	1600	1334
Rk	0,681	0,674	0,669	0,661	0,647	0,642
Rpk	0,211	0,213	0,203	0,21	0,208	0,201
Rvk	0,308	0,306	0,299	0,291	0,278	0,278
MR1	9,35	9,69	9,59	9,59	9,78	9,91
MR2	89,9	89,9	89,4	89,7	89,2	89,7
A1	9,85	10,3	9,75	10,1	10,2	9,95
A2	15,7	15,56	15,9	14,9	15	14,3
Difference (%)						
Rk		-1,03	-1,76	-2,94	-4,99	-5,73
Rpk		0,95	-3,79	-0,47	-1,42	-4,74
Rvk		-0,65	-2,92	-5,52	-9,74	-9,74
MR1		3,64	2,57	2,57	4,60	5,99
MR2		0,00	-0,56	-0,22	-0,78	-0,22
A1		4,57	-1,02	2,54	3,55	1,02
A2		-0,89	1,27	-5,10	-4,46	-8,92

Table 9. Rk parameters of grinded etalon surface with various number of data points, measures with stylus of 5 µm.

Larger percentage changes were noticed on Rpk and A1 parameters, which refer to material ratio curve start, and Rvk and A2 parameters, which refer to material ratio curve end, where the change by omission of data points is most expressed.

5. CONCLUSION

Assumptions of authors that difficulties exist, even theoretically, for determining the material ratio change trend for known level of reviewing, which is in direct dependence by another parameter, were practically confirmed. Thereof, following can be concluded:

- Data point number change has some influence upon material ratio value when its is reviewed for level of cross-sections of 0,25Rt, 0,5Rt and 0,75Rt. Unfortunately a general conclusion can not be reached from this research concerning change trend for deterministic or incidental surface. Change trend determination is made impossible by dependence of material ratio on parameter Rt, which would mean that each change of Rt influences the material ratio, and the profile shape change with the data point number change.

- Maybe researches are necessary where material ratio change for known level for reviewing shall be analyzed along with the change of the parameters it dependents upon.

- Rk parameters indicate that significant change of material ratio curve shape by data point number change does not exist.

- From functional aspect, although material ratio indicated a change especially at a small level of cross-section, it can be concluded that data point number change does not have significant affect upon the ratio and the material ratio curve shape, since spring deviations and first friction processes occur in service on protruded surface peaks. In such circumstances significant is the change of the middle part of material ratio curve, which was here determined that is not under significant influence by the data point number

6. REFERENCES

[1]. K. J. Stout. *Thre-Dimensional Surface Topography; Measurements, Interpretation and Applications*. Center for Metrology the University of Birmingham, 1994.

[2]. K. J. Stout and L. Blunt. *Tree-Dimensional Surface Topography. Secont edition.* School of Engineering. University of Huddersfield, Penton Pres, London, 1994.

[3]. Taylor Hobson. *The Parameter Tree of Surface Roughness.* Centre of Excellence. 2000.

[4]. JIS B0601 Standard. *Explanation of Surface Characteristic*. Japan.

[5]. ISO4287:1997; Geometrical product specifications (GPS) - Surface texture: Profile method – *Terms, defenitions and surface texture parameters*

[6]. Mikolaj Kuzinovski, Dejan Pavlov, Piotr Cichosz, Henryk Zebrowski. *The influence of the wear of the cutting edge on the changes of the shape of the bearing curve of the machined surface by turning with ceramic cutting inserts.* Proceedings, Faculty of Mechanical Engineering, Skopje, Vol 13, No 1 (15) 1994, ISSN 0351 6067, pp 49-58.

[7]. Protocol of the discussion hold on the 8th June 1999 by the round table during the International Symposium "*Surface Engineering in Machining"*. Wroclaw – Szklarska Poreba, 7-9.06.1999. Poland.

[8].Tomov M., Kuzinovski M., Cichosz P.: *Effect of sampling spacing on surface roughness parameter values.* XXXII Conference on Production Engineering with foreign participants, Novi Sad, Serbia, 18-20.09. 2008.

[9]. Pawel Pawlus. *An Analysis of slope of surface topography.* Metrology and Measurement System 2005, 12 (3/2005); 299-314.

[10]. Pawel P. Pawlus. *Mechanical filtration of surface profiles.* Measurement 35 (2004); pp 325-341.

[11].Tomov M., Kuzinovski M., Cichosz P.: Effect *of evaluation length on results of surface roughness measurements*. XXXII Conference on Production Engineering with forign participants, Novi Sad, Serbia, 18-20.09. 2008.

[12]. Pawel Swornowski. *The influence of the mechanical filtration of the measuring-pin on the waviness and surface roughness.*Arhives of Mechanical Technology and Automation. Poznan 2006. ISSN 1233-9709, Vol. 26 nr 2. pp 129-137.

[13]. Pawel Pawlus. *TOPOGRAFIA POWIERZCHNI.* Pomiar, analiza, oddzialywanie. Oficyna Wydawnicza Poilitechniki Rzeszowskiej, Rzeszow 2005

[14]. Tomov Mite. *Contribution to methods and measurement techniques development for research of influential factors of surface topography identification*. Application for Ph.D. dissertation, Mechanical Engineering Faculty, Skopje, 2008.

[15]. Mikolaj Kuzinovski, Mite Tomov, Piotr Cichosz, Trajčevski Neven, ...: : *Study on possibilities and accuracy of surface layer geometrical structure determination by using contact profilometers.* Scientific-research project, finance by Ministry of Education and Science on Republic of Macedonia. Number: 13-977/3-05, 1.7.2006-30.6.2009.

[16]. D. J. Whitehouse. *Handbook of Surface Metrology*. Inst. of Physics, Bristol, 1994.

[17]. EAL-G20. *Calibration of Surface Instruments for Measuring Surface Roughness,* 1996.

[18]. ISO 12179: 2000; Geometrical product specifications (GPS) - Surface texture: Profile method - *Calibration of contact (stylus) instruments.*

[19]. ISO 3274:1996; Geometrical Product Specifications (GPS) - Surface texture: Profile method - *Nominal characteristics of contact stylus instruments.*

[20]. ISO 4288:1996; Geometrical product specifications (GPS) - Surface texture: Profile method - *Rules and procedures for the assessment of surface texture.*

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INVESTIGATION OF TEMPERATURE DURING MACHINING PROCESS BY HIGH SPEED TURNING

Abstract: *This paper presents the results and obtained mathematical models of temperature during machining process by high speed turning as a function of processing parameters* v, f, a *and* r_e. *The machining process by turning is performed on lathe type "Prvomajska TVP 250" with power P=11,2 kW and step change of number of revolutions between n=16 and 2240 rev/min, by using ceramic cutting tool inserts type SNGN 120712- 120716-120720 made from mixed ceramics type MC 2 (Al_2O_3 + TiC) and manufactured by HERTEL and tool holder type IK.KSZNR -064 25x25 manufactured by KENNAMETAL. Workpiece material is **C** 1630 (DIN C 55). Cutting tool holder is reconstructed to provide transimission of the voltage signal from the cutting tool insert. Processing parameters are varied in range interval between* v *=300 and 500 m/min,* f *=0,16-0,30 mm/rev,* a*=0,5-1,0 mm and* r_e*=1,2-2,0 mm. Average temperature is determined by using of natural thermocouple method and computer aided research equipment. Experiments and the mathematical processing of the results are performed at the Faculty of Mechanical Engineering in Skopje using the program CADEX combined with MATLAB. Four factorial first order experimental plan was used.*
Key words: *Machining by turning, average cutting temperature, natural thermocouple, factorial experiments*

1. INTRODUCTION

It is known that during the transformation of workpiece machined layer into chips, because of energy transformations in the cutting zone it is released significant quantities of heat. Created heat in the cutting process is directly dependent on the applied processing parameters *(v, f, a, ...)*, workpiece material condition and cutting tool stereometry $(\chi, \lambda, \gamma, r_\varepsilon, ...)$. The heat reflected through the maximum temperature is an important factor which has a dominant influence to: the mechanism of transformation of the workpiece machined layer into chip; on the phenomenon that occur in the process of cutting tool wear (abrasive, adhesive, diffusive, heat, oxidative); the magnitude of the cutting force components, which is in close correlation with thermal model of creation residual stresses; and thus to the creation of the resultant characteristics of the new constituted technological surface layer /TSL/ [1]. Therefore, in the machining process it is important accurately to know the magnitude of the temperature that occurs in the cutting zone as function of machining parameters. The temperature in the cutting process can be determined in an analytical and experimental way, which are developed many methods [2]. From the experimental methods, the most widespread is the method of natural thermocouple, where the natural thermocouple consists of the cutting tool and the workpiece. Methods of natural thermocouple are simple to implement, but require knowledge of the thermoelectric characteristics of the natural thermocouple, and its determination is only by experimental way [3]. The emergence of modern cutting materials, especially cutting ceramics, creates conditions for the application of significantly higher cutting speeds.

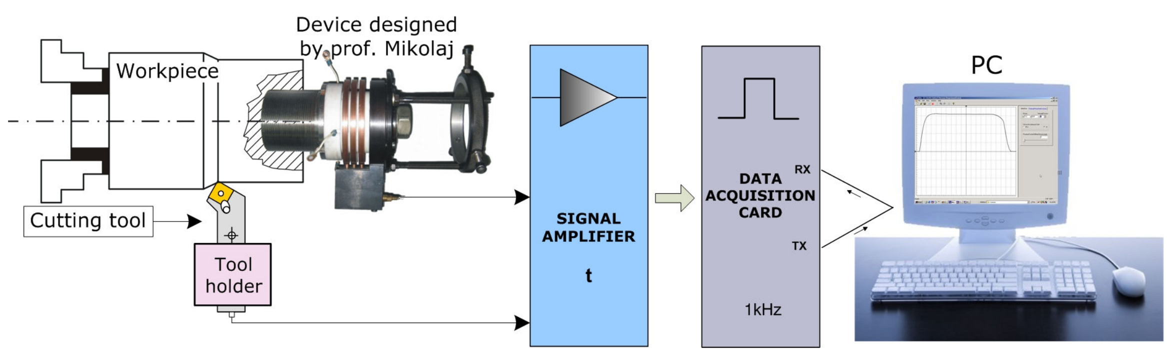

Fig. 1. Schematic view of the research experimental setup

The high temperatures and material removal dynamics in such conditions more intense influence on the mechanisms of chip creation and on the cutting tool wear, as well to technological effects in /TSL/. Increased stiffness is required from the system Machine - Device - Workpiece - cutting Tool (MDWT). The system for measuring the temperature is required: to reduce errors that occur in the transmission of the signal from the workpiece-cutting tool thermocouple; be able to record increased quantity of information in relatively short interval; application of computer technology for reliable determining of the temperature in the cutting process. The goal is to reduce the interval of measuring uncertainty of the results obtained from measurements performed. The creation of computer aided research equipment for measuring temperature in the cutting process is the result of joint research realized on the Faculty of Mechanical Engineering and the Faculty of Electrical Engineering in Skopje, in cooperation with the Institute of Production Engineering and Automation of the Wroclaw University of Technology, Poland. Using the research equipment, investigations of dependence of the temperature from the machining parameters *v, f, a* and r_ε are carried out.

2. EXPERIMENTAL CONDITIONS

2.1 Cutting tool

The processing is performed by use of ceramic cutting tool inserts type SNGN 120712- 120716- 120720 made from mixed ceramics MC 2 (Al_2O_3 + TiC) manufactured by HERTEL and cutting tool holder type IK.KSZNR -064 25x25 manufactured by KENNAMETAL. Cutting tool stereometry is:

.

$$\chi = 85°,\ \chi_1 = 5°,\ \gamma = -6°,\ \alpha = 6°,\ \lambda = -6°,$$

$$\gamma_f = -20°,\ b_f = 0{,}2\,\text{mm},\ r_\varepsilon = 1{,}2-1{,}6-2{,}0\,mm$$

Cutting tool holder was previously reconstructed to provide transmission of the voltage signal from the cutting tool insert, which is presented on Fig. 2.

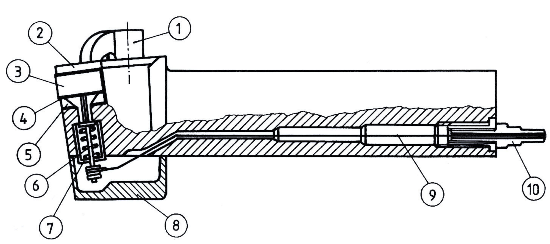

Fig. 2. Cutting tool holder cross-section, 1 - thumb, 2 - chip breaker made from Al_2O_3, 3 - cutting tool insert made from mixed ceramics MC 2, 4 - mica, 5 - washer, 6 - mechanism, 7 - isolation bushing, 8 - protective cap, 9 - signal conductor, 10 - connector.

To reduce the impact of disruption factors during transmission of the generated signal and thus to increase the accuracy of measurements, cutting tool insert is completely isolated in the nest of cutting tool holder, by using of mica. To obtain the required chip shape, a chip breaker made from zircon-oxide ceramics is used.

2.2 Workpiece

Material C 1630 (DIN C 55), normalized to the hardness of 200 HB.

2.3 Metal cutting machine

Lathe type "Prvomajska" TVP 250, with power P = 11,2 kW with step change in the numbers of revolutions between n=16 and 2240 rev/min.

2.4 Cutting parameters

Cutting speed v = 300-500 m/min, feed f=0,16-0,30 mm/rev, depth a=0,5-1,0 mm, cutting tool insert tip radius r_ε=1,2-1,6-2,0 mm.

2.5 Device for transmission of the signal from workpiece

For measuring the average temperature in the cutting process by using method of "natural thermocouple", for transmission of generated signal from the workpiece a specially designed device is constructed, Fig. 3. This device after screwing into workpiece, allows transmission of generated signal through three rotating rings and fixed brushes. Particular attention is paid to the choice of material for rings and brushes, which in this case is black-lead bronze. The thermocouple ring - brush when heated to 373,16 K (100 ° C) generate thermovoltage of 0,3 mV.

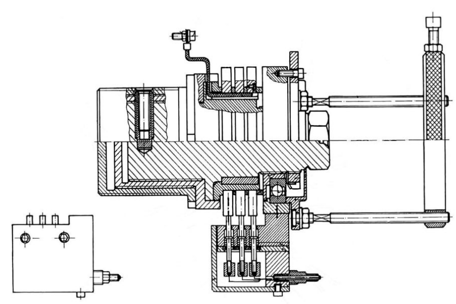

Fig. 3. Device for transmission of the signal from workpiece, cross-section [4]

2.6 Experimental plan

It is used first-order full four factorial plan of experiments (2^4 + 4), presented in Table 1. Power function is accepted for the mathematical model to describe the changes of the temperature. Mathematical processing is performed at the Faculty of Mechanical Engineering in Skopje with the application of program *CADEX* in connection with *Model-Based Calibration (MBC) Toolbox Version 1.1,* contained in the *Matlab* software package, which is intended for design of experiments and statistical modeling. Using the advanced features of *Matlab* and *MBC* provides significant advantages in the realization of experimental studies, with an option for graphic interpretation of results.

2.7 Research equipment

Monitoring of the thermovoltage (temperature) in the cutting process is done with computer aided research experimental setup, presented on Fig. 1 [5, 6]. Part of the research setup is specially designed PC interface that consist of signal amplifier and data acquisition card [7]. Measurements are done at the Faculty of Mechanical Engineering in Skopje. Graphical interpretation of monitored quantities by the software FORTMON is shown on Fig. 4.

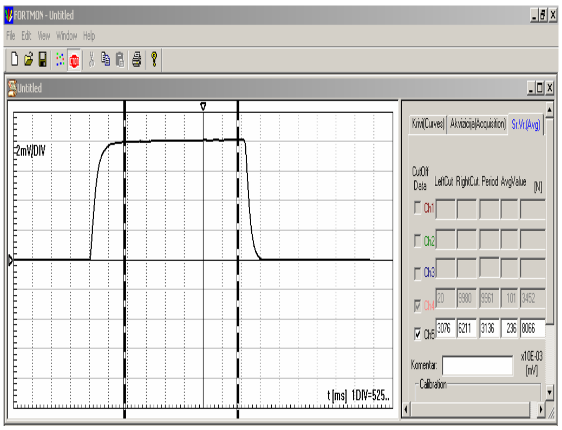

Fig. 4. Graphical interpretation of monitored quantities by the software FORTMON

Determining the average temperature by the method of natural thermocouple request to define of correlation between the thermovoltage measured by mV and the temperature expressed in °C. In this case, thermocouple is C 1630 - MC 2. For this purpose, a calibration installation is created. After regression analysis on the results obtained from the calibration measurements, the dependence between temperature T and thermovoltage u is obtained and represented as a polynomial of fourth degree [6]:

$$T = 104{,}426 - 42{,}646 \cdot u + 44{,}734 \cdot u^2 - 4{,}937 \cdot u^3 + 0{,}17 \cdot u^4 \cdots \quad (1)$$

By using of the equation (1) in the software of the research experimental installation, showed on Fig.1, it is enabled direct transformation of the measured thermovoltage into temperature.

3. RESEARCH RESULTS ANALYSIS

Changes of average cutting temperature T_C as function of machining parameters are investigated during researches. Power function was adopted for describing of these changes:

$$T_c = \mathrm{C}\, v^x f^y a^z r_\varepsilon^{\,q} \cdots\cdots\cdots\cdots\cdots \quad (2)$$

Experimental plan and results are presented in Table 1. Obtained results processing includes analysis of mathematical models with and without mutual effect, determination of 95% confidential interval for analyzed models, evaluation of significance of coded polynomial coefficients, determination of experimental error and determination of multiple regression coefficient. Performed analysis, after complete computer processing, showed adequacy of obtained mathematical model (3).

$$T_C = 444{,}662 \cdot v^{0{,}164} \cdot f^{0{,}138} \cdot a^{0{,}054} \cdot r_\varepsilon^{-0{,}088} \quad (3)$$

Obs No	Independent variables - Real matrix				Result
	v [m/min]	f [mm/rev]	a [mm]	r_ε [mm]	T_{Cav} [°C]
1	300,00	0,16	0,50	1,20	821,69
2	500,00	0,16	0,50	1,20	895,41
3	300,00	0,30	0,50	1,20	915,16
4	500,00	0,30	0,50	1,20	970,23
5	300,00	0,16	1,00	1,20	891,37
6	500,00	0,16	1,00	1,20	951,23
7	300,00	0,30	1,00	1,20	919,21
8	500,00	0,30	1,00	1,20	1043,63
9	300,00	0,16	0,50	2,00	819,56
10	500,00	0,16	0,50	2,00	845,19
11	300,00	0,30	0,50	2,00	879,32
12	500,00	0,30	0,50	2,00	961,36
13	300,00	0,16	1,00	2,00	819,57
14	500,00	0,16	1,00	2,00	887,23
15	300,00	0,30	1,00	2,00	873,42
16	500,00	0,30	1,00	2,00	998,38
17	387,30	0,22	0,71	1,55	909,53
18	387,30	0,22	0,71	1,55	917,18
19	387,30	0,22	0,71	1,55	903,37
20	387,30	0,22	0,71	1,55	901,28

Table 1. First order four factorial experimental plan

Some graphical interpretation of the influence of cutting speed - v, feed - f, cutting depth - a, and cutting tool insert tip radius - r_ε on the changes of average temperature T_C are shown on Fig. 5. It can be noticed that most significant effect on average temperature increase has cutting speed increase, then cutting feed, and, the least, cutting depth. Cutting tool insert tip radius increase results in temperature decrease. Average temperature increase as result of cutting speed increase is explained, mainly, by decreasing contact between chip and face surface of cutting tool insert, resulting with chip ramming decreases, chip sliding speed against face surface increases, heat discharge is worse and friction is increased. Heat created in cutting area is, mainly, a sum of heat of machined layer deformation, which decreases, due to cutting speed increase, till certain limit as well as of heat generated by chip friction against face surface of cutting tool, which increases by cutting speed increase, which is basic reason for average temperature increase. Average temperature increase due to feed increase is results of higher deformation, which alternatively causes higher heat quantity. However, feed increase also means increase of contact surface between chip and cutting tool, which results by conditions for improved heat discharge. Therefore, de facto, there is smaller effect of feed onto average temperature. Similar is cutting depth effect. Namely, this means that deformation work increases by cutting depth increase, thereby generating higher heat quantity, however also increasing contact surface between chip and cutting tool and improving heat discharge. In addition, cutting blade active length directly increases. This provides much better conditions for heat discharge thereby smaller temperature gradients. The cutting tool insert tip radius r_ε effect is much interesting. Average temperature decreases by r_ε increase. This is due, mostly, to increased active length of cutting blade, which provides much better heat discharge. Besides this, reduction of angle χ , as result of increase of r_ε , is, also, a reason for smaller cutting forces, smaller deformation work and thereby smaller heat quantity. It should also be stated that increase of measured average cutting temperature is result of temperature increase on rear side of cutting wedge due to increased friction of rear main surface and auxiliary rear surface with machined surface.

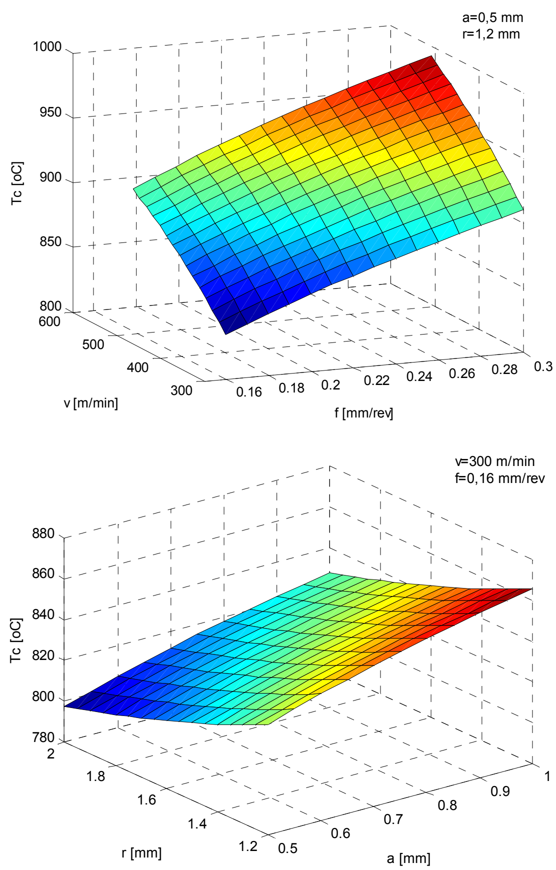

Fig. 5. Graphical interpretation of the influence of cutting speed - *v*, feed - *f*, cutting depth - *a*, and cutting tool insert tip radius - r_ε on the changes of average temperature T_C

4. CONCLUSIONS

Following remarks and conclusions can be reached from performed experimental researches, obtained mathematical models, as well as results analysis:

- Statistical analysis indicated that describing changes of average cutting temperature T_C as function of machining parameters *v, f, a* and cutting tool insert tip radius r_ε , by means of power function, is correct;

- All factors adopted in models are significant, and their effect is as follows:

- Average cutting temperature mostly depends upon cutting speed and feed, while from cutting depth, the least. The increase of these parameters causes average temperature increase, which reached highest value of 1043^{o}C in the investigated domain.

5. REFERENCES

[1] Pavlovski, V., Kuzinovski, M., Zebrovski, H., Cichosz, P.: *Experimental research of the physical phenomena in turning with ceramic cutting inserts*, Third International Conference on advanced manufacturing systems and technology, AMST '93, Udine, Italy, 1993.

[2] Milikić D.: *Temperature pri obradi rezanjem i mogućnosti njihovog tačnog određivanja*, XIV Savetovanje proizvodnog mašinstva Jugoslavije, p.p. 292-305, Čačak, 1980.

[3] Stanić, J.: *Metod inžinjeriskih merenja*, Mašinski fakultet, Beograd, 1990.

[4]. Kuzinovski M.: PATENT MKP B23Q 11/14, G01K 13/08, 900600, 30.09.2000.

[5] Trajčevski, N., Kuzinovski, M., Filiposki, V., Cichosz, P.: *Computer aided measurement of the temperature in the cutting process by machining with turning*, Proceedings of the Scientific Conference with International Participation "Manufacturing and menagement in 21-st century", p.p.129-134, Ohrid, Republic of Macedonia, September 16-17, 2004.

[6] Trajčevski, N.: *Monitoring system in experimental investigation in machining with turning*, Master thesis, Skopje, February 2008.

[7] Trajčevski, N., Filiposki, V., Kuzinovski, M.: *Personal computer interface for temperature measuring in the cutting process with turning*, Proceedings, Faculty of Mechanical Engineering - Skopje, Vol.23, No.2, p.p. 65-74, 2004.

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Deticek, E., Zuperl, U.

POSITION CONTROL OF HYDRAULIC DRIVES IN MACHINE TOOLS BY FUZZY SELF-LEARNING CONTROLLER

Abstract: *Fluid power actuators are characterized by their high-power density and excellent dynamic response. They are ideally suited to many high dynamic applications in modern machine tools. However, the disadvantages of hydraulic systems such as nonlinear dynamic behaviour due to friction, fluid compressibility need to be overcome. This is successfully obtainable only by implementation of modern digital control systems designed on the basis of modern control theory. The proposed new control strategy uses a combination of a fuzzy logic controller designed as a self-learning fuzzy system and conventional control approaches.*
Key words: *machine tools, fuzzy control, position, hydraulic drive.*

1. INTRODUCTION

In modern mechanical systems such as computer controlled machine tools, metal-forming machines, and injection moulding plastic machines, assembly and transport devices, material testing devices, etc., the demand of rapid speed operating movements to increase productivity comes to the foreground. To obtain this rapid movement, hydraulic drives controlled by resistance in impressed pressure network very often are used. Besides the excellent dynamics, the main advantage of such systems is the parallel use of multiple drives fed by one pressure net combined with energy recycling into the hydraulic accumulators. In particular, the hydraulic cylinders should be stressed at this point due to their ability of direct transformation of hydraulic energy into linear movements and forces. It is quite normal nowadays for cylinders to be equipped with electronically controlled proportional and servo-valves, as well as with position transducers and force sensors, creating together closed control loops. To fullfil another demand of the above mentioned machines, namely the accurate and precise position and force control, appropriate control strategies are needed. This paper presents a new hybrid-fuzzy control strategy for position control of electro-hydraulic linear drive. An adaptability is obtained by fuzzy logic controller designed as a self-learning system [1], while the reference tracking and position accuracy are improved by conventional control measures such as an inverse model fore-filter and switching integrator. The algorithm is experimentally investigated and implemented on the hydraulic device [2] for testing mechanical constructions-load simulator.

2. MATHEMATICAL DESCRIPTION OF ELECTRO-HYDRAULIC LINEAR DRIVE DYNAMICS

The electro-hydraulic linear drive under consideration is depicted in Figure 1. It consists of a double-road hydraulic cylinder with load mass and the electro-hydraulic servo-valve.

Without of detailed explanation of well known differential equations and by using linearization in particular operating point as well as Laplace

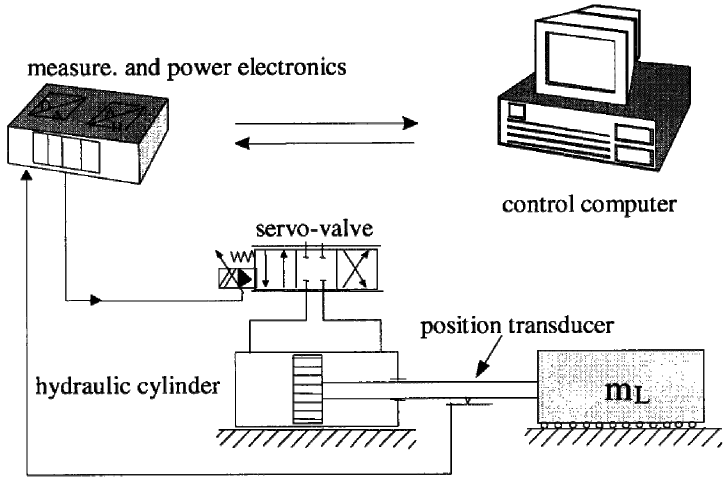

Fig. 1. Electro-hydraulic testing device of machine tool

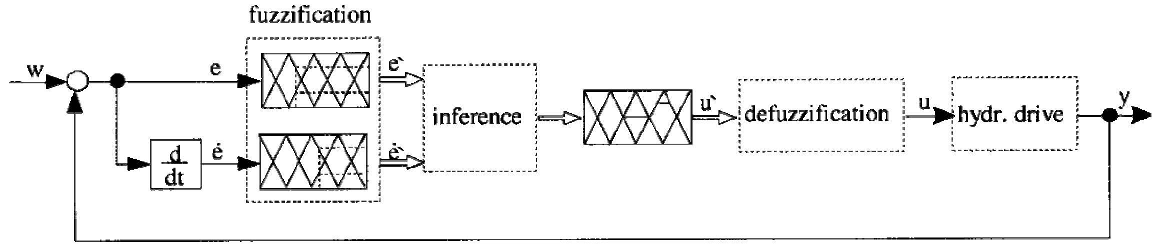

Fig. 2. Structure of fuzzy PD- controller

transformation the following transfer function can be obtained:

$$G(s) = \frac{Vs_{op}\omega^2{}_{op}}{s(s^2 + 2D_{op}\omega_{op}s + \omega^2_{op})} \qquad (1)$$

3. FUZZY PD-CONTROLLER FOR POSITION CONTROL OF ELECTRO-HYDRAULIC LINEAR DRIVE COMPONENT

The starting point for development of more intelligent fuzzy controller (self-learning system) was, in the first step, the design of a fuzzy controller similar to the conventional PD-type controller. However, the clear goal of designing a fuzzy controller for position control of electro-hydraulic linear drive was not only to make an equivalent of a known controller, but to design a controller to be able to cope with nonlinearities and parameter changes of the hydraulic system in order to achieve fast responses without overshooting and small steady state errors. However, the first step was in the direction of fuzzy realization of a PD-controller. Namely, coming out from engineering experience with classical controllers is for position control of hydraulic drives only P or PD-type appropriate. This is due to stability reasons. In addition, the differential part of the controller, if it is used, must be set very carefully to prevent noise sensibility. The fuzzy PD-controller in this case is a fuzzy system with two input variables and one output variable. These variables are the control error e, the error derivative e. , and the servo-valve input voltage u, respectively. The rules that connect the variables are collected together into the rule base. The fuzzy controller structure is shown in Figure 2. All three variables are treated as linguistic variables and described with 13 linguistic terms. These terms are denoted with abbreviations: NVB (-6) -negative very big, NB (-5) -negative big, NQB (-4) –negative quite big, NM (-3) -negative medium, NS (-2) -negative small, NVS (-1)-negative very small, ZO (0) zero, PVS (1) -positive very small, PS (2)-positive small, PM (3) -positive medium, PQB (4) -positive quite big, PB (5) -positive big, PVB (6) -positive very big. The integers in brackets are used for numerical computation. Each linguistic term is represented by the fuzzy set with triangular membership function. This means that the variables *e*, *_e*, and *u*, interpreted now as fuzzy variables, are described with 13 mutually overlapping fuzzy sets, which cover the whole real range of the variables. The ranges or universes of discourse are scaled into the interval [1, ¡1], using scaling factors *Ke K_e*, and *Ku*, respectively . As a defuzzifcation strategy the center of area has been used [1, 3]. The rules have been selected using engineering judgment and experiences. For example, one of the possible rules has the form: *IFe ˆPS AND _e ˆNB THEN uˆNQB*. It can be explained as follows: if the error signal is small, the drive is near the desired position where it should be stopped. Simultaneously, the error derivative, which is negative big, shows that the drive approaches the desired position very fast. The conclusion is that the output of the controller (servo-valve input voltage) has to be significantly negative to produce a breaking effect and to prevent overshooting [4]. The necessary rules, in such a way derived, to replace linguistic terms due to the algorithm realization.

4. A FUZZY SELF-LEARNING POSITION CONTROL

The theory of fuzzy control seems to be a suitable tool for both modeling and control of complex,

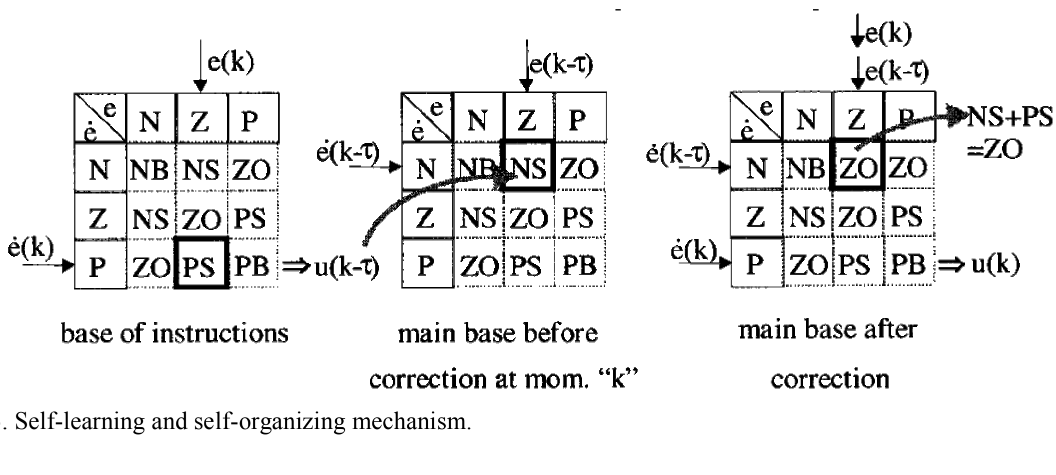

Fig. 3. Self-learning and self-organizing mechanism.

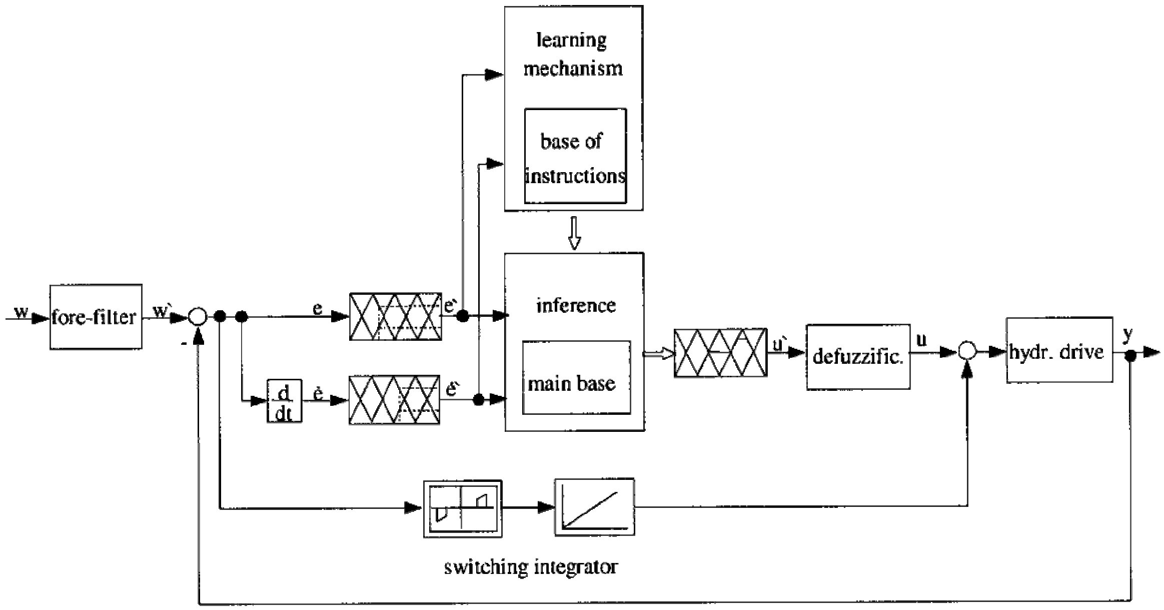

Fig. 4. The structure of hybrid fuzzy controller.

nonlinear systems. However, the primitive form of fuzzy control sometimes fails in dealing with these complex systems, mainly because it lacks enough adaptability. Several researchers have been devoted to developing fuzzy controller with more intelligence [5, 6, 7]. Unfortunately, most of them are difficult for real-time implementation. As pointed out earlier, the sampling intervals of few milliseconds are usual in digital control of drive applications.

This limitation must be taken into account in the case of designing a fuzzy controller, too.

The controller represented in this article (Figure 4) is not an adaptive system in the classical sense, but is a self-learning fuzzy system based on a so-called reinforcement learning procedure [4]. It tries to emulate human decision-making behavior, namely, the ability to create the rules and modify them according to experiences.

The system has the hierarchical structure of two rule bases. The first one is the general rule base of the fuzzy controller, as shown in the previous section.

The second one performance matrix) is constructed by ``meta''-rules and exhibits an ability to create and modify the main rule base according to desired overall performance of the system. In other words, the rules are modified on the way, in that they force the controlled drive in achieving the control errors as small as possible.

The procedure first checks the quality of control action by the comparison of present values of **e** and **e**˙ with expected values from the performance matrix. Simultaneously, the linguistic terms in the performance matrix show how the rules in the main rule base must be changed.

The question is which rule must be changed, if one knows that the present **e** and _**e**˙ mainly caused by a past control action.

The solution is determination of the time constant t, which shows that the state of the controlled drive at the *n*th discrete moment in the present, is mainly the consequence of the control action activated at the (*n*-t)th discrete moment in the past.

The determination of the t could be done on the basis of heuristic knowledge of the dynamic behavior of the controlled process.

The self-learning controller must, therefore, contain a memory buffer to save past information's, as well as a mechanism for changing rules. Through this mechanism, the creation of new rules is also possible, if they do not exist yet. So the controller possesses an ability for self-organization too.

Suppose the above learning process is convergent, then the main rule base becomes constant after a certain number of experiments, or in a certain amount of time that the controlled drive is in operation.

The main rule base stays constant as long as the system dynamic does not change.

If the variations of system parameters become significant, a new adaptation is necessary. The mechanisms of self-learning and self-organizing are explained comprehensively in Figure 3.

For the sake of simplicity, the control variables are described with three linguistic terms only.

5. EXPERIMENTAL RESULTS

The research equipment and electro-hydraulic linear drive under investigation are presented in Figure 1.

The testing device consists of the following main parts [8, 9, 10]: hydraulic cylinder (40/28 mm, h=200 mm), load mass (m=70-300 kg), servo-valve (MOOG-D-769-233) , incremental position transducer (ISKRA TGM 111-08-resolution 0.005 mm), and control computer (GESPAC-8420, CPU-68020, A/D, and D/A-16-bit). The experimental results, shown in Figure 5, prove that the self-learning controller enables a successful control of electro-hydraulic drive without any a priori knowledge of the system dynamic, not only

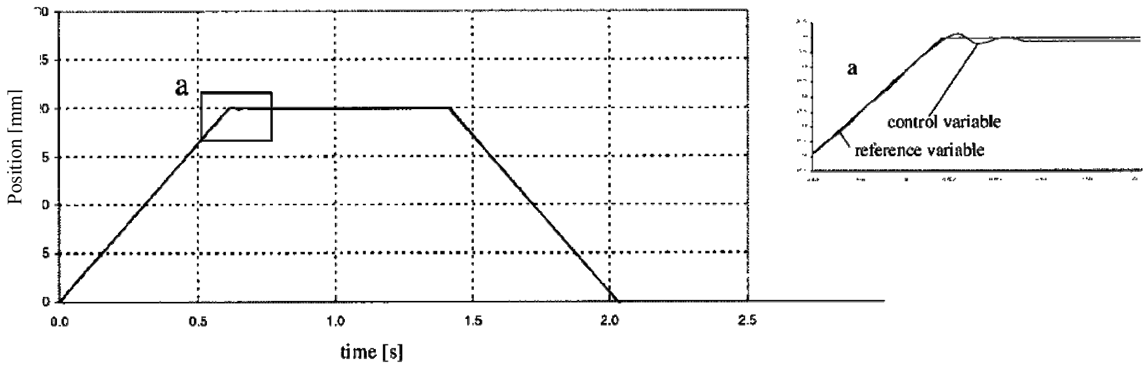

Fig. 5. Time response of electro-hydraulic drive controlled by hybrid fuzzy controller

during the operation, but also in the first start conditions [11]. It is also able to cope with nonlinearities and parameter changes, so it possesses a certain level of adaptability as well.

However, it is very difficult to predict the convergence of the learning process and, therefore, to predict the stability of the whole system in the design phase [12, 13, 14].

6. CONCLUSION

In this article are represented some results of investigations of possibilities to apply the fuzzy logic for control electro-hydraulic drive. Besides the PD-type fuzzy controller with constant rule base, self-learning fuzzy algorithm has also been developed.

The latter represents an attempt to introduce more intelligence into the hydraulic drive position control system.

The quality of control is improved by conventional control measures such as digital fore-filter and switching integrator, creating together a hybrid-fuzzy control structure. The essential advantage of a hybrid-fuzzy control structure lies in the fact that there is no need for presetting initial parameters. Furthermore there is no need for any previous knowledge about the operating regime and geometric parameters of the hydraulic drive. Although there are some very promising experimental results, it is early to exclaim the usefulness for industrial practice. This is because of the many degrees of freedom in designing a fuzzy system. The difficulties also occur in the prediction of a self-learning process convergence and overall stability of the system.

More attention will be paid to solving this problem in the future.

7. REFERENCES

[1] Astrom, K. J., Wittenmark B.: *Computer controlled systems,* London, Prentice Hall, 1994

[2] Backe, W.: *Technische Trends der Fluidtechnik*, Olhydraulik und Pneumatik, Aachen, 38 (11/12), 1999

[3] Deticek, E., Kastrevc, M., Kiker, E.: *The use of fuzzy controllers on electro-hydraulic linear drives* Automatika, Vol. ¾, p.p. 77-80, Zagreb, 1993

[4] Deticek, E., Kastrevc, M., Kiker, E:. *Self-organising fuzzy controller for electrohydraulic drives*, Gépgyártástechnológia, 33, p.p. 7-8, 1993

[5] Deticek, E., Kiker, E.: *New strategy of adaptive position control of electro-hydraulic linear drive*, Strojarstvo, Vol. 40, No. 5/6, p.p. 179-187, 1998

[6] Scharf, E.M., Mandic, N. J.: *The application of a fuzzy controller to the control of multi-degree-freedom robot arm*, Industrial application of fuzzy control, p.p. 41-62, 1989

[7] Zimmermann, H. J.: Fu*zzy set theory and its application.*, Norwell, MA: Kluwer Academic, Publishers, 2001

[8] Deticek, E.: *A fuzzy self-learning position control of hydraulic drive*, Cybern. systems, Vol. 31, No. 8, p.p. 821-836, 2000

[9] Deticek, E., Kiker, E.: A*n adaptive force control of hydraulic drives of facity for testing mechanical constructions*, Exp. tech. (Westport Conn.), Vol. 25, No. 1, p.p. 35-39, 2001

[10] Lovrec, D., Deticek, E.: *Elektrohidravlični sistem zaznavanja tlaka bremena z reguliranim porabnikom = Electrohydraulic load-sensing with close loop controlled actors*, Ventil Ljubl., Vol. 1, p.p. 24-33, 2003

[11] Kastrevc, M., Deticek, E., Lovrec, D.: *Regulacija tlaka z uporabo klasičnih in mehkih struktur*, Ventil (Ljubl.), Vol. 9, p.p 197-203.

[12] Lovrec, D., Deticek, E., Faber, F.: *Electro hydraulic load-sensing with closed-loop controlled actuators - theoretical background*, Adv. Produc. Engineer. Manag., Vol. 4, No. 3, p.p. 93-104, 2009

[13] Zuperl, U.: *Development of systems for computer-aided design of modular fixtures*, Proceedings of the 11th International DAAAM, Opatija, 19.-21. October 2000

[14] Zuperl, U., Cus, F., Mursec, B., Ploj, A.: *A Hybrid analytical-neural network approach to the determination of optimal cutting conditions*, J. mater. process. technol. 157/158, p.p. 82-90, 2004

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VIRTUAL SIMULATOR FOR FIVE AXIS VERTICAL TURRNING CENTER IN PYTHON GRAPHICAL ENVIRONMENT INTEGRATED WITH OPEN ARCHITECTURE CONTROL SYSTEM

Abstract: *This paper proposes how to simulate five axis vertical turning center in open architecture software environment EMC2 (**E**nhanced **M**achine **C**ontroller). It was shown how to integrate functions of direct and inverse kinematics, way of modelling the components of virtual machine tool in the Python environment, their connection within the machine simulator that allows movement simulation in the function of NC machining program. Machine simulator is integrated in the software environment EMC2.*
Key words: *modelling, programming, simulation, five axis vertical turning center, EMC*

1. INTRODUCTION

Researches in a field of control multi-axis machine tools as manufacturing systems are becoming dominant in many research institutions dealing with development of numerical control systems. In many different areas simulators exists, so this idea is also realised in the field of multi-axis machine tools.

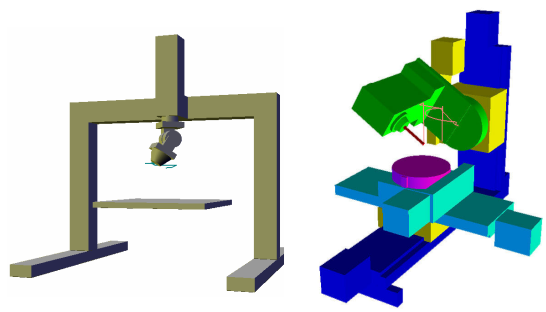
The introduction of open-source software package EMC (***E**nhanced **M**achine **C**ontroller*) [1, 2] and *AXIS* GUI (***G**raphical **U**ser **I**nterface*) [3], has dramatically improved development and availability to wide range of CNC user. New versions of the software brought significant improvements. With existing graphical environments, only possibility is to run tool path simulation. However, the idea is to create a virtual machine as a simulator, that will allow movement of complete machine in Python 3D environment and that can be integrated with EMC software. That way, any collisions that may occur during the execution of the program can be captured. With simulation of the tool path only there is no such possibility.

Integrating the virtual machine tool with EMC2 core, the simulator for programming, control and simulation, in virtual Python graphical environment were completed.

2. STATE OF RESEARCH

EMC2 software environment for machine tool and robot control are, in general, accepted by many. It has a great versatility. Ranges are from educational [4], to professional in sense of control large machine tools [5, 6, 7]. The fact that should not be ignored is that more and more new machine tools builders, as the basis for the development of its own CNC, use EMC2. Chinese machine tool builders are the leaders. In China there are very ambitious professionals who develop new control systems which are based on open architecture [8, 9].

During several years of presence on domestic and foreign software scene, EMC2 an open-source software system for machine tool control has gained a large number of users and those involved in its permanent development [1, 10, 11]. Examples of some realized multi-axis virtual machines are shown on Fig.1.

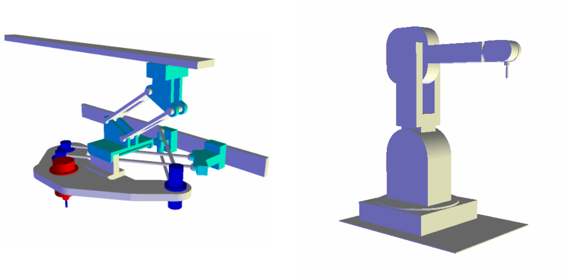


a) Portal five axis machine tool [10,11]   b) Five axis machine tool [10,11]

Fig.1. Virtual models of multi-axis machine tools

Our research and development in this area started three years ago, with configuration of control system for educational three-axis desktop parallel kinematics machine pn101_st V.1 [12] (Fig.2a). Successful realization of this project, continued with the implementation of control system for industrial robot Lola 50 as a reconfigurable multifunctional manufacturing system [7] (Fig.2b).

Alongside those control systems, virtual machines are developed on the same basis, as a support for programming and control of machines and in education of students [4]. First emerge the virtual model of a robot LOLA 50 (Fig.2b), as a result of the need for off-line programming system for reconfigurable manufacturing system based on the robot. The following implementation of virtual machines is achieved for the educational three-axis desktop parallel kinematics machine pn101_st V.1 (Fig.2a).



a) *pn101_st V.1* b) *LOLA 50*

Fig.2. Virtual models of machine tool and robot

3. CONCEPT OF 5-AXES VERTICAL TURNING MACHINING CENTER

Adopted concept of vertical five-axis turning center was founded by upgrading vertical three-axis turning center with two-axis head capable of milling, drilling and turning, Fig.3.

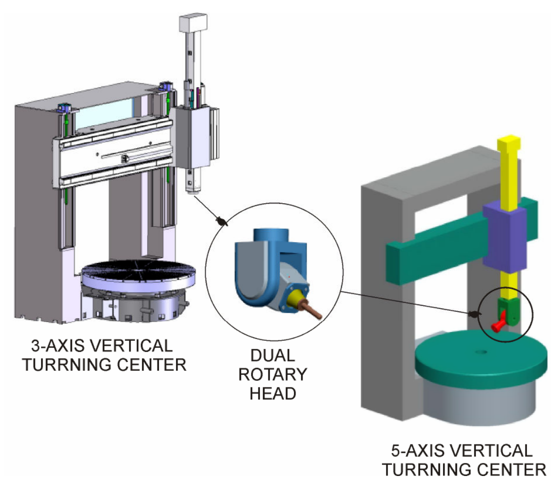


Fig.3. The concept of upgrading three-axis to five-axis turning center

In this way, five-axis machining is achieved. The first axis of milling head is collinear with Z-axis of machine. Rotating milling head around this axis to ±180° allows rotating the cutting tool in XY plane. Second axis of the milling head enables cutting tool tilting in relation to the horizontal axis. Each of these two axes has its own independent drive.

On the machine there is no movement along Y-axis, like one that exist on conventional portal milling machine. To achieve movement of the Y-axis, the base coordinate system of the machine must be fixed to the rotary table, Fig. 4. Composition of movement on all machine axes in accordance with inverse kinematics will led to Y-axis move.

This concept of the machine allows machining (turning, drilling, milling) of large, complex geometry, parts. This avoids the setup and clamping on different machines, and machining can be done in one setup on one machine.

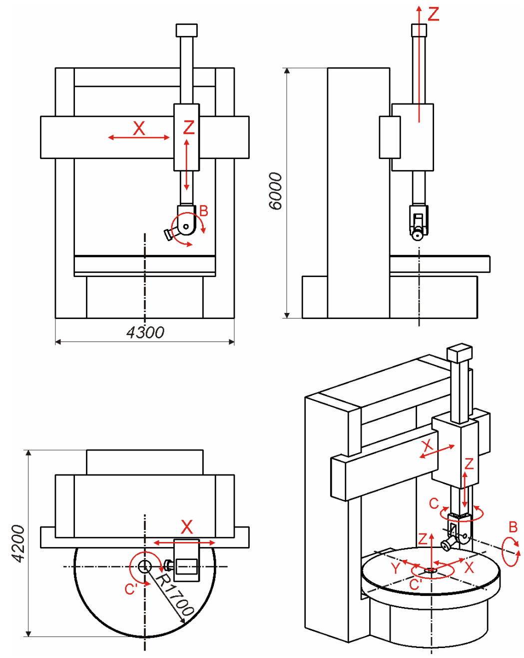


Fig.4. Concept of five-axis vertical turning center with coordinate system axes

4. STRUCTURE OF OPEN ARCHITECTURE CONTROL

The basic structure of applied open architecture control system is: PC as a base, CNC interface cards, a software-oriented CNC and a real-time operating system, Fig.5.

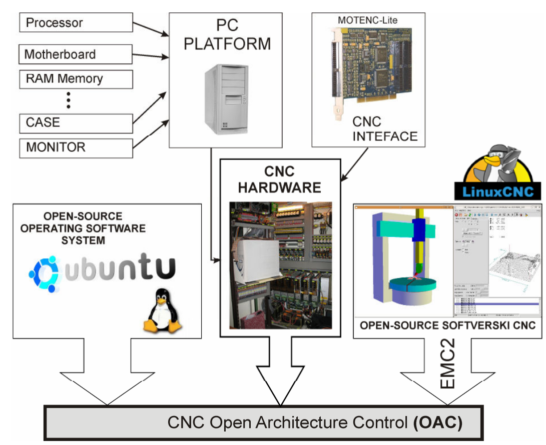


Fig.5. The structure of the developed concept – open architecture CNC on a PC platform

For the realization of the control unit for multi-axis machines it is necessary to provide a stable hardware platform, real-time operating system and driver software with appropriate performance. PC platform was chosen as a hardware platform, along with the compatible operating system for real time processing. Ubuntu Linux with real time extension (RTLinux) was chosen as a very reliable and widespread solution. This operating system fully meets the assigned criteria relating to time-critical processes of software CNC. The 1ms servo loop period of execution and 5ms for generation of new tool path interpolating segment along with timely execution not less important processes of lower priority and parallel, comfortable, work of user with less demanding application are the main criteria which are taken into account when building CNC hardware platform and operating system.

To complete a conception of control unit it is necessary to add an adequate CNC interface cards into a PC platform. PCI interface on PC motherboard was one of the main criteria for selection MONTEC Lite Cards. Two of these cards, which are attached to primary computer platform with a total of eight analogue outputs for connections to the frequency converters and eight square digital inputs for connection to the optical measuring systems. There is a multitude of digital inputs and outputs for connection to sensors and micro-switches of machine. This is more than enough to control five axis of auxiliary motion and one main drive of the machine.

Software oriented PLC is another element within the EMC2 software system. Software PLC is executed on the same hardware platform as software CNC. It is basically a program that is executed in parallel, concurrent, with other software components on the same hardware platform. PLC provides board of additional possibilities to the machine tool, such as control of tool-changer etc.

5. SIMULATOR OF VIRTUAL MACHINE IN PYTHON GRAPHICS ENVIRONMENT

Configuration of virtual model of vertical five-axis turning center is accomplished in the programming language Python. Algorithm for configuring model is shown in Fig.5. The modelling process of the virtual model boils down to programming the coordinates for the definition of elementary geometric bodies. To facilitate work, good practice is to model simplified model of machine in any CAD system, where one can easily download necessary coordinates to define primitives. Based on information from the CAD model simplified virtual model is programmed, it can be described using the primitives (Box, Cylinder ...) displayed in Fig.5. These primitives are grouped in a rotating or translation axes. It is important that all essential geometric parameters be correctly modelled, while the dimensions which do not affect the kinematics can be approximate. The programming should take into account the axis directions. They should be set according to the kinematics model established before. During the configuration of virtual models, one by one axis is programmed and immediately after checking must be done in order to prevent mistakes.

As a result one can get a virtual model of the machine in *Python 3D* environment that integrates in graphical interface *Axis* and control core of EMC2. In the window of virtual machine one can see moving segments of virtual machine according to control program (G-code) and a trace curve made by tool tip.

Virtual simulation is considered here to test and verify program before going to the real machine. Virtual simulation allows movement of modelled segments of turning center, with the tool at the end. Tool draws on the screen tool path, which is a result of the execution of program (G-code). All is done in a real time, in the same way as the real machine. This is very important especially when it is done for the first time for testing machine with a new control, or when one have a machine, and wants to perform testing and verification of the program and control.

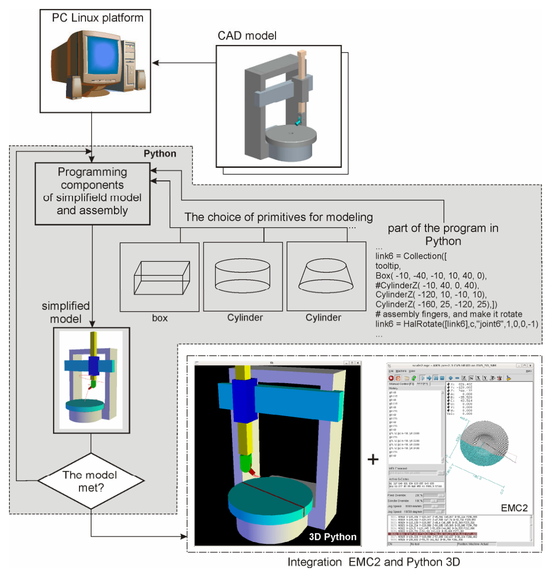


Fig.5. Configuration of a virtual machine in Python 3D environment and integration with EMC2 and Axis

6. OFF-LINE PROGRAMMING

Virtual simulation allows off-line programming with verification and testing on a remote site without machine engagement. Since there is a word about the real-time simulation of the machine, it can also be used for monitoring of machining operation from remote location. Working in the virtual environment is also suitable for training and education in programming of such manufacturing systems.

Programming of vertical five-axis turning center is similar with the five-axis milling machine with conception of axes XYZBC, whereby the programmer’s habits do not change.

The first rehearsal with machining simulation of virtual model are realised by programming in Pro/Engineer environment. For obtaining a G-code the appropriate postprocessor is configured. Testing is done on a virtual machine of vertical five-axis turning machine, realised in the Python programming language, which is integrated with the Axis user interface. In Fig.6 is shown five-axis machining of complex surface in virtual environment.

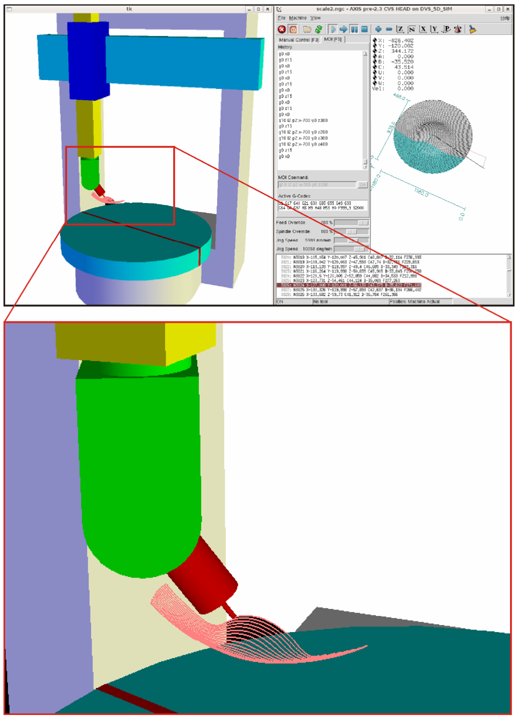


Fig.6. Five-axis vertical turning center as a virtual machine integrated with the environment AXIS

7. CONCLUSION

The main objectives of the presented research can be summarized in the concept of developing a control for CNC machine tools of specific configurations with integrated virtual simulator.

Development of virtual environments such as simulators for programming and simulation of machine tools during the machining is important because it allows off-line programming with verification and testing of the program. Working in the virtual environment is suitable in terms of training and education for programming of such manufacturing systems, especially in educational institutions in country, where there is chronic shortage of multi-axis machine tools. In this way, and without existence of resources, i.e., new machines, it is possible to receive training for their programming.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1] EMC - Enhanced Machine controller web site - www.linuxcnc.org

[2] NIST - National Institute of Standards and Technology web site - www.nist.gov

[3] AXIS: A User Interface for EMC2, 5-axis machining with EMC, http://axis.unpythonic.net/, 2008.

[4] Dimić, Z., Živanović, S., Kvrgić, V., Konfigurisanje EMC2 za programiranje i simulaciju višeosnih mašina alatki u Python virtuelnom grafičkom okruženju, XXXII Savetovanje proizvodnog mašinstva sa međunarodnim učešćem, Zbornik radova ISBN 978-86-7892-131-5, str.353-356, FTN Departman za proizvodno mašinstvo, Novi Sad, 2008.

[5] Glavonjić, M., Milutinović, D., Živanović, S., Dimić, Z., Konfiguracija jedne hibridne petoosne mašine, 33. JUPITER konferencencija, 29. simpozijum NU-Roboti-FTS, ISBN 978-86-7083-592-4, str.3.19-3.6, Mašinski fakultet, Beograd-Zlatibor, maj 2007.

[6] Dimić, Z., Kvrgić, V., Živanović, S., Krošnjar, A., Koncept upravljanja petoosnog vertikalnog strugarskog obradnog centra upravljačkim sistemom otvorene arhitekture, XXXIII Savetovanje proizvodnog mašinstva sa međunarodnim učešćem, Zbornik radova ISBN 978-86-7083-662-4, str. 195-198, Mašinski fakultet, Katedra za proizvodno mašinstvo, Beograd, 2009.

[7] Milutinović, D., Glavonjić, M., Živanović, S., Dimić, Z., Multifunkcionalni rekonfigurabilni obradni sistem na bazi robota, XXXII Savetovanje proizvodnog mašinstva sa međunarodnim učešćem, Zbornik radova ISBN 978-86-7892-131-5, str. 369-372, FTN Departman za proizvodno mašinstvo, Novi Sad, 2008.

[8] Sungsik Park, Sun-Ho Kim, Hyunbo Cho, Kernel software for efficiently building, re-configuring, and distributing an open CNC controller, Int J Adv Manuf Technol Vol 27, pp 788-796, 2006.

[9] Ji H, Li Y, Wang J.: A software oriented CNC system based on Linux/RTLinux, Int J Adv Manuf Technol Vol 39, pp 291-301, 2008.

[10] Open source software development web site https://sourceforge.net/projects/emc/

[11] Chris Radek's stuff, web site http://timeguy.com/cradek/

[12] Milutinovic, D., Glavonjic, M., Zivanovic, S., Dimic, Z., Kvrgic, V., Mini educational 3-axis parallel kinematic milling machine, Proceedings of 3rd Interanational Conference on Manufacturing Engineering ICMEN and EUREKA Brokerage Event, pp.463-474, Kallithea of Chalkidiki, Greece, 1-3 october, 2008.

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Pozhidaeva, V., Kandeva, M., Assenova, E.

ESTIMATION OF WEAR AND SERVICEABILITY OF ROLLING BEARINGS IN OPEN PIT COAL MINING MACHINES

Abstract: *The matter of determining the bearing triobological characteristics and serviceability of spherical roller bearings employed in mine mechanization is discussed in the paper. A characteristic specifying the working capacity of the bearing is determined through solving a contact hydrodynamic problem for determining the thickness of lubrication film in the contact zone and reading the roughness of bearing surfaces.*
Key words: *mine machines, technical diagnostics, tribology of rolling bearings*

1. INTRODUCTION

The literature dealing with mining machines operation and repairs makes no reference to any systematic quantitative assessment with breakdown of defects and presenting the waste signs of rolling bearings in wheel excavators and other large-size mining machines. Therefore, as first approximation, we could assume that the data of defects in more than 2800 bearings in most heavily loaded actuators of 139 wide-gripping cleaning combines, 74 cleaning combines 2K-52 and 1200 additional bearings in other types of underground operated mining machines are consistent also with the actual data about open pit mining machines. According to the performed research, the quantity of waste bearings, corresponding with the main rejection criteria, is as follows:

1. Wear - 46,6 %
2. Fatigue - 41,3 %
3. Break - 2,6 %
4. Seizure - 2,0 %
5. Tempering and other factors - 7,5 %.

These data confirm also the preliminary assumption that the tribological processes wear and fatigue of rolling bearings are the main reasons for loss of their serviceability.

Rolling bearings are designed mostly for long-lasting fatigue and a high wear-resistance, but the fact that the actual life-time of most of them does not exceed 45% of the designed life-time indicates that new indicators should be sought to make the calculations more precise. The role of contact interaction properties and parameters like quality of bearing surfaces, respectively surface roughness, the contact pressure, as well as the state and thickness of the lubricant layer are therefore of great importance. Optimization of layer service ability is highly related to modeling and control of these tribological parameters [1].

Furthermore, bearings used for the prevailing part of units in open pit mining machines are large-size rolling bearings with barrel-type rolls. Their great number and their not insignificant cost require precise forecasting of the resources.

2. THEORETICAL FORMULATION AND METHODS FOR ESTIMATION

During the recent years the maintenance initiatives in mining enterprises are constantly improving through implementation of methods and means of technical diagnostics. The SPM method proved to be a reliable method of quality assessment of the condition of bearings in mining machines. According to this method the pulse levels as an indicator of the condition of a bearing are interrelated with the thickness of the lubricant layer h_o [μm] and the roughness of bearings contact surfaces R_a [μm], respectively for the rollers and for the slot of the external ring.

$$h_o = c\sqrt{R_{a_1}^2 + R_{a_2}^2}\ ,\ \mu\mathrm{m} \qquad (1)$$

In equation (1) the coefficient of proportionality "c" is defined as "oiling number" and its value is indicative of the condition of a particular bearing. This fact gives us a good reason to assume that the oiling number can be used as a parameter for determination of the residual bearing resource after presetting the values, which determine it. In the particular case, the roughness of the bearing surfaces, as allowable limit values, is limited by the existing roughness standards, and the thickness of the lubricating layer should be determined for hydrodynamic considerations.

Pursuant to D. Kodnir [2], the amount of pulse forces from the interaction of bearing elements in oil environment depends on the amount of the lubricating layer at the point of contact and the hydrodynamic pressure in it (Fig.1, Fig.2). The latter could be determined after the theory of Herz by the maximum contact pressure σ in the particular case of a point contact [3].

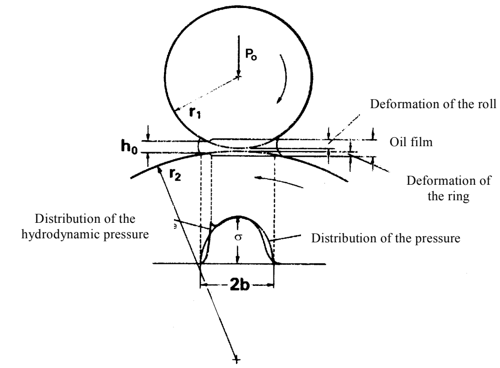

Fig. 1. Pressure distribution in the loaded zone

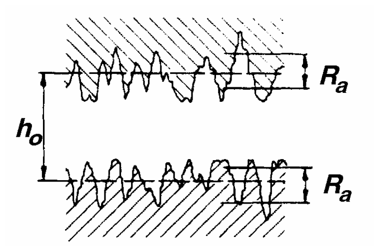

Fig. 2. Connection between the thickness of the lubricant layer h_0 and the roughness of bearings contact surfaces Ra

$$\sigma = 0{,}418\sqrt{P_o.E(\lambda_a \pm \lambda_b)},\quad \text{N/m}^2 \qquad (2)$$

where: P_o is the intensity of load distribution in the bearing roll under maximum pressure.

$$P_o = \frac{4{,}6.F_r}{2.z.a.\cos\theta},\quad \text{N/m} \qquad (3)$$

where F_r [N] is the radial load in the bearing, which pursuant to Author's summary [4] can be assumed to be within the limits of the actual loading value and the load under which it becomes impossible to guarantee a rolling mode, limited by SKF [5[;

z is the number of the rolling units,

θ is the angle of contact of the rolls with the bearing rings,

E – module of elasticity, $E = 2.08.10^{11}$, N/m^2

a - length of the contact platform, m

$(\lambda_a \pm \lambda_b)$ - reduced curvature of the friction surfaces for external (internal) contact.

$$(\lambda_a \pm \lambda_b) = \frac{2}{d_p} - \frac{2}{D_0 \pm d_p},\qquad \frac{1}{m} \qquad (4)$$

where d_p is the largest diameter of the drum-like roll, and D_o is the average diameter of the bearing.

For determination of the oil film thickness in the contact zone we shall make reference to the contact and hydrodynamic problem solved by D.Kodnir [2], namely:

$$h_o = \frac{0{,}1.\xi^{0{,}6}.(\mu.V_T)^{0{,}7}}{(\lambda_a \pm \lambda_b)^{0{,}43}.P_o^{0{,}13}}.\left(\frac{E}{1-\frac{1}{m^2}}\right)^{0{,}03},\mu\text{m} \qquad (5)$$

where:

$$V_T = \frac{\pi.n}{60}\frac{(D_o^2 \pm d_p^2)}{D_o},\ \text{m/s} \qquad (6)$$

is the aggregate velocity of rolling bearings movement against an external or an internal ring;

$$\mu_o = \frac{\mu}{e^{\xi\sigma}},\quad \text{N.s/m}^2 \qquad (7)$$

is oil viscosity under atmospheric pressure. In this case it is assumed that the lubricant has Newton properties and its viscosity depends on the pressure σ after the Barus law.

After equalization of both equations (1) and (5) is obtained:

$$c = \frac{0{,}94.10^{-3}.V_T^{0{,}7}}{(\lambda_a \pm \lambda_b)^{0{,}43}.P_0^{0{,}13}.\left(R_{a_1}^2 + R_{a_2}^2\right)^{0{,}5}} \qquad (8)$$

3. CONCLUSION

The solving of equation (8) for the limited cases of radial loading, respectively for the size of the contact pressure, determines standard limit values of the oiling number "*c*", with which the latter becomes a serviceability indicator.

REFERENCES

[1] Neale, Michael J. Tribology Handbook (2nd Edition), Elsevier, 1995.
[2] Kodnir S.D., Contact hydrodynamics of machine components lubrication. "Mashinostroenie" Magazine, 1976. (in Russian)
[3] Stoev St., Pozhidaeva V., Limit radial clearance as a criterion of roll bearings lifetime. "Mashinostroenie" Magazine, book 10, 1996. (in Bulgarian)
[4] Pozhidaeva V., Research on slow-revolution, large size rolling bearings in mining machines for feasibility study of the virbodiagnostic methods. Author's summary of dissertation, Sofia, 1999. (in Bulgarian)
[5] SKF, Catalogue of rolling bearings, Germany, 1989.

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FUNDAMENTALS FOR PLANNING AND CALCULATION OF MACHINING SYSTEMS' CAPACITY

Abstract *Standard process plans for rolling bearings manufacturing are fundamentals for the organization and effective implementation of the process serial and mass production of these products.*
The paper presents basic information for planning and calculation of machining systems' capacity for rolling bearings manufacturing in terms of products from this production system.

Key words**:** *Rolling bearings, Planning, Calculation, Capacity, Machining system*

1. INTRODACTION

In modern conditions of business activities, production systems are forced to redesign their production processes, or made their reengineering, in accordance with the diverse of needs and demands of the market. One of the main directions is process plans reengineering, which involves development and improvement of manufacturing process plans, development of the technological database, the application of modern and more efficient usage of existing production and technological resources, determining the real technological norms, more effective job preparation, etc.

Standard process plans for rolling bearings manufacturing are fundament of organization of manufacturing of these products. Development of standard technological process is based on the concept of typical and group technology.

With development of standard technological processes of rolling bearings production it will be provided the following, the most important goals:

- More efficient organization and implementation of technology and production processes,
- Better planning and management of production,
- Reduce the number of technology flows,
- Better planning and control of usage of technological capacity,
- Increased flexibility to market demands,
- Efficiency of technological preparation of production, etc.

In the development of standard process plans, except assortment of rolling bearings production and volume of production, it is also necessary to take into account the technological and installed equipment for the production of bearings.

The paper introduces basic information for planning and calculation of machining systems' capacity for rolling bearings manufacturing in terms of products from production system FKL.

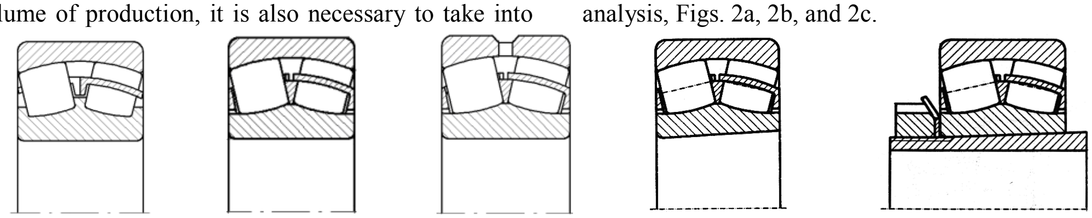
2. SHORT REVIEW ON PRODUCTION PROGRAM OF ROLLING BEARINGS

Based on the analysis of rolling bearing production for 2008. year, it was determined a quantity, i.e. realized production volume, as for individual bearings, as for the total volume of production for the formed group, that make up the cylindrical roller bearings, spherical roller bearings, double row rolling bearings, single row deep groove rolling bearings and single row angular contact rolling bearings, single row angular contact rolling bearings with grub set screws and needle roller bearings (total more than one million).

Within this analysis it was determined a realized amounts for the production of above mentioned types of bearings, and with the application of ABC analysis it was determined the representative products for the individual groups of bearings, which are shown in detail in the project [1]. In this paper it will be shown necessary information for the selection of representative product for spherical roller bearings.

The observed production system spherical roller bearings are produced in five different variants, with a range of different sizes (Figure 1).

In Table 1 it is shown a production program of spherical roller bearings for 2008. year, on the basis of which was made quantitative, mass and value ABC analysis, Figs. 2a, 2b, and 2c.



a) classical variants *b) C and E variants* *c) C and E variants W33* *d) C i E variants with tapered bored* *e) C i E variants with tapered bored and saddle*

Figure 1. Variants of spherical roller bearings [5]

Product	Identification number	Mark	Quantity piece/year	Mass kg/piece	Price €/piece
P1	519233	22205 ES.TVPB	12	0,18	20,5
P2	510092	22210 C.W33	98	0,60	15,1
P3	510091	22211 C.W33	29	0,82	16,7
P4	510132	22211 CK.W33	28	0,82	16,7
P5	510068	22214 C.W33	8	1,65	25,5
P6	510001	22215 C.W33	2	1,72	28
P7	510055	22215 CK.W33	9	1,72	33,6
P8	513246	22219 M	12	4,13	50,6
P9	519582	22220 JB	2	4,96	57
P10	510120	22220 JB *YU	12	4,96	58
P11	501188	22308 C.C3	3	1,0	18,9
P12	510097	22310 C.W33	17	1,85	25,4
P13	501985	22311 C.W33	3	2.35	29,8
P14	501965	22311 CK.W33 *YU	14	2,35	35,8
P15	501975	22312 C.C3.W33	6	2,95	24,8
P16	510098	22312 C.W33	25	2,95	35,3
P17	519636	22315 CC C3	2	5,40	39,2
P18	519583	22317 JB	3	7,40	70,6
P19	501699	22215 CK.W33	9	1,72	28

Tabela 1. Production program of spherical roller bearings

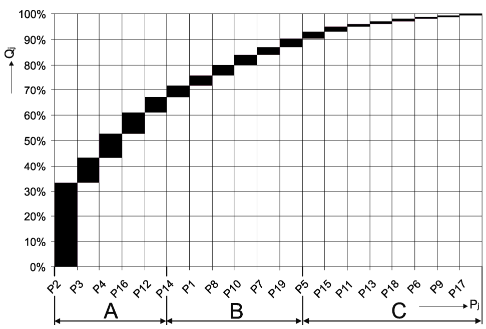


Figure 2a. Diagram for volume ABC analysis of spherical roller bearings

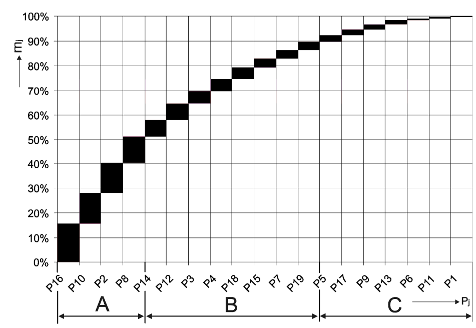


Figure 2b. Diagram for mass ABC analysis of spherical roller bearings

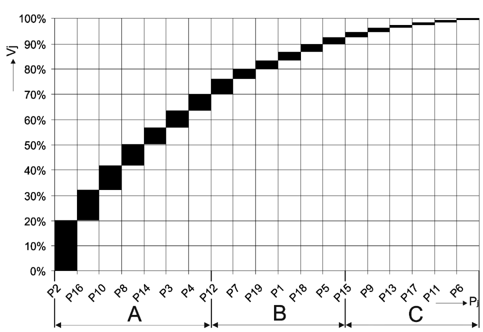


Figure 2c. Diagram for value ABC analysis of spherical roller bearings

As can be seen from the diagram for volume ABC analysis (Fig. 2a), diagram for mass ABC analysis (Fig. 2b) and diagram for value ABC analysis (Fig. 2c), a product 22210 C.W33 (P2) in all three cases is located in the A area of presented ABC analysis, on the basis of which it is chosen for the representative product for group of spherical roller bearings. Fig. 3 shown representative products for six formed groups of rolling bearings which are selected by applying ABC analysis [1, 2].

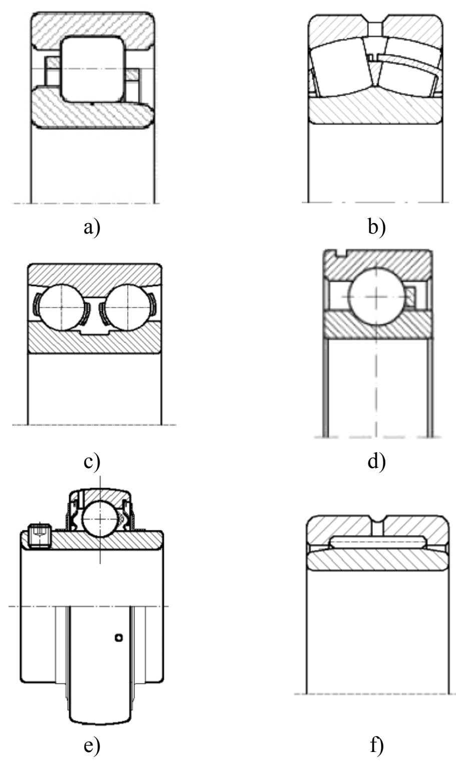


Figure 3. Representative products for formed groups of rolling bearings: a) Cylindrical roller, b) Spherical roller, c) Double row ball, d) Single row deep groove ball and Single row angular contact ball, e) Single row angular contact ball with grub set screws, f) Needle roller bearings

3. FOUNDATION FOR THE DEVELOPMENT OF STANDARD PROCESS PLANS

The terms of the observed production systems are designed standard manufacturing process plans of outer and inner rings of these six groups roller bearings on the principles of typical and group technology [1]. Content of manufacturing process plans of the rings bearings includes the following operations: Parting off, Turning, Drilling, Threading cutting, Heat treatment, Grinding facet, Grinding outside, Roll track grinding, Grinding openings, Super-finishing, Demagnetization, Final control.

Production volume and dimensions of the rings, require different types of raw material and different machining systems for operation turning, grinding and super-finishing. At Fig. 4 it is shown rules for machining system selection for turning of ring from rolling bearing, while in the works [2, 3] presented rules for the operations of grinding and super-finishing.

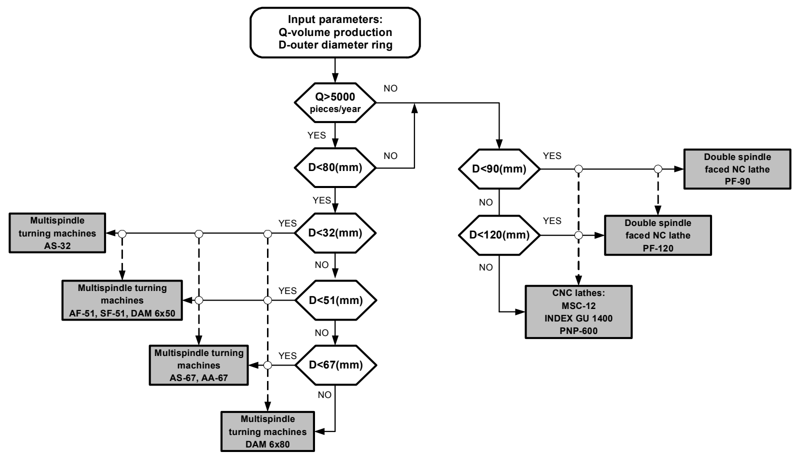


Figure 4. Rules for machining system selection for turning of ring from rolling bearing

Thus defined rules for the selection of machining systems for operation of turning, grinding and super-finish, enable for the group of rolling bearings, which are covered with this analysis, effectively defining of suitable standard manufacturing process plans, which enables fast refinement of process plans for each bearing.

In the scope of project [1] it was developed a standard process plans for the six groups of early mentioned rolling bearings and it was carried out the refinement of process plans for the appropriate representative products of these groups.

At Fig. 5 it is shown the group operation sheet for the standard process plan of outer ring production from group of double row spherical roller bearing, which are related to the operation of turning on the appropriate double-spindle faced NC lathe.

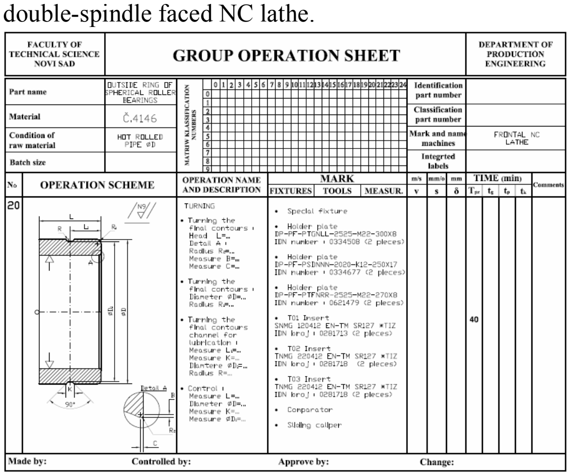


Figure 5. Group operation sheet for turning of outer ring from group of spherical roller bearing

Based standard ie group or typical operations processing specifies appropriate operations processing for outer and inner rings mentioned groups roller bearings, which detailed shown in project [1].

In Figure 6, shown is specified operations processing turning the outer ring of the product representative of group spherical roller bearings.

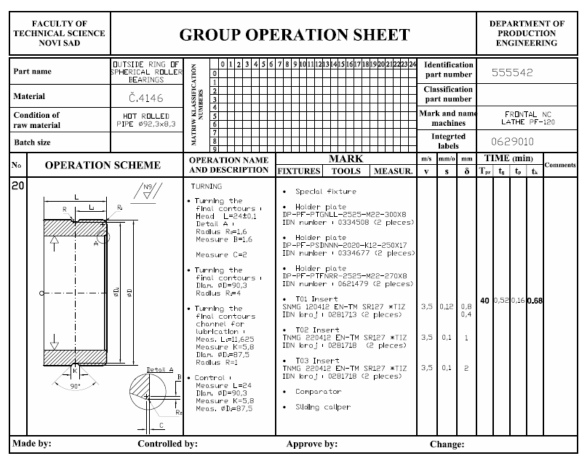


Figure 6. Refinement turning operations for the representatives of the group spherical roller bearings

4. CALCULATION OF CAPACITY MACHINING SYSTEM

For the effective use of technological resources installed can be applied methodology is based on data on the times in some processing operations, product representatives and the appropriate of reduced quantity [4].

4.1 Reduced quantities

It is generally known that the reduced quantity of one group of products is reduced to an appropriate quantity of product representatives. Thus the expression for the reduced quantity of ith products from these groups:

$$Q_{ri} = Q_i \cdot r_i \quad (1)$$

where the factor of reduction (r_i) of the ith product given expression:

$$r_i = r_{mi} \cdot r_{qi} \cdot r_{ci} \quad (2)$$

where the mass, quantity and value reduction factors given expressions, respectively:

$$r_{mi} = \frac{m_i}{m_p} \quad r_{qi} = \frac{q_i}{q_p} \quad r_{ci} = \frac{c_i}{c_p} \quad (3)$$

m_p, q_p, c_p, referring to mass, quantity and price of product representatives.

Reduced quantity of a group of roller bearings can be determined from the expression:

$$Q_r = \sum_{1}^{m} Q_{ri} \cdot r_i \quad (4)$$

where m-number of bearings in a given group, m=19 for a group of spherical roller bearings.

According to the presented methodology and data in the project [1], is determined by the reduced quantity of group spherical bearings which is $Q_r = 285$ pieces/year.

Based on the reduced quantity and time of processing operations bearings representatives, it is possible to determine the time of engagement machining systems in the individual operations. So for the outer ring of representatives spherical bearing, according to Figure 6, processing time on a single processing operation turning is $t_k = 0.68$ min.

The time of this engagement machining system for processing outer rings spherical bearings during the year, will be:

$$T_2 = Q_r \cdot t_k + T_{pz} \cdot n_s \quad (5)$$

$T_{pz} = 40$ min/series
$n_s = 4$ series/year
ie:

$$T_2 = 285 \cdot 0{,}68 + 40 \cdot 4 = 353{,}8 \text{ min/year}$$

If you are using the same methodology determine the time of engagement of this machining system for processing rings other groups roller bearings, can be determined the total time T_{total}.

Efficiency of this machining system for processing only the outer rings spherical bearings will be:

$$\eta_2 = \frac{T_2}{K_e} \quad (6)$$

where the effective capacity of a time machine:

$$K_e = m_e \cdot s_e \cdot n_e \cdot \eta_e = 162000 \text{ min/year} \quad (7)$$

m_e=240 day/year.
s_e=2 shifts/day
n_e=7,5 h/shift
η_e=0,75

$$\eta_2 = \frac{353{,}8}{162000} = 0{,}22\,\%$$

5. CONCLUSION

On the basis of standard process plans for the six groups of rolling bearings, it is possible to accelerate the process of refinement process plans for all the bearings in certain groups, and of course, for the representative products of these groups.

Refinement (precisely) process plans for the representative products enable, that on the basis of reducing quantities, easy way to planning of limits of organization and realization of production process, as well as effective monitoring and planning of utilization installed technological capacity and human resources.

Standard manufacturing process plans of bearings, which are developed by applying the concept of typical and group technology, as well as layers for the selection of machining systems on the mentioned key operations, make solid base for the development of systems for automated design of manufacturing process plans of these products, and the corresponding CAPP system.

6. REFERENCES

[1] Todić, V., Borojev, LJ., Milošević, M., Lukić, D., Živković, A.: *Development of the Typical Process Plans for Rolling Bearings Manufacturing*, Projekat tehnološkog razvoja koji finansira Ministarstvo za nauku i tehnološki razvoj Republike Srbije.

[2] Todić, V., Milošević M., Lukić, D.: *Foundation for Development of The Standard Process Plans for Rolling Bearings Manufacturing*, 33 Conference on Production Engineering of Serbia 2009 with foreign participants, pp. 127-130, Faculty of Mechanical Engineering, Belgrade, 2009., ISBN 978-86-7083-662-4.

[3] Todić, V., Lukić, D., Milošević M.: *Analysis of the Process Plans for Rolling Bearings Production*, 9.th–Intenational Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology - DEMI 2009, pp 227-234, Faculty of Mechanical Engineering, Banja Luka, 2009., ISBN 978-99938-39-23-1.

[4] Zelenović, D.: *The Design of Production Systems*, Academic books, Belgrade, 1987.

[5] *FKL Rolling Bearings*, cataloge, Temerin, 2004, ISBN 86-906415-0-5.

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THE CONSIDERATION OF THE DYNAMIC UNBALANCE PROBLEM OF ROTATING MACHINERY

***Abstract**: Dynamic unbalance is the mainly source of undesired dynamic phenomena in the technical systems work. The source unbalance analysis, type of unbalance and procedure for unbalance elimination are shown. Also, the criteria estimation for permissible unbalance of rotating machine is presented.*
***Key words:** rotor, unbalance, vibration, mass, balancing*

1. INTRODUCTION

In practice the origin of the biggest part of dynamic problems on rotating machinery are from constraint forces and moments as a results of emerging consequences of deficiency designed construction and technology characteristics of real machinery system and the influence of technology processes. Comprehension of multilateral rate and relations that exists between dynamic motions and nature of observed machinery system define its dynamical as well active status. Mechanical vibrations are an ideal mean for reliable identification and determination of almost every active machinery system. Vibration signal recorded at the body of machine represent the complex harmonic functions acquired from superposition of elementary vibration with different particular characteristics. Every of these components have its own place and reason of existence and with diagnose of particular proportion and basic characteristics we get the reliable answer what happens in whole machinery system. Considering that the most frequent cause of unwanted dynamical features is dynamical unbalance of moving components of rotation machinery, in this paper we present the analysis of this phenomenon, the methods and criteria for evaluation of type of dynamic rotor unbalance.

2. CAUSE OF ORIGIN AND CONSEQUENCES OF ROTOR MASS UNBALANCE

As the most frequent cause of rotor mass unbalance appear:

- construction errors: rotor surfaces without machining, wedges shorter than slots, eccentricity due to rough tolerances;
- material faults: cavities in welded and forged parts, uneven thickness of weld at welded constructions, uneven thickness of yoke ring, ribs or other rotor reinforce elements;
- production and installation faults: deviation from drawings at welding process, forge and hammering, appearance of eccentricity, oval and slanted machining of sleeves, permanent deformation in machining process, deformation due unbalanced screw tightening , uneven mass of screws, washers and nuts;
- running effects: wearing of rotor parts, deposit of different residues on the rotor, mechanical damages, deformation due to thermal stress, assembling errors.

All of these errors reflects on the rotor center of gravity, main axis of inertia regarding axis of rotation respectively and induce significant centrifugal forces of inertia with manifestation effect on machinery system as constraint oscillatory movement revealed as mechanical bias and we name it linear vibration.
Unbalance of rotor mass has multiple harmful effects regarding appearance of kinetic stress and vibration become the accelerated wearing of vital assemblies particularly bearings and sleeves; degrading machinery running accuracy; and through foundation transfer the shocks to the next machinery equipment as well on the building objects.

3. UNBALANCED RIGID ROTOR TYPES

Unbalance of rigid rotor could be static, kinetic and dynamic.
Static unbalance is the case when the rotor center of gravity is not on the rotation axis and the main axis of inertia is parallel with the axis of rotation at some distance. The result of this deviation is the presence of centrifugal force with action point at rotor center of gravity.
Kinetic unbalance is the case when the rotor center of gravity is on the axis of rotation, and the main axis of inertia deviate for an angle, and the cross of axis are in the center of gravity. The occurrence arises when the rotor is slant to the axis of rotation. The corporal presentation of this case are two equal unbalanced masses on rotor in single plane over and under of axis of rotation at the same distance. Due to these masses occurs the moment of unbalance and the result centrifugal force is equal to zero. This moment we could cancel with additional masses which produce moment with the same amplitude but opposite direction. Additional masses are in the same plane as the unbalanced moment exists.
Dynamic unbalance is the combination of static and

kinetic unbalance with additional deviation on position of center of gravity from rotation axis and main axis of inertia. The rotation axis bypasses in space the main axis of inertia. In practice the most frequent case is dynamic unbalance.

4. ELIMINATION OF ROTOR UNBALANCE

There are more methods of balancing depending on type and function of rotor as well available instrumentation and device. There are two technologies for rotor balancing: on stable machinery and in its bearings, i.e. at running conditions. In both cases the purpose is to determine the location and amplitude of unbalance to eliminate centrifugal forces and reduce dynamic stress on bearings and vibrations of machinery system to permissive limits.

4.1 Static balance of rotor masses

For static balance we use the method of stable and labile equilibrium for the disk shaped rotors and the mass concentrate in single plane. During the process the aim is to bring rotation axis and center of gravity to the position of coincide. Mostly practice before final installation with purpose of reducing unbalance, and charging the bearing during later dynamic balancing of assembled rotor, particularly on technology equipment with high running revolutions. This method nowadays is rare because of limited accuracy and considerable amount of time for act of unbalancing.

4.2 Dynamic balance of rotor in its bearings

Rotor is completely dynamic balanced if its main axis of inertia coincides with axis of rotation. Such type of rotor does not induce vibrations, which means that the bearings not tolerate unnecessary dynamic stress.
Dynamic balance of stiffed rotors of technology equipment is possible to accomplish on two ways:
∗ on stable machinery out of original bearings,
∗ on own bearing and on right technology equipment.
By technology equipment of large dimensions and mass it is not rational to uninstall the rotor and transport to the stable machinery owing to balance because of long period of inactivity, and the cost of transport are not negligible. Beside economy fact the realization of quality is far reliable with dynamic balance of rotor in its bearings, which is performed on technology equipment at running conditions because the real gaps in bearings are present and real axis of rotation. The vital condition for application of this method is to have access to rotor regarding a process of correction. We emphasize that in measurement of unbalance, apart of method, is necessary to fulfill the conditions: constant number of revolutions per minute, the same direction of revolution and the same measurement places and direction of measurement. By rotor balance in own bearings it is not possible to estimate from single measurement the amplitude and location of unbalanced mass like stable machinery for balancing.. The reason for this is that dynamic balance in its bearings measure the amplitude of vibration on the parts of technology equipment, but the dynamical parameters as stiffness of machinery, damping of bearing and the support method. We compensate the unknown parameters with additional measurements with some pilot mass, and from acquired data of primary status of machinery and data with pilot mass we compute analytic and draw diagrams with or without appropriate software, for corrective mass and location on rotor. Depending on rotor geometry the balancing we could perform in single plane, in two planes and in special cases in multiple correction planes.

4.2.1 Dynamic balance of rotor in its bearing in single plane

This procedure we perform on disk shaped rigid rotors with ratio b/D ≤ 0,5, and we deem it as a case of static unbalance. Procedure is performed on running number of revolutions, and on rotors with high turning number and severe unbalance it is recommended to perform on lower number of turns, and afterwards on operation number of revolutions.
Description of procedure:
a) *primary vibration status measurement:*
we measure the amplitude of vibration V_{10} on housing of a bearing and phase angle of vibration φ_{10} regarding reflective marker of photocell;
b) *pilot mass effect measurement m_{p1} located on random place on rotor (Fig. 1):*
the amplitude of vibration V_{11} on bearing housing and phase angle of vibration φ_{11} present a new status of vibrations emanate from superposition of primary status and the effect of pilot mass (vector diagram Fig. 1).

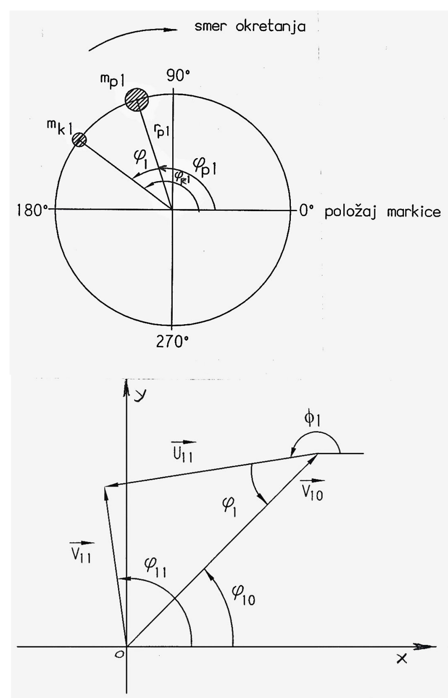


Fig. 1 Dynamic rotor balance in its bearing in single plane -Vector diagram-

Ascendant vector of pilot mass on level of vibration in bearing is:

$$\vec{U}_{11} = \vec{V}_{11} - \vec{V}_{10}$$

Vector amplitude $\vec{U}_{11}$ depends of amount of pilot mass $m_{p1.}$ Relocation of pilot mass on circumference of rotor moves with same angle and vector $\vec{U}_{11}$.

c) *determination of corrective mass and location in aim to annulment unbalance*

Vector $\vec{U}_{11}$ (Fig. 1) rotate for angle φ_1 to be collinear with vector V_{10} but with opposite direction. Owing to annulment of primary unbalance the amplitude of vector $\vec{U}_{11}$ should be equal to amplitude of vector $\vec{V}_{10}$, what we get by setting a pilot mass:

$m_{k1} = m_{p1} \times V_{10} / U_{11}$ at angle:

$\varphi_{k1} = \varphi_1 + \varphi_{p1}$

4.2.2 Dynamic balance of rotor in its bearings in two planes

At rigid cylindrical rotors the balance is performed in two correction planes, and the select of planes depends on the form of rotor support which could be between supports or out on bracket.

Description of procedure:

a) *Measurement of primary vibration status:*

- we measure the amplitude of vibration V_{10} on housing of bearing and phase angle of vibration φ_{10} for first correction plane;
- we measure the amplitude of vibration V_{20} on housing of bearing and phase angle of vibration φ_{20} for the second correction plane;

Measured values are represented by vectors in polar coordinates for every correction plane (Fig. 2)

b) *Measurement of pilot mass effect m_{p1} located on random place for first correction plane:*

- amplitude of vibrations V_{11} and phase angle of vibrations φ_{11} represent the new status of vibration on bearing housing -1 for first correction plane, which emanate from superposition of primary state and effect of pilot mass $m_{p1.}$
- amplitude of vibrations V_{21} and phase angle of vibration φ_{21} represent new status of vibration on bearing housing-2 for second correction plane, which emanate from superposition of primary status and effect of pilot mass m_{p1}.

Effect vectors of pilot mass m_{p1} on the condition of vibrations on both bearings 1 and 2 are:

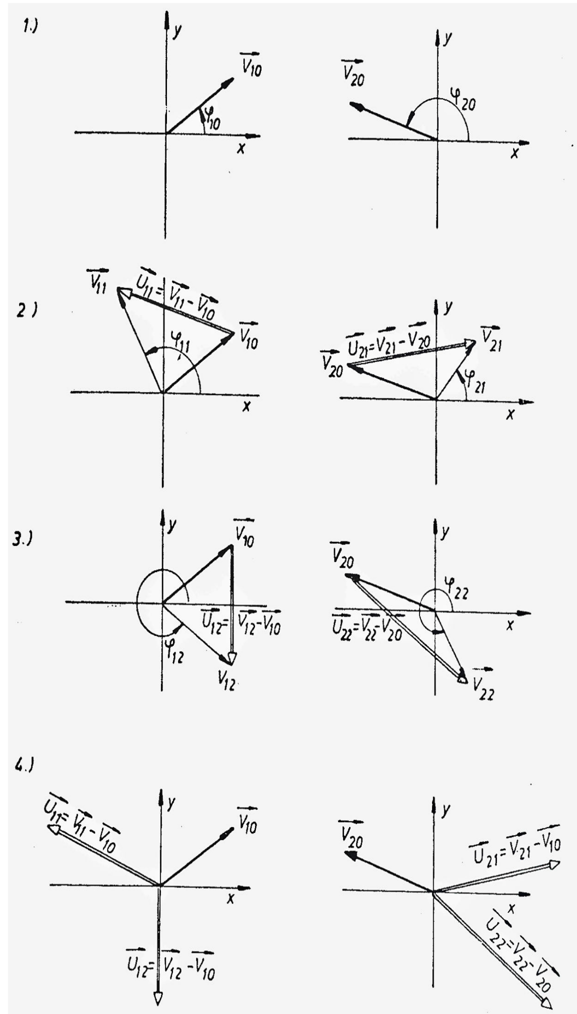
$$\vec{U}_{11} = \vec{V}_{11} - \vec{V}_{10}$$

$$\vec{U}_{21} = \vec{V}_{21} - \vec{V}_{20}$$

These vectors are shown on Fig. 2.

c) *We remove the pilot mass m_{p1} from the first correction plane and we measure the influence of pilot mass m_{p2} located on random place at second correction plane:*

- the amplitude of vibration V_{12} and phase angle of vibration φ_{12} represent the state of vibration on bearing housing "1" for the first correction plane, which emanate by superposition of primary state and effect of pilot mass $m_{p2.}$
- the amplitude of vibration V_{22} and phase angle of vibrations φ_{22} represent the state of vibration on bearing housing "2" for second correction plane, which emanate from superposition of primary status and effect of pilot mass m_{p2}.



Sl.2 Dynamic rotor balance in its bearing in two plane -Vector diagram-

Effect vectors of pilot mass m_{p2} on the condition of vibrations on both bearings 1 and 2 are:

$$\vec{U}_{12} = \vec{V}_{12} - \vec{V}_{10}$$

$$\vec{U}_{22} = \vec{V}_{22} - \vec{V}_{20}$$

Fig. 2 show primary vectors of unbalance $\vec{V}_{10}$ and $\vec{V}_{20}$, as well effect vectors of pilot mass located on correction planes 1 and 2. We have to find a solution to annul these vectors $\vec{V}_{10}$ and $\vec{V}_{20}$. We can reach it on several ways:

∗ with diagrams which has the less precise solutions.

∗ mathematics method using vector and matrix computing.

Conditions for primary vectors V_{10} and V_{20} to annul are:

$$\vec{U}_{11} x k_1 + \vec{U}_{12} x k_2 = -\vec{V}_{10} \qquad 1)$$

$$\vec{U}_{21} x k_1 + \vec{U}_{22} x k_2 = -\vec{V}_{20} \qquad 2)$$

where k_1 and k_2 are correction vectors or vector operators respectively and needed to determinate.
Equations 1) and 2) as matrix:

$$\begin{bmatrix} U_{11} & U_{12} \\ U_{21} & U_{22} \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = -\begin{bmatrix} V_{10} \\ V_{20} \end{bmatrix} \qquad 3)$$

This matrix we can show as:

$$U \text{ x } k = - V_0 \qquad 4)$$

From this equation 3) we could find the matrix of correction vectors:

$$k = U^{-1} - V_0 \qquad 5)$$

where U^{-1} is inverse matrix of matrix U.
Because we get the values of matrix elements by measurement "U" and "V_0" we can calculate elements of matrix "k" and we get correction masses:

$$m_{k1} = m_{p1} \text{ x } k_1$$
$$m_{k2} = m_{p1} \text{ x } k_2$$

The angle of location for correction masses regarding placement of pilot mass is:

- for correction plane 1: $\varphi_1 = \text{arc tg } k_{1y} / k_{1x}$
- for correction plane 2: $\varphi_2 = \text{arc tg } k_{2y} / k_{2x}$

- k_{1y}, k_{1x} and k_{2y}, k_{2x} are components of vector k_1 and k_2.
For annulment of primary unbalance the corrective masses should be placed m_{k1} and m_{k2} on:

$$\varphi_{k1} = \varphi_{p1} + \varphi_1$$
$$\varphi_{k2} = \varphi_{p2} + \varphi_2$$

The mathematics for determination of correction masses and their placement is performed on computer and with adequate software and programs.
Today measurement equipment for recording vibration signal consist appropriate software program for determination corrective masses and their location for corrective planes respectively.

5. CRITERIA FOR EVALUATION OF PERMISSIBLE UNBALANCE OF ROTATION MACHINERY

To determine permissible residual unbalance, after the correction process, we need to know the purpose and the power of machinery regarding the class of accuracy, number of turns per minute, rotor mass, location of correction planes and bearings, as well construction data. Permissible residual unbalance for certain accuracy class must be small if the speed of the rotor is high.
According standard ISO 1940/1 [3,4] we have norms for permissible values of unbalance of rotation machinery regarding different turns per minute. This standard has 11 quality requirements for balance of rotors depending on type and equipment.

6. CONCLUSION

The most frequent cause of dynamic problems in practice which occur on rotation machinery has origins from constraint forces and moments which emerge from rotor unbalance. Rotor mass unbalance is multiple destructive because of appearance of kinetic stress and vibrations and quick wear of vital components, particularly bearings and sleeves; for machinery it low down the accuracy in operation and through foundation transfer the shocks to next technology equipment as well on to the building object.
Dynamic balance of rotor in its bearing we achieve quality and economy because it performs on technology equipment in operation conditions. With this process we comprehend real gaps in bearings and real axis of rotation. The necessary condition for this method is to have an access to rotor regarding procedure of correction. Depending on geometry shape of rotor the balance is possible to perform in single plane, in two planes and in special cases in multiple correction planes.

REFERENCES

[1] Chung, J., Jang, I., Dynamic Analysis of an Automatic Dynamic Balancer for Rotating Mechanisms, Journal of Sound and Vibration, 228(5), pp.1035-1056, 1999.
[2] The Rationale of Dynamic Balancing by Vibration Measurement, Brüel&Kjær Technical Review, No.3, 1979.
[3] ISO 1940-1: 1986 (E), Mechanical vibration – Balance quality requirements of rigid rotors – Part 1: Determination of permissible residual unbalance, International Organization for Standardization
[4] ISO 1940-2: 1997 (E), Mechanical vibration – Balance quality requirements of rigid rotors – Part 2: Balance errors, International Organization for Standardization

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10th INTERNATIONAL SCIENTIFIC CONFERENCE ON FLEXIBLE TECHNOLOGIES

PROCEEDINGS

mma 2009
FLEXIBLE TECHNOLOGIES

TOPIC:

TOOLS, TRIBOLOGY, FIXTURES, METROLOGY AND QUALITY

Novi Sad, October 2009.

Invited Paper

Cep, R., Sadilek, M., Kouril, K., Budak, I., Hadzistevic, M.

MEASURING OF MACHINE TOOL ACCURACY BY RENISHAW BALLBAR QC10

Abstract: *For cutting more complicated parts, above all in lump and small-lot productions, such as production in tool works, it is of advantage to use CNC machine tools. A very important condition for exact cutting is the machinery stability in order to keep high accuracy of its programmed (in most cases non-linear) path. The following text deals with this accuracy detection, it describes particular tests carried out in toolshed RIETER Elitex Inc. Hnatnice in Czech Republic.*

Key words: *dynamic accuracy, cutting, CNC programming, spline path*

1. INTRODUCTION

It is impossible to ensure the required speed, surface finish and first of all production operability by the traditional tooling method. It is also impossible to ensure the needed functional surface accuracy in that way. It is even impossible to size some surfaces by this technology. Therefore a new HSC (High Speed Cutting) technology is introduced. This new method successfully solves problems of the traditional cutting technology of 3D surfaces. One of the possibilities how to reduce the prime costs, operation times and to improve constructional parts quality nowadays in the splintery cutting area displays cutting high rate [1].

By this technology it is possible to shape thoroughly without hand-made finalization. This is enabled only by using computer techniques with top CAD/CAM systems. It is necessary to start a close cooperation between companies producing machinery or tools, users and companies offering CAD/CAM systems.

Characteristics of HSC cutting:

- high cutting speed
- high feed speed
- temperature rise in the cut point
- smaller warming-up of work piece
- better surface finish
- major formative accuracy and position accuracy
- high efficiency
- great operational safety

In the development of the machine for splintery cutting, producers´ obvious effort can be seen to increase labour productivity and to achieve a higher machined surface quality. A significant progress has been recently made especially in terms of the main times, which have no small influence on prices of manufactured parts. Good results were achieved especially by the development of new cutting materials, which demand high feed values for optimal cutting conditions. To match technological requirements, not only high feed speeds are required, but also their high dynamics and high speed of the spindle. An obvious requirement is the high stiffness of the whole machinery and especially of the feed mechanisms.

Mechanized 3D surfaces often contain complicated and mathematically indefinable surfaces and preparation of the programs for their cutting on NC machines is possible practically only while using CAD programs. These way generated programs are demanding on memory size and on speed and quality of information processing in the control system. CNC systems fit for HSC cutting are equipped with circuits of re-contouring prediction (Look Ahead) that checks the speed with regard to the shape strain of the cutting surface. Their task is to operate the feed speed in order not to make formative mistakes on sharp angles and edges [2].

If we summarize the introduced demands on the high-speed cutting, these items are concerned:

- cutting materials for achievement of high cutting speeds
- high - speed spindles
- feed mechanisms enabling high feeds and high acceleration
- high stiffness of the whole system: machine - tool – work piece
- CNC control systems with high speed of block processing and with Look Ahead function

2. EXPERIMENTAL PART

2.1 Tested machine tool

Measuring was carried out on a machine-tool WHN 13 CNC produced by TOS Varnsdorf Inc. It is a horizontal milling machine with a cruciate make-up of beds, a lengthwise adjustable stand, a telescopic spindle and a crosswise adjustable rotary desk. Module construction offers wide range of variations in all the parameters. It is also equipped with digitally controlled AC propellants SIEMENS and a control system HEIDENHAIN TNC 426 M. The task of metering is to find out the roundness departure by dynamic data scanning. This departure is decisive for cut part accuracy and its quality. The results of this metering form the basis for the choice of cutting conditions, especially the feed speed v_f.

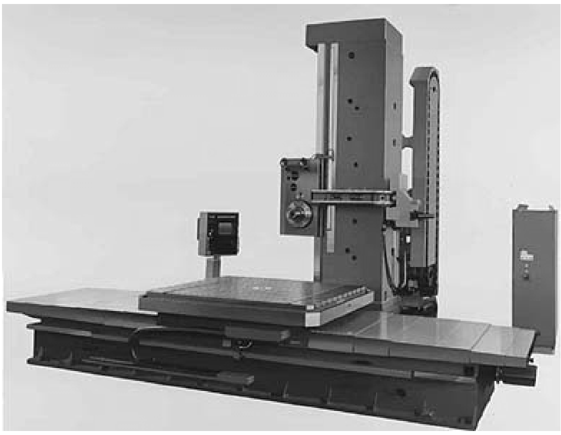

Fig. 1. Measured machine tool

2.2 Measuring condition requirements

Robust construction focused on optimization of preparation speed and design metering is a basic sign of apparatus QC – 10 (Fig. 2). The apparatus set is in transport position put in a firm plastic case. Main part of the apparatus is a linear sensor equipped with balls on both ends, which are put into magnetic cups during metering. One cup is fixed on the machine bed, the second one in the spindle of the machinery.

Fig. 2 Detail of Renishaw QC10

While installing the apparatus on the machine the software analyzes eccentricity from the title of the apparatus assembly and revises measured values, which accelerates the installation very much. The sensor is connected with a cable to an interface, which supports transmission of the measured values into the computer (Fig. 3). The interface is linked through a serial port with computer (stationary or notebook), where diagnostic software of the firm RENISHAW is installed. For absolute measurement the apparatus is equipped with zerodur´s calibration units. Before the metering itself it is necessary to insert into the control system machinery a program for fulfillment of cyclic interpolation with a set radius. For assessment of the roundness departure according to the ISO 230-1 or ANSI B5.54 standards. Non-Roundness satisfies execution of circular interpolation only in one way [3].

Analysis of the deviation causes requires implementation of the interpolation both clockwise and anti-clockwise.

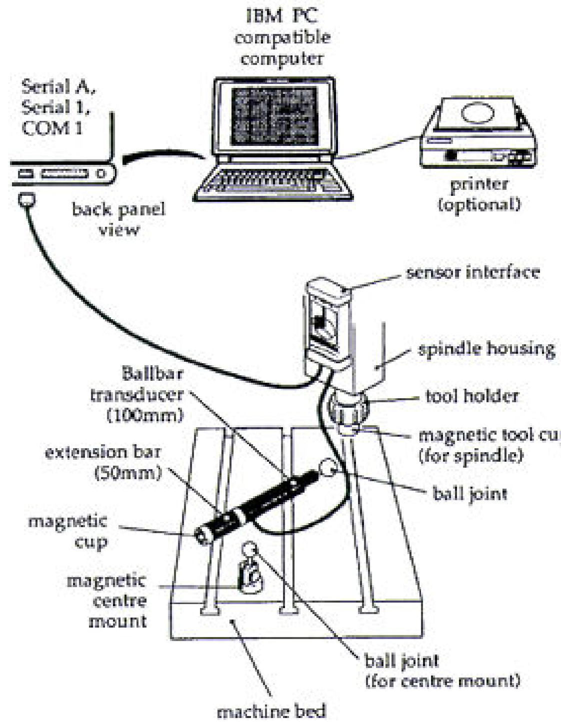

Fig. 3. Scheme of measuring

2.3 Accuracy requirements

- It is necessary to ensure firm constriction worm contacts.
- It is recommended to touch as little as possible the measuring scanner and calibrating unit, warmth of a hand can cause inaccuracy owing to heat expansivity. While handling use cotton gloves. A touch of the case of metering scanners can cause extension by several micrometers.
- Necessary to enable temperature composition of the system QC and calibrating units to the surrounding temperature.
- Recheck cleanness of storage of the metering unit magnets
- Recheck, whether the metering sensor QC is well stored on magnetic gripping, by moving slightly that metering system

2.4 Influence of the feed speed on departure of roundness

The feed speed influences the roundness departure as it is shown in Table 1. Generally, it reads that the higher the feed speed is the higher is the departure of roundness. The graphic dependence is presented in Fig. 4.

plane \ v_f [mm/min]	1000	1500	2000	2500	3000	3500	4000
XZ	3,6	9,3	15,6	21,8	27,2	30,1	33,4
YZ	22,6	38,7	51,4	63,5	71,3	78,9	85,7

Table 1. Departure of roundness

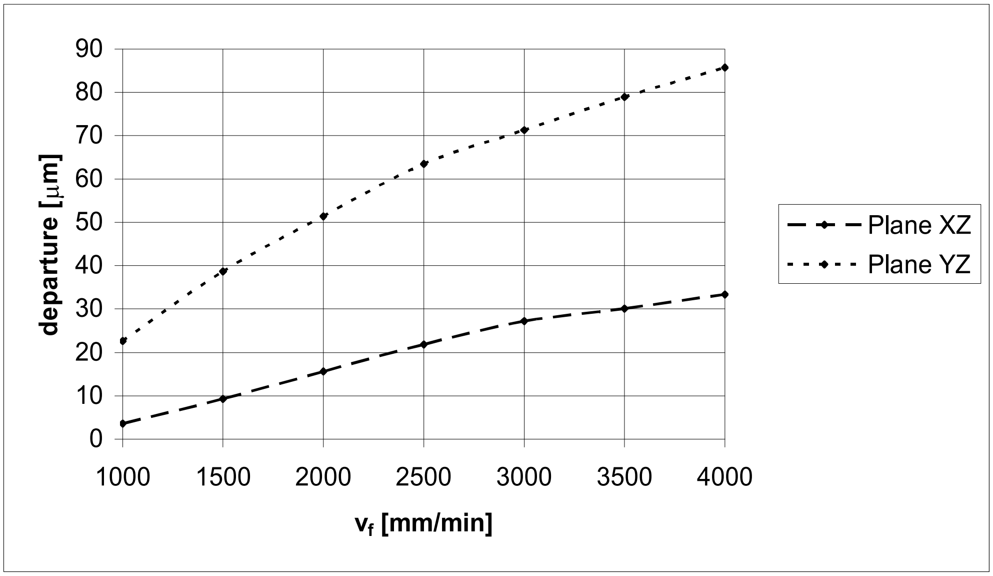

Fig. 4. Dependence of the departure of roundness on the feed speed

3. TECHNICAL – ECONOMIC ESTIMATION

Achievement of the required parameters of the components made on CNC machine definitely depends on the machine accuracy. It results in serious consequences for both producer and user of the CNC machine.

Producers are made to manufacture accurate machines capable to keep long term guarantee characteristics. These characteristics must meet the international standards.

Users of the machine more often face the task of classification of their machinery park, following trends of accuracy development, testing and certificate of the accuracy of the machines, and minimalization of the costs connected with low quality production and machinery put out of order.

This metering is to show whether the machine is sufficiently accurate for production and acceptable for user of the CNC machinery. Practically it means that a less accurate machine will only be used for scrub work. Next point is that cutting of complicated surfaces requires reduced feed speed. Straight or less complicated surfaces may be cut at high feed speed, which means, great acceleration up to maximum possible speed on complicated flat. That is only possible with powerful and stiff enough machines.

Acquisition costs on metering system QC-10 were about 1,000,000,- Kc. This amount is relatively high, but with respect to the fact, that machine tool in the company Rieter - Elitex Inc. is tested approximately once per 2 months and there are 10 machines there the return is approximately 2 years. Presuming, that the prestigious company has costs on metering of 1 machine about 10.000,-Kc, total costs are 100.000,- Kc. After 2 years it is necessary to have all the machines checked by the state accredit test-room, which resets the machine and provides certificate [1].

4. CONCLUSIONS

HSC technology has already been introduced in some developed countries and in the following years a further expansion into all manufacturing industrial branches can be expected.

In spite of this advanced technology, the importance of the human factor cannot be neglected. Only a sufficient number of properly trained workers ensures competitiveness and matches high accuracy requirements.

A significant part of production accuracy is the efficient metering system. This enables to observe the state of the machinery stock and its production accuracy. It makes possible to choose the cutting characteristics, especially the feed speed v_f. Inaccurate and unadjusted machinery cannot achieve the required quality and accuracy of the final product and so it is unserviceable.

5. REFERENCES

[1] Čep, R.: *Influence of cutting conditions to production accuracy at machining of 3D surfaces (in Czech)*. Diploma thesis. Ostrava, VŠB-TU, 2000, 46 p.

[2] Machalínek, M.: *Trend is high speed cutting (in Czech)*. Technický týdeník 24/1998, str. 6-7.

[3] -----: *Manuál to system QC-10 BALLBAR SYSTEM v 4.21*., RENISHAW.

[4] Dobránsky, J., Hatala, M.: Influence of selected technological parameter to quality parameters by injection moulding. In: Annals of DAAAM for 2007 & proceedings of the 18th International DAAAM Symposium : Intelligent Manufacturing & Automation: Focus on Creativity, Responsibility, and Ethics of Engineers : 24-27th October 2007, Zadar, Croatia. Vienna : DAAAM International, 2007. 2 p. ISBN 3-901509-58-5.

[5] Mrkvica, I., Uhlář, V.: Počáteční kontakt břitu nástroje při frézování. In. *Sborník referátů VIII. mezinárodní konference Nové smery ve výrobných technologiích 2006.* Prešov: Technická univerzita v Košicích, Fakulta výrobních technologií se sídlem v Prešově, 2006, s. 101-104. ISBN 80-8073-554-9.

[6] Panda, A., Jurko, J., Pandová, I, Zajac, J.: *Vývoj, výroba a overenie nových výrobkov pre automobilový priemysel. 1. časť.* Monografia, FVT TU Košice so sídlom v Prešove, 2009, 67 strán, ISBN 978–80–553–0149–5.

[7] Monková, K., Monka, P.: Digitalizácia dokumentácie. In: Technika. č. 12 (2004), s. 31.

[8] Stević, M., Hodolič, J., Vrečić, T.: Primena BALLBAR QC10 sistema, Zbornik radova, IX Međunarodna naučno-stručna konferencija Fleksibilne tehnologije MMA 2006, Ćosić, I. (Ed), ISBN 86-85211-96-4, pp. 51-52, Univerzitet u Novom Sadu, Fakultet tehničkih nauka – Institut za proizvodno mašinstvo, 15. - 16. Jun, Novi Sad, Srbija i Crna Gora, 2006.

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mma 2009 FLEXIBLE TECHNOLOGIES
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Invited Paper

Sovilj, B., Javorova, J. G. , Geric, K., Brezocnik, M.

INFLUENCE OF TEMPERATURE ON THE PHASE TRANSITION IN CoPt ALLOY

Abstract: *The variations of internal friction, magnetic susceptibility and loss angle with time and temperature of disoredered CoPt equi-atomic alloy, during annealing induced phase transition from cubic to tetragonal are shown.*
The paper presents results of investigation of magnetic and anelastic relaxation of "as-quenched" CoPt alloy measured from 300 K to 840 K versus annealing induced ordering starting from 460 K.
Internal friction and magnetic susceptibility/ time and temperature signatures can enable a better understanding of ordering processes and mechanisms.
Key words*:phase transition, CoPt alloy, magnetization*

1. INTRODUCTION

Atomic ordering can affect the anelastic and ferromagnetic properties of metals and alloys. The internal friction (IF) level, the initial magnetic susceptibility, its magnetic after-effect (MAE) and magnetic loss angle can be used as an indication of the degree of order.

CoPt has a cubic (Al) structure in the "as-quenched" (disordered) phase. It transforms during annealing into the tetragonal (Ll_0) phase. The transformation is of diffusion like type and can be attributed to the ordering processes and establishing of short - range order.

In the disordered phase CoPt exhibits a high level of IF (magneto- elastic damping) and soft ferromagnetic properties, while in the ordered phase it show a low magnetic susceptibility and IF level.

The aim of the present paper is to investigate the change of IF, magnetic susceptibility and loss angle during continuous or successive annealing of disordered samples from the room temperature up to 840K. Reason for this type of research is to study the magnetic and anelastic properties of pure, equi-atomic CoPt alloy by controlling the heat treatment and temperature during the ordering and phase transition processes.

2. EXPERIMENTAL PROCEDURE

The measure of IF in the case of a wire is the logarithmic decrement 5 of free torsional vibrations of a CoPt sample:

$$Q^{-1} = \frac{\delta}{\pi} \tag{1}$$

The inverted torsion pendulum is working at low frequency, fo=60 Hz, and at strain amplitude of 2×10^{-3}.

Electronic timer with the accuracy of the order of 10 JIS has been used.

Magnetic measurements - performed by differential ac technique based - on a Wilde bridge [1] at a frequency of 3 kHz in a field directed parallel to the wire has been also done.

After demagnetization of the sample at t_1=30s in ac field of about $10^3 Am^{-1}$, MAE measurements started at t_2=32 s and are continued up to 1800 s. The measuring field amplitude of 0.24 Am^{-1} has been chosen.

Expressions for the loss angle

$$\tan\phi = \frac{\chi``}{\chi`} \tag{2}$$

following from the complex initial magnetic susceptibility

$$\chi = \chi` - \chi`` \tag{3}$$

and for the **MAE** :

$$\frac{\Delta r}{r_1} = \frac{r(t_2,T) - r(t_1,T)}{r(t_1,T)} \tag{4}$$

are used, where the reluctivity $r = 1/\chi`$ and $\chi`$ is the real part of the complex initial susceptibility; t_1 = 30 s, and t_2 varied from 32 s to 1800 s; T is the temperature of the sample.

2.1. Sample preparation

A high purity, equi-atomic CoPt (50 at % Pt) sample in the form of a wire, the diameter of 1.0 mm has been sealed off under a vacuum of 10^{-5} Pa in a quartz tube, annealed above the critical temperature of 1100 K (see

Fig. 1) for five hours, and than ice - cold water quenched in order to obtain the disordered fee phase.
IF and magnetic measurements have been taken on the "as-quenched" (disordered) samples during heating up to the Curie point. The rate of temperature change during these measurements has been 0.3 K/min.

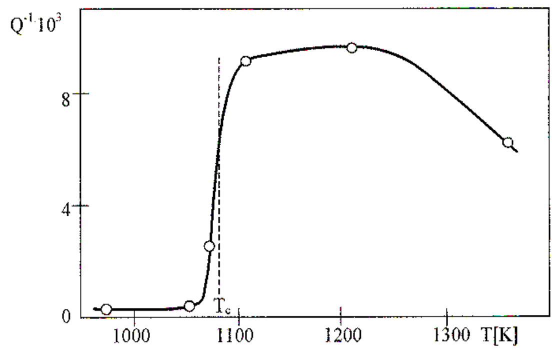

Fig.l. The change of IF level of CoPt alloy as function of the quenching temperature. Tc is the critical temperature [2].

In samples quenched from temperature $T > T_C$, a high IF level is observed in Fig. 1. The high internal friction level in "as-quenched" samples is due to the magneto-mechanical damping of the Bloch domain walls as observed in the micro-scale, or due to the losses caused by the magneto-elastic hysteresis as measured in the macro-scale[3].

3. RESULTS AND DISCUSSION

The **IF** measuring results for two different heating rates of CoPt during ordering are shown in Fig. 2. The high level of internal friction as seen in Fig.2 at T < 450K is observed after quenching the samples from 1430 K to 273 K.

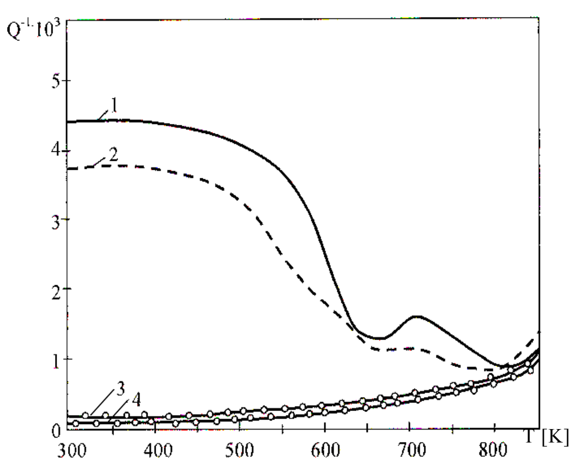

Fig.2. The temperature dependence of IF of disordered CoPt alloy for two different heating rates: 2 K/min. - curve 1, and 6 K/min. - curve 2. Curves 3 and 4 represent damping for saturated and ordered sample respectively [6].

Between 300 K and 450 K, IF changes only a little, but from 450K to 650 K, it decreases significantly - up to the level of partly ordered sample.

In the second temperature region, where the ordering process started, we see in Fig. 3, a maximum of $\Delta r / r_1$ and simultaneously a decrease of the real part of the initial susceptibility χ'.

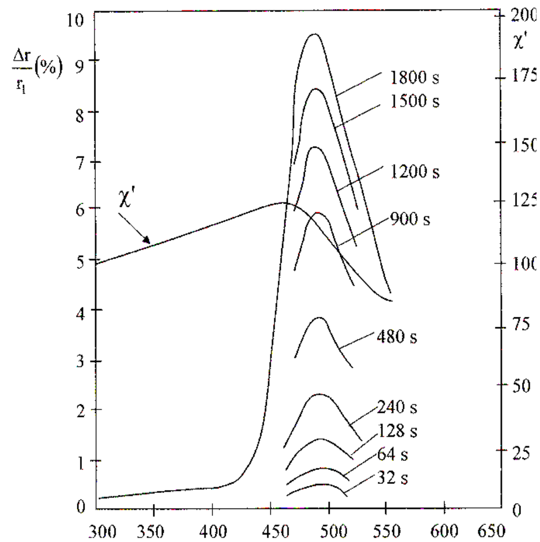

Fig.3. The magnetic after-effect and the initial magnetic susceptibility of disordered CoPt sample versus annealing temperature during a run from 300 K to 556 K, as determined at t_1=30 s after demagnetization; t_2 varied from 32 s to 1800 s.

We suppose that during annealing of disordered sample in this step of ordering the frozen in vacancies, produced during quenching, are moving to the partially ordered regions, increasing the level of order, as observed by the initial susceptibility measurement during two successive annealing runs: A from 3000 K to 556 K and run B from 300 K to 650 K as seen in Fig.4, and as calculated in paper [4] and [5]. The maximum of the initial susceptibility observed at about 460 K anneal and has completely annealed out by measurements in the run B.

In [5] we have shown, that the MAE maximum at 500 K in Fig.3 is due to the rotation of the easy magnetization vector from [111] to the [001] axis, its position depends upon the heating rate and it disappears in the course of the two successive annealing runs A and B as seen in Fig.4.

The Richter type, reversible magnetic relaxation maximum at 500 K, seen in Fig.3 has an activation energy of E_R = 1.4 eV, and is ascribed to the reorientation of Co - Pt atomic pairs [6].

The high temperature IF peak at 700 K, whose amplitude increase with decreasing heating rate, as seen in Fig.2, and huge increase of magnetic losses, seen in Fig.5, are due to a structural relaxation process that occur during annealing induced phase transition from cubic to tetragonal.

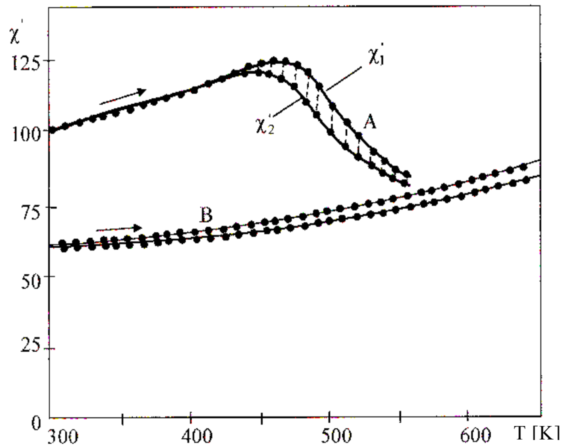

Fig.4. Variation of the real part of initial susceptibility of disordered CoPt sample, measured during two successive annealing runs A and B; χ_1'' - at t_1=ls and χ_2'' - at t_2=30min. after demagnetization [7].

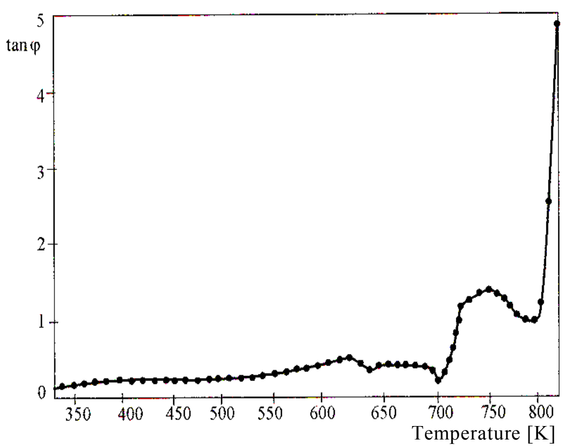

Fig.5. Loss angle versus annealing temperature of disordered CoPt alloy after quenching the sample from 1450 K to 273 K.

In Fig. 2 we observe at T> 800 K a high temperature background (HTBG) of IF. The HTBG is higher for higher heating rates. The characteristics of the background are basically dependent from interaction between dislocations, point defects and other defects like residual fcc-phase or stacking faults.

By applying a steady magnetic saturation field it is possible to reduce the IF to the level of saturated magneto-mechanical damping (curve 3 in Fig.2), which is very close to the IF level of ordered sample (curve 4 in Fig.2).

The background of IF follows the function:

$$Q_{BG}^{-1} = a \cdot \exp\left(\frac{-E}{kT}\right) \qquad (5)$$

with E=1.5 eV for $Q_{BG}^{-1} = 1.3 \cdot 10^{-4}$ at T=530 K, and $a = 1/\omega\tau_0$ [3] at $\tau_0 = 10^{-13} s$ and $\omega = 2\pi f_0 = 377\,Hz$

As seen in Fig.5, at T >530 K, the structural changes started influencing the increase of the magnetic losses.

4. CONCLUSION

Annealing from 300 K up to 840 K of disordered by quenching equi-atomic CoPt alloy results in:

- phase transition from cubic to tetragonal,
- decrease (about ten times) of the initial magnetic susceptibility,
- rapid, thermally-activated reorientationa! relaxation of Co-Pt atomic pairs, leading to short- range order,
- a slower, migrational, structural ordering process, which results in reduction of Co - Co

atomic pairs with ferromagnetic bonding, leading to long - range order. Our approach could be extended up to the Curie point (T^{A1}= 830 K) [7], therefore we could observe a huge increase of magnetic losses (in Fig.5).

5. REFERENCES

[1] E. Klugmann, HJ. Blythe, F. Walz, *Investigation of Thermo magnetic Effects in Mono crystalline Cobalt near the Martensitic Phase Transition, phys*. stat. sol (a) 146 (1994), 803-813

[2] W. Chomka, *Internal Friction in Ordered Mg-Cu, Ag-Mg and Co-Pt Systems*, Sci. Papers of the Technical University of Gdansk (Poland), Fizyka, No 176 (1971), 3-66

[3] W. Chomka, *The Mechanism of Internal Friction in Metals,* Sci. Papers of the University of Katowice (Poland), No 165 (1977), 80-113

[4] E.V. Gomonaj, E. Klugmann, *Atomic and Magnetic Ordering in CoPt Alloy,* J. AppL Phys. 77 (5) (1995), 2160-2165

[5] E. Klugmann, *Relationship Between Structure and Internal Friction in CoPt and FePd Alloy*, Fundamentals of Tribology and Bridging the Gap Between the Macro- and Micro/Nanoscales, Ed. B. Bhushan, Kluwer Academic Publishers, NATO Sci. Series, Printed in Netherlands, 2001, pp. 299-304

[6] E. Klugmann, HJ. Blythe, B. Augustyniak, *Kinetic of Ordering in Equi-Atomic CoPt Alloys*, J. de Phys.

Colloq. C8, 48 (1987), 513-517
[7] E. Klugmann, HJ. Blythe, *Atomic and Magnetic Ordering in CoPt Alloys Studies by Magnetic and Internal Friction Measurements*, J. Magn. Magn. Mater. 101 (1991), 99-101
[8] SOVILJ, B., *Identifikacija triboloških procesa pri odvalnom glodanju*, Doktorska disertacija, Fakultet tehničkih nauka, Novi Sad, 1988.

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Invited Paper

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DEVELOPMENT A DATABASE OF MODULAR FIXTURES

Abstract: *Importance of fixtures in the productional systems with automated production and automated product design imposes the need for modern approach to those designs. The aim is to create conditions which could provide the choice and construction of fixtures with the aid of computer hardware and modern applicative software which accelerate and facilitate the resolution of needed fixtures. This paper shows a model of database for designing and archiving of fixtures as well as segment of output data. The Application is developed on PC using Microsoft Access and ProENGINEER applicative software. The paper finally butlines relevant conclusions and expected future trends of the research.*

Key words: *Fixture, database*

1. INTRODUCTION

Computer application has reached an enviable level in the last decades, and hence, began to be used in almost every human working and living segment; in some areas, it has become almost irreplaceable. One of these areas is certainly manufacturing industry. Constant development in computer technology enables continual increase in its application possibilities in the engineering activities. The illustration can be numerous worldwide examples stating about developed CAx systems and software with various purposes for automated task solutions in product design area.

Increasing the automation level with the simultaneous increase in production system flexibility is possible to achieve only by applying CNC – Computer Numerical Controlled, and the increase in flexibility and productivity of the completely manufacturing system by applying CIM – Computer Integrated Manufacturing. Computer application in modern engineering practice is certainly multiple; however, one of applications that are more important is definitely manipulation and control of large sum of information and data of technical or some other nature, realized by new and increasing software class known as databases or DBMS – Database Management System. In every production system there is a need for manipulating a large sum of data, whether it is product design, technology preparation, control, and the like. Efficient database is only the one enabling fast access to the desired data and efficient data manipulation, and today it is impossible without a modern DBMS system.

2. PROBLEM DEFINITION

Modern production systems in manufacturing industry are characterized by product range extension, high frequency in changing the range, demands for constant product quality improvement, shortenings in production time, constant need for increasing technological level of products and decreasing their manufacturing costs. With such market demands, and intensive development of science, technique and new technologies, the level and the trend of further development of technological processes in manufacturing industry depend on all the composing factors. The factors with the highest influence on the quality of technological solutions are the following: preparation type of blank, machining processes, order of operations, operation structure, machine tools, tools, fixtures, measurements, etc. In order to raise technological solutions to a higher level, it is necessary to solve optimally all these elements.

To set the adequate measures for rational fixture usage, it is necessary to analyze the existing situation. Today, inadequate organizational conception in almost all companies obstructs the optimal usage of the already present fixtures. The unexploited capital is shown after the research of fixture constructions in a company (Fig. 1). The diversity in fixture constructions indicates the presence of a number of same or similar fixture drawings (fixture construction). Very often new constructions are being elaborated although minor change on the existing drawings would do the job. New fixtures are being made although the existing one could be redesigned with a small cost. In addition, there are cases when there is a suitable fixture, but a new one is designed and manufactured.

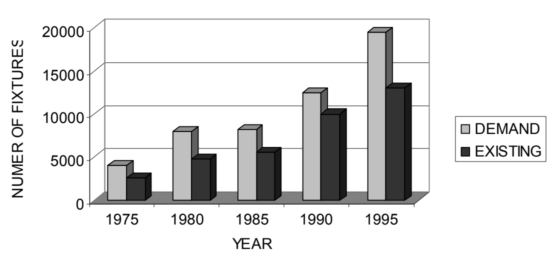

Fig. 1. Proportion between the existing fixtures and a demand for them

Second example, also presenting current situation in the field of fixtures, is given in Fig. 2. According to some researches elaborated in the USA, the average cost of an individual Flexible manufacturing cell

(FMC) is around $1,000,000. A significant financial segment from that amount goes to fixtures. The costs are increased proportionally in relation to the final costs. Fixture value share in the costs is 19% in average, which demonstrates that they are complex, precise, qualitative and efficient elements.

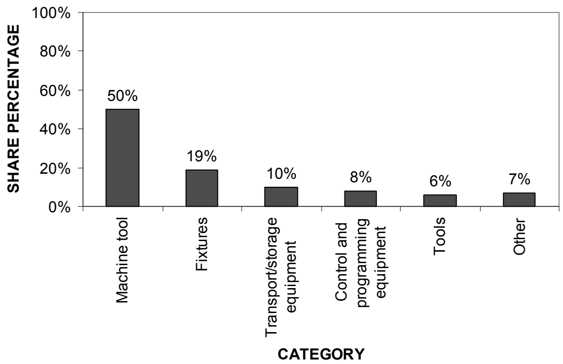

Fig. 2. Participation of individual components of FMC in total price

The problem of time analysis has a special importance when dealing with fixtures (Fig. 3). The reason lies in the fact that fixture design, as a rule, can begin only after technological process has been completely defined. As it can be observed in the picture, this time is six weeks in average, while two weeks are needed for fixture design.

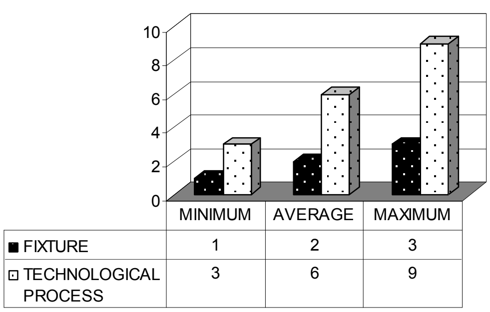

Fig. 3. Time needed for designing fixtures within the total time needed for defining technological process

Most time in manual fixture design and adjoining costs is related to the following: elaborating general construction aspect, detailed construction elaborating and searching for necessary information on the existing fixture solutions, fixture elements, and the like.

All other activities require significantly shorter time and smaller costs. These are, primarily, introducing design task, performing necessary calculations, composing the bill of material (BOM), control, etc. Therefore, it is appropriate to automate at least those functions whose realization requires more time, and subsequently more adjoining costs. The researches impose a need for introducing new technologies into fixture design process, which are based on the so-called flexible automation, and whose main objective is to shorten time and decrease costs when designing new fixture constructions and re-use the existing solutions with or without modification. Fixture design with computer applications presents a newer design aspect (first attempts of fixture design automation go back to the 1980s), originating as the cause-effect answer to the negative aspects of classic design methods. This aspect of fixture design implies the computer application that, partially or completely, automates the sequences of fixture design. The goal is to generate adequate fixture within the acceptable time period and to reduce the designer's subjective influence and labour to the minimum. The most important assumptions for computer application in fixture design process are "translating" the designer's knowledge and experience onto the language that is understandable to the computer, developing selection and decision-making logics, etc.

3. MODULAR FIXTURE DATABASE STRUCTURE

The objective of this paper is to set a concept for a database for automated modular fixture design, which would ensure an integral approach while selecting the existing fixtures, their possible corrections and modifications, as well as new fixture design. The system should enable selecting the necessary fixture to realize a machining operation with different degrees of operational readiness if there is such fixture in the database, or to modify offered solutions or design new ones when there is no solution.

Database ensures system functioning in a sense of qualitative performance of its main functions, data searching and updating. Likewise, it presents main system support to select the existing fixtures, modify them or design new solutions, by setting all the necessary information. For a system to function successfully, database has to have certain datafiles (Fig. 4): fixture datafile, workpiece datafile, and fixture elements datafile.

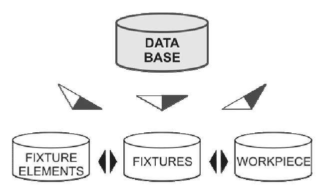

Fig. 4. Database general structure

Datafiles are easy to organize in tables, so that columns present the existing features, workpieces and fixture elements, and rows present their characteristics. Tables can be used in the automated system for selecting, modifying and designing fixtures as a means of formalizing the process of making an algorithm for selecting a variation from a group of possible ones, and as a means of automating the necessary tasks programming.

	Code		Name of operation	Machine		ID code workpiece	Note	Designer		Design date	Drawing	
	ID	CLASS		Name	Code			Name	Surname		2D	3D
Solution 1												
Solution 2												
...												
Solution n												

Table 1. Fixture datafile structure

	ID code	Name	Material	Batch size	Operation		Drawing		
					Code	Name	2D	3D	Operation
Workpiece 1									
Workpiece 2									
...									
Workpiece n									

Table 2. Workpiece datafile structure

	ID code	Name	Functional group	Group of elements	Mass	QTY	Drawing		Technological and geometric characteristics:			
							2D	3D	X_1	X_2	...	X_N
Element 1												
Element 2												
...												
Element n												

Table 3. Fixture elements datafile structure

4. MODULAR FIXTURE DATABASE FUNCTIONING

The main principle used while modelling a database was the principle of hierarchic system decomposition. Modelling began from the demands significant to the future users. The following important processes have been identified:

- Database updating – the process involving data input, change and delete from the base,
- Database searching – the process ensuring the possibility to search through database by previously set criteria.

4.1. Database Updating

Database updating implies input, change or delete of data related to fixture elements, final constructive fixture solutions and their workpieces.

Deleting some data implies removing data from database, i.e. adequate datafile, primarily after usability of an element expires, and so it would not be used in the design process leading to confusion during the modular fixture assembly process.

Data change is done whenever there is a change (geometrical, technological, etc.) of an element, a fixture, or a workpiece, also with the aim to ensure reliable design process.

Data input into a database refers to the input of data linked to modular fixture constructions, modular fixture elements and workpieces, and it is performed in the following cases:

- Supply and/or manufacture of new additional elements of modular fixtures,
- Finished modular fixture design, when it is necessary to be stored into the database together with the adjoining workpiece so the latter could be used subsequently if the need appears.

Information update is performed using forms (Fig. 5). Data are input, changed or deleted in the fields reserved for it and they are automatically updated into appropriate tables in databases. Tables are organized so that rows present different fixture, fixture elements and workpiece variations, while columns show adequate geometric, technological, organizational and other characteristics of each of them individually.

From the form for data input, change and delete, it is possible to generate reports automatically like fixture report, workpiece report or fixture element report (Fig. 6).

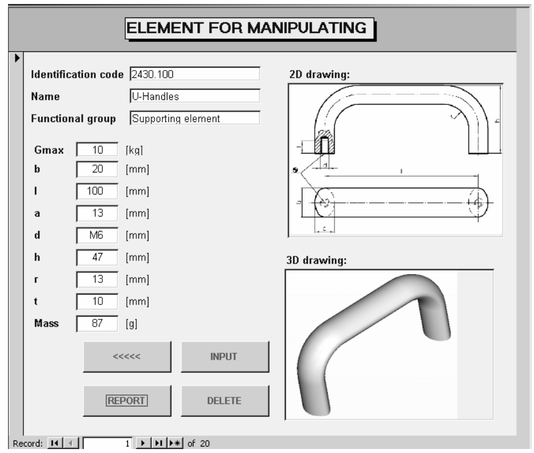

Fig. 5. Appearance of a form for updating fixture element data

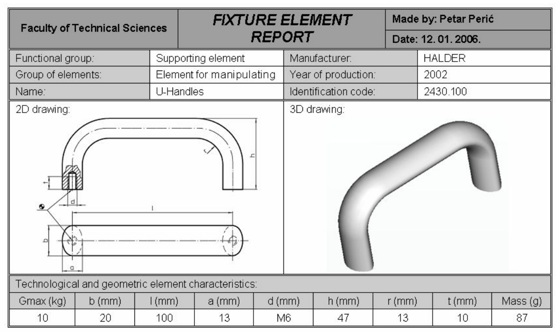

Fig. 6. Database general structure

4.2. Searching database by diverse criteria

The designer uses the option to search database to acquire information on elements and finished constructive fixture solutions. Depending on the demands, the designer defines search criteria. It is possible to name one or several criteria. On the basis of the chosen criteria, adequate forms are generated (Fig. 7), and within them, a selection and/or an input of the adequate parameters (one or more) are performed, since they are to be used for searching later.

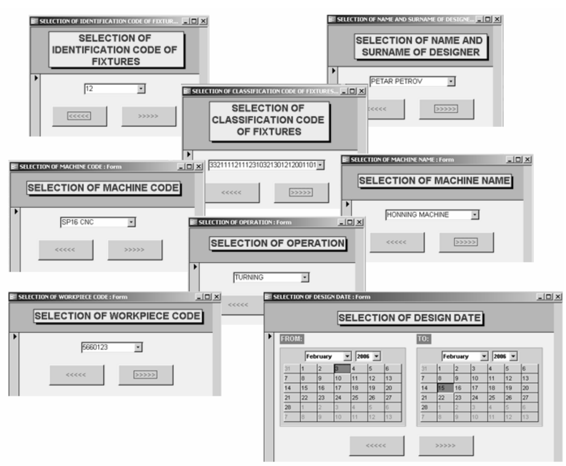

Fig. 7. Forms for searching databases by constructive fixture solutions

This is the way, by setting various inquiries and types of sorting necessary data, to generate different database search reports (Fig. 8). Generated reports are the basis to obtain system output results, i.e. adequate modular fixture necessary to realize a machining operation.

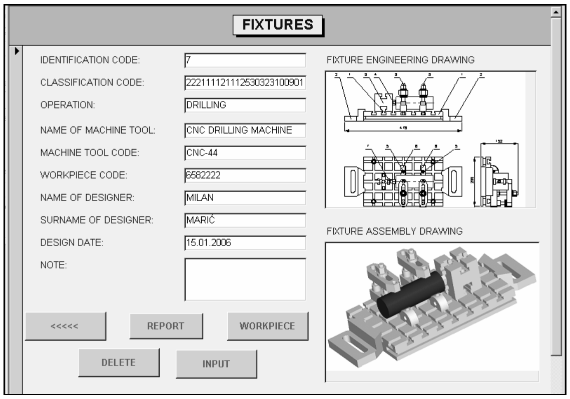

Fig. 8. Form for presenting fixtures

5. CONCLUSION

Modern production is doubtlessly directed towards the increase in productivity, economy, flexibility and working quality. To achieve it, it is necessary to have general databases that efficiently integrate all technical, technological, and organizational functions of an industrial system. The developed database for modular fixtures is one of foundations for developing an integral CAD/CAPP/CAM system that would significantly increase industrial system efficiency in total.

The developed database for automated modular fixture design enables, within technological production preparation, to efficiently reach adequate fixture solutions in the ongoing production, and for given conditions, to find or design the best fixture while conquering a new product or its parts, which is a way to influence the increase in techno-economic output presentations of the total production process.

For wider application of the developed system for automated fixture design and to ensure practical production and financial effects, it is necessary to continue the activities on improving databases, with the adequate number of reliable information bases, that is, proposed and checked contents of adequate data files. Efficiency degree could be further increased if the database was to be integrally linked to some of the automated product design systems. Further research should also be directed towards the integration of the developed systems with program systems for machining process simulation to prevent possible collisions and FEM analyses. It is a way to predict the behavior of fixture and workpiece connections during processing (deformations, oscillations, etc.). That would be a basis to perform optimization of positioning and clamping place on the workpiece.

Finally, it could be said that fixture design with computer application presents a complex problem demanding the knowledge on conventional design methods, declarative and procedural knowledge in the field of fixture design, and knowledge on the application of new methods and design techniques. Since the computers, regarding capacity, memory, speed and working quality, significantly surpass human abilities, fixture design automation enables considerable decrease in design process, decrease in total design costs, and obtaining qualitative solutions. Furthermore, designer's level of satisfaction is higher, while working labour in almost all design phases is lower.

6. REFERENCES

[1] Balasubramanian, S.: *Fixture-Based Design Similarity Measures for Variant Fixture Planning*, University of Maryland, Department of Mechanical Engineering and Institute for Systems Research, 1999.

[2] Campbell, P.: *Basic Fixture Design*, Industrial Press Inc., 1994.

[3] Cecil, J.: *Computer Aided Fixture Design - A Review and Future Trends*, The International Journal of Advanced Manufacturing Technology, Vol. 18, No. 11, 2001, pp 790 - 793.

[4] Henriksen, K. E.: *Jig and Fixture Design Manual*, Industrial Press Inc., 1973.

[5] Hoffman, G. E.: *Jig and Fixture Design*, Thomson Delmar Learning, 2003.

[6] Lin, Z. C. Huang. J. C.: *The fixture planning of modular fixtures for measurement*, IIE Transactions, Vol. 32, No. 4, pp. 345-359, 2000.

[7] Joshi, P. H.: *Jigs and Fixtures Design Manual*, McGraw-Hill Professional, 2002.

[8] Nee, A.Y.C., Tao, Z. J. and Senthil Kumar, A.: *Advanced Treatise on Fixture Design and Planning*, World Scientific, 2004.

[9] Pehlivan, S., Summers, J. D.: *A review of computer-aided fixture design with respect to information support requirements*, International Journal of Production Research, Vol. 46, No. 4, pp. 929-947, 2008.

[10] Rong, Y., Zhikun, H. and Huang, S. H.: *Advanced Computer-aided Fixture Design*, Academic Pr, 2005.

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SIVUR SOFTWARE APPLICATION FOR MODELING OF PENDING CONVEYER

Abstract: *Management and running of technological processes of production, warehousing, packing, shipment of finished products to buyers, etc. often is not possible without appropriate transportation system in multi floors production facilities. Therefore all design processes, construction and dimensioning, of transportation systems need to be rationalize, speed up, and make them as simplest as possible. In this paper is presented developed utilize software "SIVUR" as a tool for rationalization of constructional and working parameters calculation during development of new one or changing of parameters on existing pending conveyors.*

Key words: *internal transport, pending conveyer, modelling, simulation*

1. INTERDUCTION

Modern development and technological improvements had a great impact on structure, management and philosophy of production systems regardless to industrial field which they belong. It is important to note that, by opening of local markets in last few decades, is made such ambient that existence of production systems in any moment is very questionable, in other words on global market only the best survives. This situation doesn't need to be consider as a threat, contrary this situation can be consider as a opportunity. Namely, only production systems whose existence is based on innovation, efficiency and economical sustainability will be able to advance and enlarge its share on global market. Main goal of each production system is achievement of planned production (quantitative, qualitative and on time). All processes in production systems, except direct manufacturing, are costs making processes (transportation, quality control, warehousing, preventive maintenance, etc.), there is no creation of additional values to products. However, those cost making processes are necessary in production processes, and because of that it is important to find the methods to decrease/minimise share of those processes in whole production cycles. Modern production systems required that this decreasing/minimising of cost making processes share in production cycle need to be implement during whole production system life, from a moment of business idea creation until a moment of closing of business subject. Implementation of this approach significantly increases concurrent abilities of business subject and its belonging production processes.

1.1 Role of internal transport in production systems

All production processes irrespective to theirs kind have one common point and that is transport, disregarding to type of transported goods (row materials, intermediate goods, finished products, etc.). Significance of transportation for production systems is reflected thru its share in price of finished products. Depending to industrial area amount of transportation costs is between 20 and 90% of total production costs [1]. In following text, of this paper, transportation systems as a fundamental part of production systems in detail are considered. Specifically, internal transportation system - pending conveyer is installed in metal processing factory for transportation of finished parts between production lines and storage on ground floor. Observed transportation system has direct influence on [2]:

- Timely transportation of semi-finished products to given or within technological departments with the aim to fulfil whole manufacturing process;
- Work productivity;
- Manufacturing costs;
- Amount of investment in building of production system;
- Utilisation of working area in production and storage objects, etc.

More and more dynamical development of transportation systems and devices create important presumptions for implementation of modern solutions for material flow control within production systems. Flow of material in production systems in most cases presents integrative factor, and in the same time area with significant reserves and opportunities for production rationalisation (time of material flow, time of serving, time of delay, etc.). Modern approaches to building of production capacities in industry imply building of factories facilities on several floors too. In this way significant reducing of facility/es building costs is possible, through reducing of investment in base ground area and infrastructure.

Management and running of technological processes of production, warehousing, packing, shipment of finished products to buyers, etc. often is not possible without appropriate transportation system in multi floors production facilities. Therefore all design processes, construction and dimensioning, of transportation systems need to be rationalize, speed up, and make them as simplest as possible. Possibilities of informational technologies implementation in above mentioned transportation systems design processes was inspiration for creation of utilize software for working parameters of pending conveyor calculation.

2. SOFTWARE „SIVUR“

Developed software "SIVUR" (SIVUR - Software for rationalisation of pending conveyors calculation), created in Visual Basic, is a tool for calculation and optimisation of construction and working parameters of pending conveyers with possibilities of conveyer's contour variation. Named software has data bases for calculation coefficients, building element characteristics and has capability for graphics processing of gain results. Algorithm for calculation on which is software "SIVUR" based is presented on figure 1.

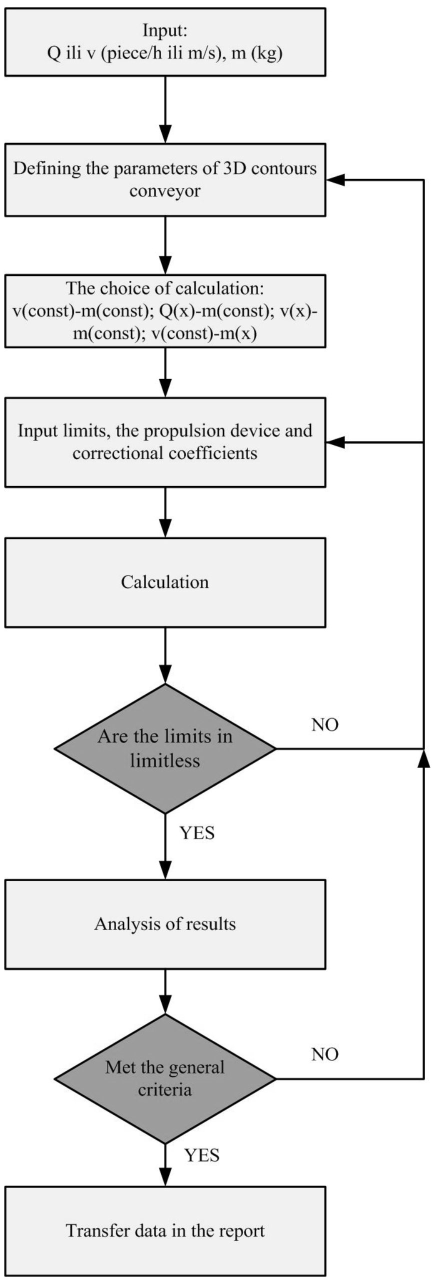

Fig. 1 Algorithm of "SIVUR" software

In the first phase is require: to propound main input data (weight of transported material, speed/capacity), to generate 3D contour of pending conveyor and to indicate construction points at conveyer (places for chain tighten, places for driving elements, places for loading and unloading).

Fig. 2 Layout of pending conveyer

Next step is optional and allows selection of calculation type, apropos methods for parameters calculation. Following combinations of calculation methods are available:

- Speed (constant)- weight (constant),
- Capacity/speed (variable)- weight (constant),
- Speed (constant) - weight (variable).

By afore mentioned option of calculation type selection, "SIVUR" achieve additional flexibility and enables some kind of a working parameters area scanning with the aim to find weaknesses (insufficient capacity of actuating device, insufficient strain of chain, to large strain force in chain, material strength violation of pending conveyor constructional elements, etc.) in constructional and working parameters.

In following step user need to select boundary values, correctional coefficients and characteristics of driving devices (guiding chain).

By finishing of previous presented steps process of input parameters defining is finished and calculation phase begin. Calculation phase is fully automatic, and it finished by presentation of preliminary results through diagrams and textual files (intensity of contour forces – figure 3, strain forces/weight, circular forces on sprocket wheel – figure 4, minimal allowed distance between transported pieces, maximal load of hanging trolleys, load of hanging trolleys over horizontal, vertical and curvature sections, and derived values such as: power of electric engine, load of hanging trolley bearings, etc.). In the case of unsatisfactory calculated results or if calculated results are not included in set up boundary values there is an option for correction of input data and recalculation. If the calculated results are satisfy and in set up boundary values then final textual file with results, finale diagrams and numerical presentations are created and available to users. In this phase user can return in initial phase – setting of input data too, with the aim to perform certain corrections over construction or working parameters of pending conveyor.

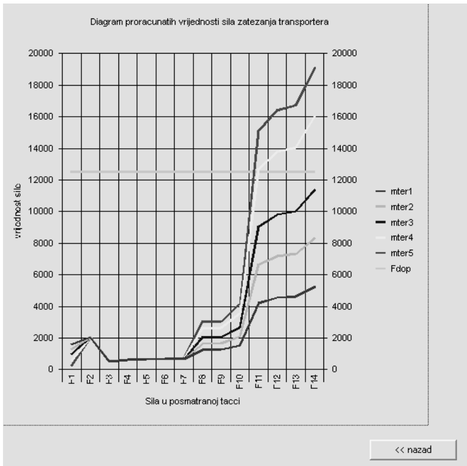

Fig. 3 Diagram of contour forces

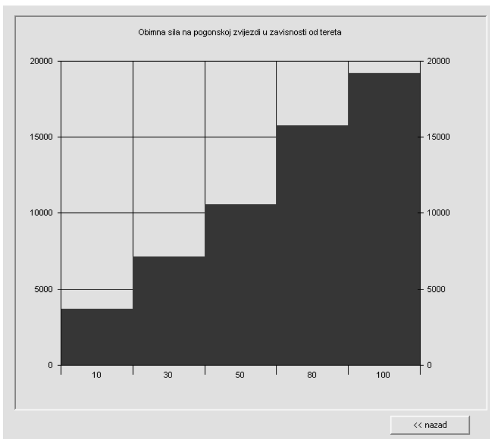

Fig. 4 Dependency of circular force on sprocket wheel

When verification process of general calculation is finished user has opportunity to generate report about accomplished process of pending conveyor designing. Additional software "SIVUR" allow user to utilize interface with another software through recording of wanted parameters in **.txt* form.

3. APPLICATION OF „SIVUR“SOFTWARE IN INDUSTRY

3.1 Characteristics of model

Developed software "SIVUR" is implemented in analysis of loads of industrial pending conveyer, with construction parameters adopted from literature [3]. The software was used in innovation process for improvement of existing pending conveyer characteristics according to new working parameters:

- Conveyer capacity: Q_{max}=1400 pcs/h, v_{max}=0,5 m/s;
- Transported weight: m_{max}= 250 kg;
- Transportation loads distance: t=1,28 m.

Current working parameters of pending conveyer are:

- Conveyer capacity: Q_{max}=1125 pcs/h, v_{max}=0,4 m/s;
- Transported weight: m_{max} = 30 kg;
- Transportation loads distance: t=1,28 m.

Due to fact that transportation systems are usually design with certain reserve in construction and working parameters it is necessary to verify are existing parameters satiable for new placed criteria. By this way will be possible to avoid unnecessary investment in new transportation system – pending conveyor. Only appropriate adjustment of existing construction of pending conveyor will be sufficient.

On figure 5 is present trace of pending conveyor installed in observed production facility. Adopted minimal tension force is 500 N, and it is presumed in point 3 of pending conveyer trace. Driving element is in point 1, and dragging elements are in points 4 and 5.

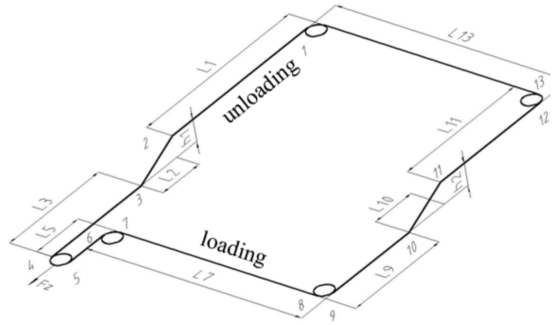

Fig. 5 Route of observed pending conveyor

For analysis of observed transportation system is used following variation of working parameters:

- For speed: v=0,05; 0,15; 0,25; 0,35; 0,45; 0,5 m/s;
- For weight of transported material: m=10; 25; 50; 75; 100; 125; 150; 175; 200; 250 kg.

By this distribution of working parameters was tried to get access in all working conditions of transportation system, in other words it was tried to notice working conditions which are above boundary conditions.

3.2 Results of calculation

In the table 1 are presented aggregate results gain by implementation of software "SIVUR", and in figure 6 is presented diagram of contour forces which appear in observed working area of pending conveyor. It is important to emphasize the fact that by analysing of above mentioned results is possible to conclude where boundary of pending conveyor dragging elements is.

m (kg)	10	50	150	250
v (m/s)	0,5	0,5	0,5	0,5
F_{dop} (N)	29652			
F_{max} (N)	4844,2	8703	18351	27999
F_{min} (N)	1748,6	1380,7	461	-458,7
W (N)	3157,5	7469	18247	29026
P (kW)	2,1	4,97	12,17	19,35

Remark:
F_{dop} – allowed force in chain
F_{max} – maximal force in chain
F_{min} - minimal force in chain
W – cylindrical force on drive sprocket wheel
P – theoretical power of electro motor

Table 1 Results of calculation - summery

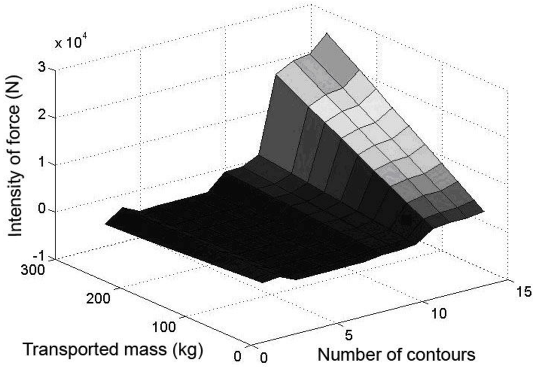

Fig. 6 Diagram of pending conveyor contour forces

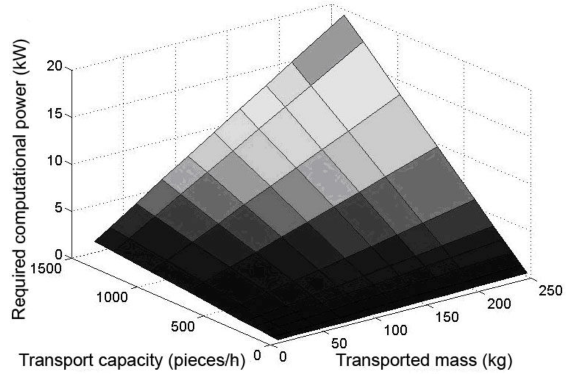

Fig. 7 Diagram of required theoretical power of pending conveyor

Thru analysis of gain data it is possible to conclude that with maximal transportation weight of 250 kg, forces which appear on chain don't override allowed limit for tension of chain, which is 29652 N. Taking in to account criteria of chain minimal tensile force, which is F_{min}=500 N and by analysis of calculated data for contour force values it is possible to conclude that with transportation weight above 150 kg on contour 1 this condition is violate. Reason for this occurrence can be explained by the fact that with unloading of transportation weight, chain is relieved till degree that tensile state becomes state of total unloads (with transportation weight 250 kg, tensile force in point 1 is F_1=-458,7 N). On basis of presented case transportation weight is limited on 150 kg or it is necessary to increase tensile force in chain with the aim to avoid above mentioned phenomena.

In the next step strength of construction elements material of pending conveyor is tested, taking in to account extreme values gain by calculation. By this way degree of security for values above boundaries values is defined.

Due to changing of working parameters need for adjustment of driving elements to new conditions is appeared. According to those new conditions diagrams of theoretical force, transported weight and transported capacity dependencies are created, table 2 and figure 7.

m (kg)	250	250	250	250
v (m/s)	0,01	0,25	0,35	0,5
W (N)	29026			
P (kW)	0,387	9,68	13,55	19,35

Table 2 Summary results of required theoretical power of electric motor

4. CONCLUSION

With the aim to provide production of wide scope of products in production systems it is necessary to implement internal transportation systems with proper level of flexibility. Work of those systems must be completely planed in the order to avoid unnecessary flow of materials. One of possibilities for fulfilling of above mentioned request can be achieved through creation of mathematical model.

By implementation of created mathematical model for designing and defining of pending conveyor construction parameters optimisation of certain values is enabled. In addition, if there are demands, during exploitation, for changing of pending conveyor working parameters, by implementation of developed mathematical model, adjustment of construction and working parameters of analysing internal transportation system are possible for relatively short period of time.

5. REFERENCES

[1] M. Klarin: *Industrijski inženjerstvo Knjiga II – Organizacija unutrašnjeg transporta i upravljanje kvalitetom*; Univerzitet u Beogradu, Mašinski fakultet, Beograd, 1995.

[2] R. Šelo, Dž. Tufekčić: "Fleksibilni transport", Mašinski fakultet u Tuzli, Tuzla, 2002.

[3] S.B. Tošić, *Proračun mašina neprekidnog transporta i dižaličnih uređaja*, Univerzitet u Beogradu ,Mašinski fakultet, Beograd, 1994.

[4] Dž. Tufekčić, M. Jurković: *Fleksibilni proizvodni sistemi* , Mašinski fakultet u Tuzli, Tuzla, 1999.

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APPLICATION OF REVERSE ENGINEERING BASED ON FEATURE RECOGNITION

Abstract: *In this paper application of reverse engineering based on feature recognition is shown. Short description of measurement, data analysis and method of creating CAD model with emphasis on potential errors is also given. This method proved to be quick and efficient in cases when element is defined with relatively prime geometric shapes. Applied method of reverse engineering enable easy verification of CAD model with real measurements, which simplify next step in creation needed tool for late production.*
Key words: *reverse engineering, feature based recognition, CMM*

1. INTRODUCION

With the rapid development of 3D data acquisition devices, design, a first step in process of development and planning, along with *RE* (Reverse Engineering) has become increasingly easier than ever before. Digital design applications such as *CAID/CAD* (*Computer Aided Industrial Design*), *CAE* analysis (*Computer-Aided Engineering analysis*) and *RP* (Rapid prototyping) are helping designers in conceptualizing, visualizing, prototyping and delivering product models; and shortening the concept-to-market lead time, enabling product better placing on market. The goal of RE is to generate a *CAD* model from measured data of a physical model as a replica of the original one, and pass the *CAD* model to *CAE* and *CAM* (*Computer Aided Manufacture*).

There are many ways for application of RE, but any method contains following steps, which may be different from method that has been used:

- 3D scanning of physical projects, typically generation a point cloud or points that will give us required forms
- Data processing such as noisy data removal, smoothing, sampling or any operation that is used to remove errors which may be due to errors of measurement equipment or methods of measurement.
- Surface reconstruction from *mesh* or point cloud by direct surface fitting or surface reconstruction through curves such as section of curves and feature lines – creating *CAD* model form taken data
- Application of *CAE* analysis of the new model, its modification and optimization

The results of RE are usually surfaces that need to be imported into 3D CAD software. Modeling technologies are at the heart of *CAD* and *CAID* software packages. There have been a lot of developments in the area of modeling technologies during the last decade. Using this software, imported surfaces can be modeled and later used in *CAE* analysis or in *RP*. [1]

Today RE is used in almost all areas where is necessary to replace the worn part or modify part to better fit into the whole, quickly and with high precision, be it on a machine or part of the human body. The paper [2] shows typical application of RE in the field of mechanical engineering. The process of obtaining new work from worn is the same as shown in the above sequence.

2. FEATURE BASED RE WITH APPLICATION OF STEP

Feature based *RE* is based on the recognition of geometric entities by the software for data collection. One such software is Calypso. Specifically, using a *Carl Zeiss*'s CMM *Contura G2* Coordinate Measurement Machine (CMM) for data collection from the working part and the use of Calypso software, one can very easily collect basic geometric characteristics of the working part. *CMM Contura G2* is bridge-type measuring machine for measuring physical characteristics of geometric objects. The data acquisition is done using mechanical probe that have direct contact with the work piece, which is on the desk, preferably bonded in order to eliminate moving of work piece, thereby reducing the error of measurement.

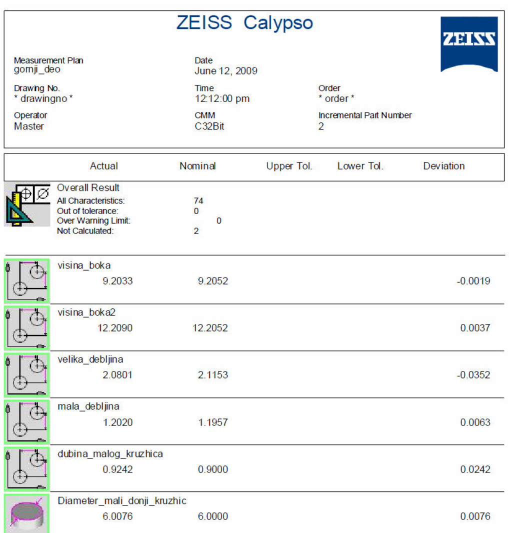
3. MEASUREMENT

The main task is obtaining a *CAD* model of the work piece. Work piece consists of two elements: casing, which consists of two parts: upper and lower part, and a button for potentiometer. The bottom of the case is appropriate for storing electrical elements and the subsequent fixation of the element which will be attached. The upper part has a role to protect the electrical elements and makes the connection between the casing and button for potentiometer, which is connected to the electrical elements.

When considering the ways for the collection of data from the work piece/part, it was decided to retain the feature-based recognition. Although the part contains large number of elements, particularly the inner area of the lower part, they are all relatively simple geometric shapes (cylinders, cones, prisms, etc.). The program itself recognizes geometric shapes based on the number of recorded points from the part. For the simplest geometric form - the plane (which may represent one of the sides of a more complex geometric form) is sufficient to take 3 points that do not belong to the same line. Of course, measurement accuracy is increased if a greater number of points are used.

Before the start of the measurement it is necessary to properly calibrate the measuring equipment, according to manufacturer's instructions. After the calibration is done, it is necessary to choose a coordinate system. Coordinate system is chosen to provide easy organization of later received data, and easy manipulation with STEP files *(STandard for the Exchange of Product model data)* if such files are used for inspection in the appropriate *CAD* programs.

The results of measurement are presented via generated report in PDF format (*Portable Document Format*) for each element that is measured, shown in Fig. 1, its coordinates, error of measurement (nominal value and the actual measured value), diameter if a measured element is cone/cylinder/circle etc..



ZEISS Calypso

Measurement Plan: gornji_deo
Date: June 12, 2009
Drawing No.: * drawingno *
Time: 12:12:00 pm
Order: * order *
Operator: Master
CMM: C32Bit
Incremental Part Number: 2

	Actual	Nominal	Upper Tol.	Lower Tol.	Deviation
Overall Result All Characteristics: 74 Out of tolerance: 0 Over Warning Limit: 0 Not Calculated: 2					
visina_boka	9.2033	9.2052			-0.0019
visina_boka2	12.2090	12.2052			0.0037
velika_debljina	2.0801	2.1153			-0.0352
mala_debljina	1.2020	1.1957			0.0063
dubina_malog_kruzhica	0.9242	0.9000			0.0242
Diameter_mali_donji_kruzhic	6.0076	6.0000			0.0076

Fig. 1. Generated report in pdf form

The report can also be generated in the form of STEP record which suggests that further modeling continues to use a CAD software (ProEngineer, Catia, SolidWorks ...).

CALYPSO work environment (Fig. 2) offers the opportunity for high quality recording of the given values. Recorded data can be shown in tables and be used for later modeling, or data can be saved like STEP universal file that can also be used to create *CAD* model of work piece.

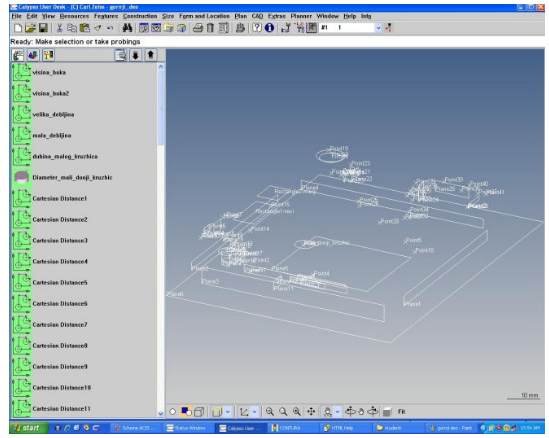


Fig. 2. *CALYPSO* work environment

Data recorded during the measurement are shown in working environment, this way measurement plan can be easily modified or unnecessary data can be removed. Described system provides easy control of shape and size because it allows defining some of elements based only on control points as shown in Fig. 3.

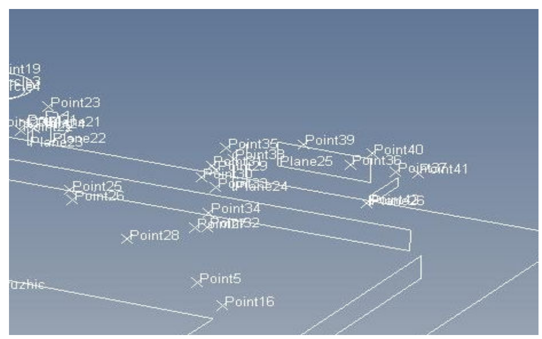


Fig. 3. Defined control points

Feature based recognition offers a very fast way of recording dimensions. In this way, through several points (depending on the complexity of the object) segment shape of the object is defined. In this case, the measuring device recognized several planes, the angle and skew of their holes - described in Fig. 4. Specifically it's about the upper part of the casing. After data processing, *CAD* model shown in Fig. 5 can be made, in this case using software *CATIA V5*.

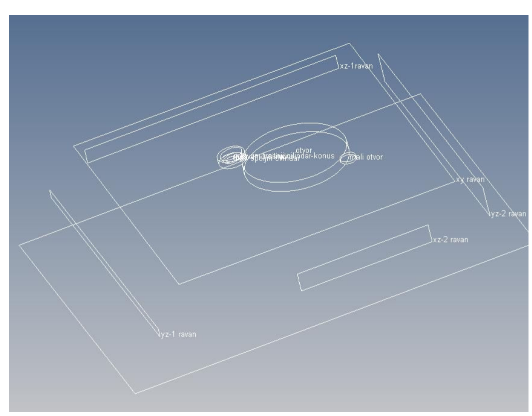


Fig. 4. Identified entities of measured element

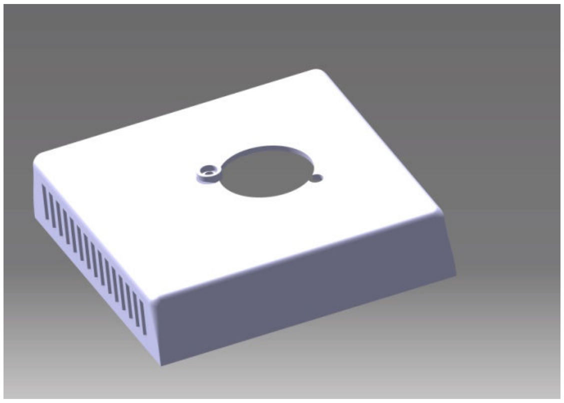


Fig. 5. *CAD* model of the upper part of casing

It should be noted that the obtained STEP record, should not be understood as simple solution of problems related to creating the final model. Generating STEP file in this case is the result of recognition of the entity, however, such an entity is recognized only as a basic form of two relevant information - dimensions and orientation of such entities in space. Information on the primitives that are recognized cannot be used in such original form. STEP file must be processed with the help of other entities, and only then can be used for verification.

One such STEP file is shown in Fig. 6. This picture shows the file that was obtained by recording the points from the button of potentiometers. Although the real subject of the sphere consists of clippings of sphere, feature based recognition in this case gives the entire sphere. Over other information, such as the position of the plane that intersect sphere, more realistic image of the investigated object can be created. One such segment is displayed in the same picture; in this case the larger diameter of the sphere is cut off from the previously identified plane.

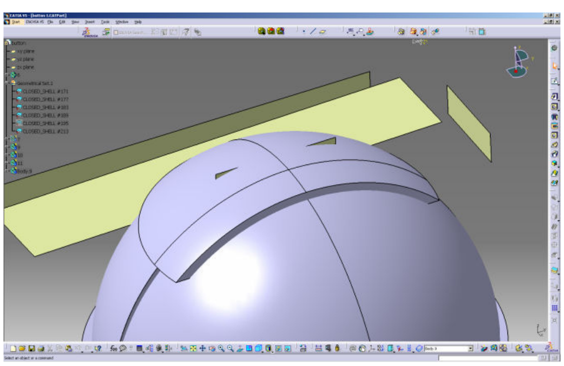


Fig. 6. STEP processing results in the CAD program

Measurement accuracy depends on the measurements and equipment, but in this case there may be an error, which is located in the original part. Because the spheres which constitute the part don't have the same center point, which is the result of error design, these errors in the STEP file can/must be corrected (knowledge of the position of the center of the sphere) shown in Table 1, described in Fig. 7.

	S_l	S_c	S_i
G_x	51.925	51.325	50.95
G_y	23.475	23.875	23.875
G_z	13.4	13.4	13.4

Table 1. Coordinates of centers of shperes
S_l - Large (outer) sphere
S_c - Central Sphere
S_i - Small (inner) sphere
Gx - coordinates of the center of the sphere at x-axis
Gy - coordinates of the center of the sphere at y-axis
Gz - coordinates of the center of the sphere at z-axis

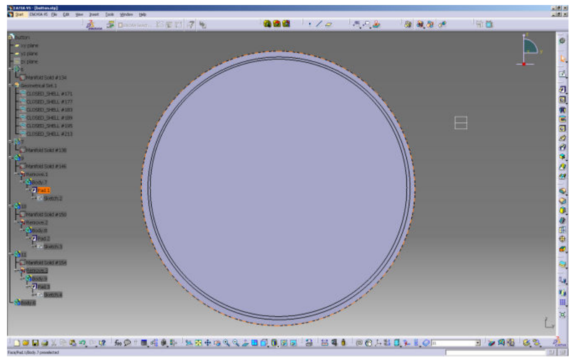


Fig. 7. Measurement deviations of recorded entity

It can be noted that in this case error occurred only in x and y axes. Knowing the size of such errors CAD model can be created so that its digital model actually does not have that kind of error, and as such is much more favorable for the development of tools for its future development, in this case tools for plastic injection. In other words, the method offers creation of new model that may contain fewer errors than the examined original subject.

4. VERIFICATION

One of the benefits of STEP file is verifying the correctness of the *CAD* model with a point cloud and determination of possible errors, as to their size and areas where these errors appear. It should be noted that every *CAD* program have their own module for displaying required distance between objects; in this case module of *CATIA V5* was used.

Fig. 8 shows the case when an error exists, which is higher than the values that are tolerated, such deviations are marked in red. Fig. 9 shows the case when the errors are smaller than the values that are tolerated, where the tolerance is selected depending on the needs of manufactured item. Exactly the same operations can be performed with scanning complex surfaces, but such areas would not be spherical segment, but a curve surface which can be approximately regarded as a spherical segment. Exactly here we can see advantages of feature recognition method, which in combination with STEP files provides a very easy verification.

Table 2 shows the creation of models of his physical appearance to the final digital CAD format.

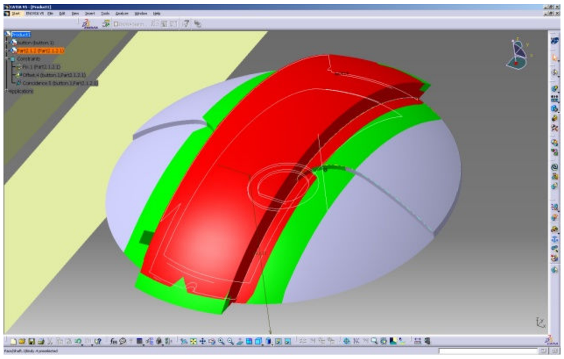


Fig. 8. Verification with not allowed deviations

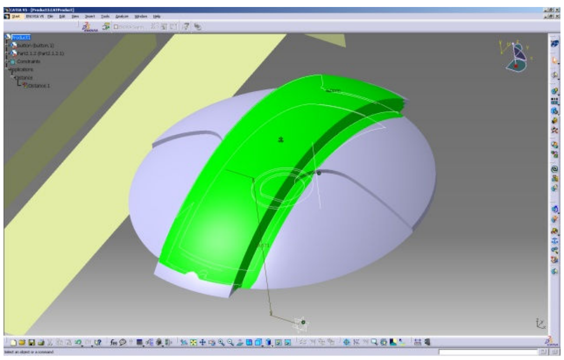


Fig. 9. Verification with allowed deviations

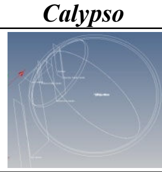
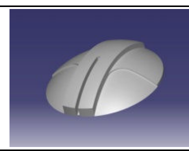
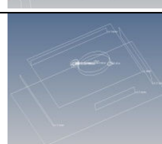
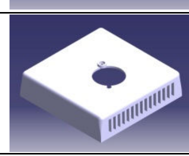
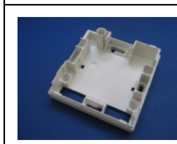
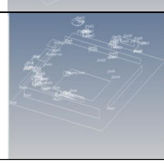
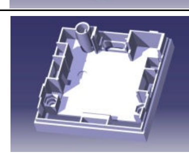
Photo	*Calypso*	*CATIA V5*
		
		
		

Table 2. Comparative view of real part, Calypso and CATIA model

5. CONCLUSION

The paper describes the process of reverse engineering with emphasis on feature based recognition method. This way of recording entity proved to be very fast and quality way for the design *CAD* model. Processing of these data is relatively simple and fast, which provides users with an easy ability to create *CAD* models and their verification with the actual model. Feature based recognition method should not be understood as a method that offers a simple solution to create *CAD* models, but as a quick method of determining the basic geometric shapes in combination with other entities or points offers easy to scan the surface. This method should be used only for the elements with predominantly simple geometrical shapes, applying these methods to some complex shapes is very difficult and creates a comprehensive process than the standard recording points. Shown is an example of scanning surface element is intended for mass production, where given the opportunity to review the adjustment of real dimensions in order to accurately design tools for the production of such elements.

6. REFERENCES

[1] Ye, X., Liu, H.: *Reverse innovative design - an integrated product design methodology*, Computer-Aided Design, Vol. 40, pp. 812–827, 2008.

[2] Bagci, E.: *Reverse engineering applications for recovery of broken or worn parts and re-manufacturing: Three case studies*, Advances in Engineering Software, Vol. 40, pp. 407–418, 2009.

[3] Budak, I., Hodolič, J., Bešić, I., Vukelić, Đ., Osanna, P. H., Durakbasa, N. M.: *Koordinatne merne mašine i CAD inspekcija*, Novi Sad, Fakultet tehničkih nauka u Novom Sadu, 2009

[4] Budak, I., Hodolič, J., Soković, M.: *Development of a programme system for data-point pre-processing in Reverse Engineering*, Journal of Materials Processing Technology, Vol. 162-163, pp. 730-735, 2005.

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TESTING SOME SIGNIFICANT PARAMETERS ON MEASUREMENT ERROR OF COORDINATE MEASURING MASHINE

Abstract: *Latest generation of Coordinate Measuring Machines are complex mechatronic products that have they own parameters of accuracy. CMMs are used for a wide range of precise measurement and inspection tasks including complex parts with curved lines and shapes. CMMs are used in metrology laboratories as well as on shop floor. They are often exposed to variety of microclimatic influences on accuracy (temperature, humidity, dust, noise, vibrations). Therefore it is necessary to investigate precision and accuracy of machine after installation as well as in production.*

Key words: *CMM, measurement error, precision, accuracy*

1. INTRODUCTION

Latest generation of Coordinate Measuring Machines (CMMs) are complex mechatronic products that have they own parameters of accuracy. CMMs are used for a wide range of precise measurement and inspection tasks including complex parts with curved lines and shapes. CMMs are used in metrology laboratories as well as on shop floor. They are often exposed to variety of microclimatic influences on accuracy (temperature, humidity, dust, noise, vibrations). Therefore it is necessary to investigate precision and accuracy of machine after installation as well as in production.

With CMMs it is not possible to specify measurement accuracy for all measurement types because:

- CMMs can measure all geometrical properties of work pieces. Other measuring equipment can measure only one type of task,
- Measurement results are made from number of points obtained from surface of the work piece,
- Object can be measured utilizing various measurement strategies and on various locations on the measurement table and
- The method used for coordinate system definition respond to the data sampling.

2. MEASUREMENT ERROR ESTIMATION

Standards used for measurement error estimation are defined for maximum allowed error for clearly defined measurement task (for example ISO 10360). These values are designated as MPE with a subscript. In this context “error” is not something “wrong” but something that can be allowed.

Maximum allowed error for dimensional measurement of parallel and ladder gage blocks is designated as MPEE (Fig. 1).

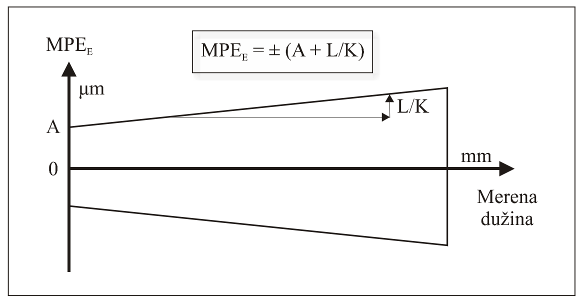

Fig. 1: Maximal dimensional length error [2]

MPEE is a function of length L. All the measurement result must lie in denoted field.
General directive is:

$$MPEE = \pm (A + L/K) \qquad (1)$$

Where A and K are constants that the manufacturer is specifying.

Errors that have influence on CMM accuracy can be divided in two categories:

- Errors from CMM itself
- Errors from the environment.

The main causes that leads to geometrical errors of CMMs are:

- errors from straightness and perpendicularity of modules of the machine,
- errors from inner strains of material,
- errors from friction between moving elements of the machine,
- errors from plastic deformation caused by applied mass, forces inertia and friction,
- errors of position off coordinate system relative to referent coordinate system

Errors sourcing from the environment and from the work piece can be divided in three categories sourcing from:

- Environmental influence,
- Influence from the work piece and
- influencing from operator.

Errors from environmental conditions and from the workpiece are:

- temperature variation in the laboratory or the shop floor where the CMM is installed,
- vibrations in measurement,
- humidity,
- non cleared work piece or machine or sensor ,
- surface quality of the work piece,
- surface hardness of the workpiece,
- mass,
- elasticity of the workpiece,

Errors from the operator point are:

- selection of measurement strategy,
- controlling the machine,
- fixturing and
- CMM service.

When the sources of errors of measurement are analyzed, it can be concluded that they are various. More concise way of showing those sources is a “fish bone” method shown on the Fig. 2.

Knowing the influencing factors and knowing the relationships between them is a key to improving CMM accuracy trough compensation of errors.

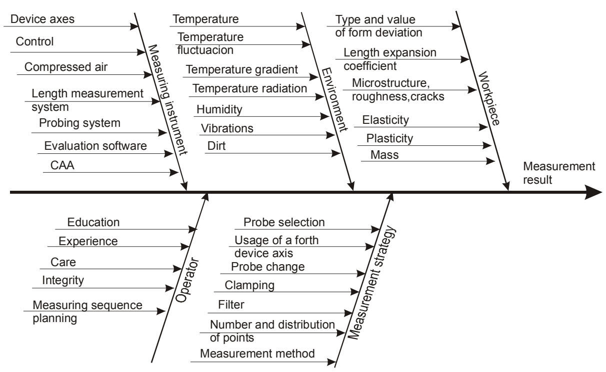

Fig. 2. Influencing parameters on CMM in working mode [3]

3. INVESTIGATION SET-UP

In order to investigate CMM accuracy and its relation to parameters of measurement strategy, measurement of callibration ring of fixed diameters have been conducted (Fig. 3.). The difference between measured and callibrated diameter of rings was indication of accuracy of selected measurement task.

Fig. 3. Callibrated rings with diameters d_2

The measurement task was completed using Zeiss Contura G2 CMM installed at Laboratory for measurement, fixtures, quality and environmental engineering.

Parameters that have been selected for possible impact on CMM accuracy were:

- stylus tip diameter d_1,
- scanning speed v,
- callibrated ring diameter d_2 and
- number of probed points n.

The abouve mentioned parameters where selected by the means of possibility to control and availability. For example, measuring speed is parameter easy to control. The diameter stylus tip is available only for fixed number of tip diameters. The selected styli are show on Fig. 4.

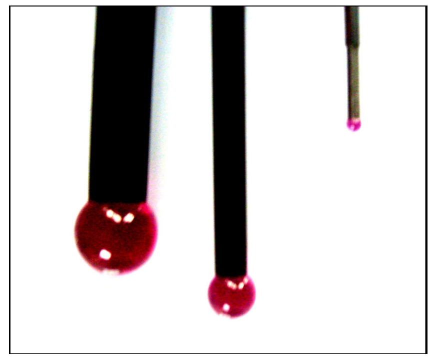

Fig. 4. Stylus tips with diameters d_1 = {2, 3, 5}[mm]

The position of center of calibrated rings was hold contstant, using the fixture. Ambient temperature was also hold constant.

The whole measurement plan along with the experiment results is presented in Table 1.

r. br.	***red. mer.***	***d_1* [mm]**	***d_2* [mm]**	***n***	***v* [mm/s]**	***ΔD* [mm]**
1	13	5	79.9995	600	20	0,0006
2	5	2	79.9995	600	20	0,0008
3	16	5	19.9995	600	20	0,0032
4	3	2	19.9995	600	20	0,0035
5	7	5	79.9995	50	20	0,0007
6	11	2	79.9995	50	20	0,0009
7	14	5	19.9995	50	20	0,0032
8	20	2	19.9995	50	20	0,0039
9	6	5	79.9995	600	5	0,0013
10	9	2	79.9995	600	5	0,0014
11	18	5	19.9995	600	5	0,0003
12	4	2	19.9995	600	5	0,0003
13	15	5	79.9995	50	5	0,0019
14	19	2	79.9995	50	5	0,0014
15	2	5	19.9995	50	5	0,0003
16	10	2	19.9995	50	5	0,0030
17	12	3	39.9995	173	10	0,0005
18	8	3	39.9995	173	10	0,0005
19	1	3	39.9995	173	10	0,0006
20	17	3	39.9995	173	10	0,0006

Table 1. Design of experiment matrix

Only limit of the CMM was a limit of number of sampled points per second. This limitation was used when selecting combination of number of points per circle on the smallest circle and fastest scanning speeds. The limitation is connected to control system of the machine and is cca. 200 points/sec.

Two examples of plots are shown on figure 5 and figure 6. Figure 5 shows plot of measurement points and least square circle for measurement with greatest error (measurement number 8) in experiment. The combination of parameters for this measurement was diameter of stylus tip, diamater of calibration ring and number of sampled points on low level and scanning speed on high level.

The measurement number 15 shows plot for the same callibration ring with different stylus and scanning speed on low level.

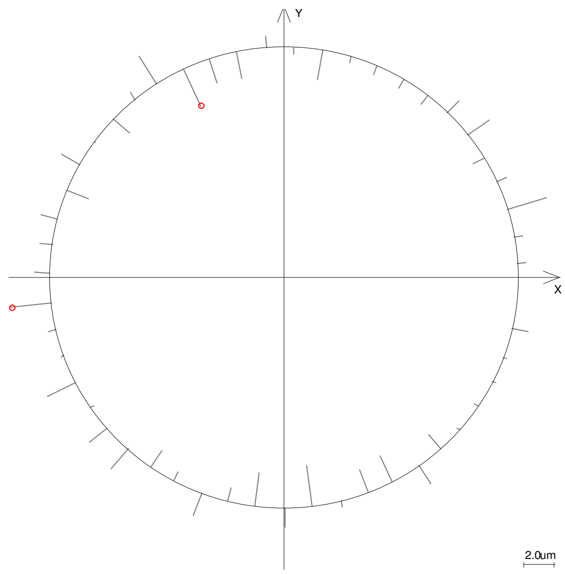

Fig. 5. Measurement results plot for measurement number 8

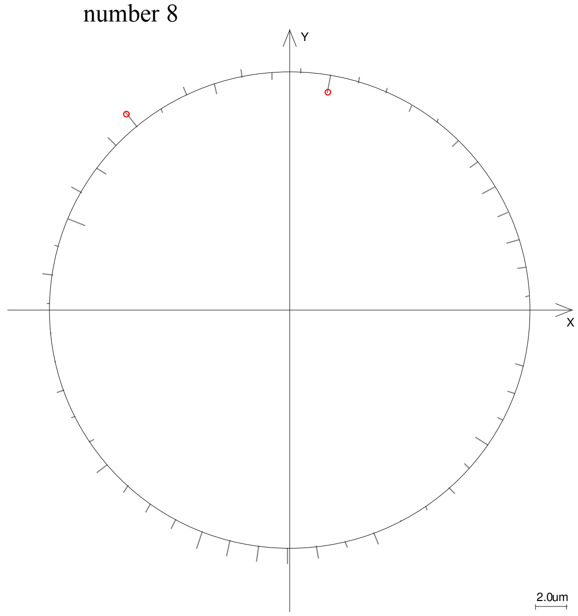

Fig. 6. Measurement results plot for measurement number 15

These two plots are offten used for documenting and analysis of roundness. The lines shown on both Figures show the sampled points from the real surface with magnification of deviation from the Least SQuare feature (LSQ). In this case the magnification is around 5000 times and the LSQ feature is a circle with resulting diameter. This diameter is used in futher analysis. The maximum and minimum points can be also observed by this graph. They are denoted with a smaller circles.

4. RESULTS ANALYSIS

For the purpose of measurement results analysis an exponential mathematical model was selected.

$$\Delta D = C \cdot d_1^{\beta_1} \cdot d_2^{\beta_2} \cdot n^{\beta_3} \cdot v^{\beta_4} \quad (1)$$

After linearisation and coding the model becomes

$$\hat{y} = b_0 x_o + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 \quad (2),$$

and is suitable for the linear regression analysis. Using the data obtained by measurement the problem becomes a linear system of equations.

$$\begin{bmatrix} -7,41858 \\ -7,13090 \\ -5,7446 \\ -5,65499 \\ -7,26443 \\ -7,01312 \\ -5,74460 \\ -5,54678 \\ -6,64539 \\ -6,57128 \\ -8,11173 \\ -8,11173 \\ -6,26590 \\ -6,57128 \\ -8,11173 \\ -5,80914 \\ -7,60090 \\ -7,60090 \\ -7,41858 \\ -7,41858 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 \\ 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 \\ 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 \\ 1 & -1 & -1 & -1 & -1 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix}$$

After solving this system of equations the model constant b_0 and all four b_i parameters are obtained, thus the model is being determined

$$\triangle D = 0,001 \cdot d^{-0.198} \cdot D^{-0.092} \cdot n^{-0.077} \cdot v^{0.211} \quad (3)$$

For the purpose of modeling and calculation a *Dataplot* engineering and scientific software was used (Fig. 7.).

Figure 8 shows plot of this model of measurement error for replication points (d_1=3[mm], d_2=39.9995[mm] and n=173 points) and scanning speed range from 0.1 to 20 [mm/s].

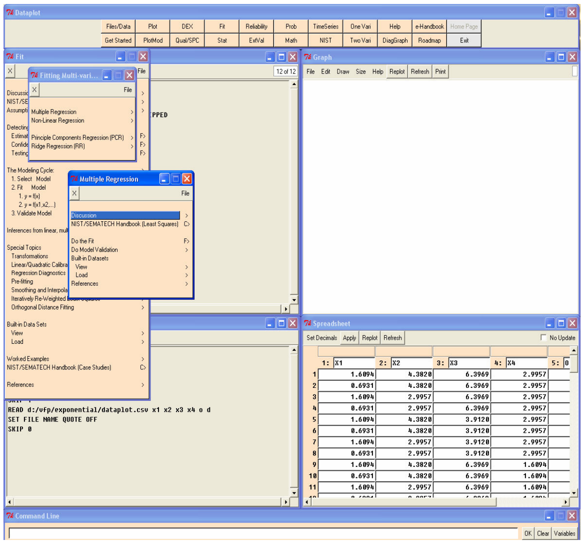

Fig. 7. Dataplot engineering and scinetific statistcs software

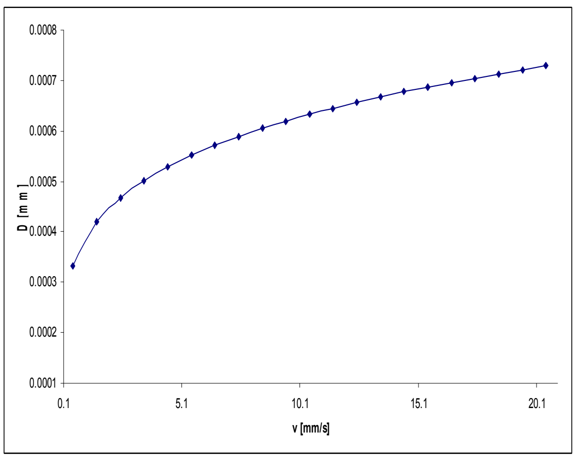

Fig. 8. Plot of the model (3) for center point of experiment for variables d_1, d_2 and n

The analysis proved parameters diameter of probe tip d_1, diameter of calibration ring d_2 and number of scanned points n to be insignificant to the measurement error. Only significant parameter on the measurement error found as a result of this experiment is scanning speed.

4. CONCLUDING REMARKS

The results of experiment show that the measuring machine has a good response to the measurement task and that the accuracy is at high level.

Some parameters that have been varied in this experiment proved to be insignificant to the CMM accuracy. Those are diameter of stylus tip, number of points sampled and diameter of measured object. It must be considered that last parameter can be interpreted as measured length. Experiment didn't cover a range where the accuracy depends on length of measured object. To cover this range, experiment requires a calibration ring of significant size.

Only parameter proved to be significant to accuracy of the CMM is scanning speed. With the increase of speed of scanning the measurement result (measured points) gets noisier and therefore influences the measured result estimate (such as LSQ circle, plane, line etc.).

The experiment didn't include any filtering of the measured points. One example is eliminating outliers method. Outliers are measured points that differ significantly from the geometric form yielded by the other measured points and as such, they can produce a large error when the computed feature is calculated. An error of this nature would easily propagate through the actual-value determination of the characteristic. [8]

The usage of elimination of outliers method and its influence to the measurement accuracy is interesting field to be investigated in the future

5. REFERENCES

[1] Stević, M.: *Povećanje tačnosti merenja numeriči upravljanih mernih mašina*, Novi Sad, Fakultet tehničkih nauka u Novom Sadu, 2006. ISBN 86-7892-028-9.

[2] ISO 10360 Part 1-6, Coordinate metrology, International Standard Organization, Geneve, 1994.

[3] Weckemann, A.: *Influences on result value and uncertainty using flexible measuring instruments*, Summer Academy 2001., Dubrovnik, 2001.

[4] Neumann, H.m J.: *Industrial Coordinate Metrologz (Ten years of innovations)*, Himmer, Augsburg, 2000.

[5] Hodolič, J., Stević, M., Bešić, I., Antić, A., Palencar, R., Halaj, M.: *Merna nesigurnost u industrijskoj metrologiji*, Novi Sad, Fakultet tehničkih nauka u Novom Sadu, 2009. 198str., ISBN 978-86-7892-184-1.

[6] Budak, I., Hodolič, J., Bešić, I., Vukelić, Đ., Osanna, P. H., Durakbasa, N. M.: *Koordinatne merne mašine i CAD inspekcija*, Novi Sad, Fakultet tehničkih nauka u Novom Sadu, 2009., ISBN 978-86-7892-195-7.

[7] Budak, I., Hodolič, J., Soković, M.: *Development of a programme system for data-point pre-processing in Reverse Engineering*, Journal of Materials Processing Technology, 2005, Vol. 162-163, str. 730- 735, ISSN 0924-0136.

[8] ---: Carl Zeiss: *Calypso Basics, Operating instructions*, June, 2008.

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INFLUENCE OF FLUID INERTIA ON THE STABILITY OF EHD JOURNAL BEARINGS

Abstract: *In the analysis of HD journal bearings the effect of fluid inertia is generally neglected in view of its negligible contribution compared with viscous forces. However, there is a necessity to evaluate its influence at moderate values of the modified Reynolds number. An attempt is made to study the effect of lubricants inertia forces on the stability of finite journal bearing for a flow in a laminar regime. Furthermore, the stability analysis is extended to bearing with elastic layer on the shaft. In this way a complex solution of the problem is achieved with consideration of the shaft motion, instigated from the unbalanced HD forces of lubricant. The generalized Reynolds equation is obtained by averaged acceleration method. To solve the elastic part of the problem without linear approximations, a new, more precise method of displacements determination is used. In present study modified stability criteria by Hurwitz and Ljapunov are introduced. An adaptive procedure for determination of critical stability of the considered dynamic system is used.*

Key words: *stability analysis, journal bearing, fluid inertia*

1. INTRODUCTION

In most cases the fluid film bearings provide stable support for the rotor, but not always. One of the basic reasons for unstable motion and appearance of self-induced oscillations is the fluid film motion - especially its unbalanced HD forces. This instability mechanism is one of the well-known problems in rotor dynamics that has received intensive study [1-5, etc.], but this problem is not solved completely yet.

In the contemporary investigations of the similar kind of problems as shown, that different effects must be taken into consideration - deformability of the bearing surfaces, surface roughness, lubricant's rheological behaviour, lubricants inertia forces, thermoelasticity, etc. Along with that, for a better understanding of the HD instability mechanism, a complex solution with simultaneous rendering an account of some of the above mentioned effects must be achieved, which is the main goal of this work. Focusing particular attention on the influence of the elastic deformations of the shaft liner on the bearing stability, the effect of local inertia forces of the lubricant is taken into consideration as well.

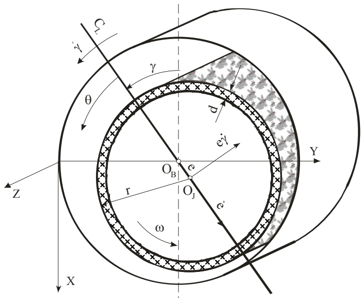

Fig.1 Journal bearing with a soft layer on the shaft

In this study the motion of Newtonian incompressible lubricant in finitely long journal bearing under isothermal conditions is considered. The shaft is covered with a thin resilient layer, whose radial displacements are of the same order of magnitude as the film thickness (Fig. 1). The generalized Reynolds equation is obtained by averaged acceleration method. The elasticity problem is solved in nonlinear treatment. The solution of pressure distribution equation is referring to prescribed loci of the shaft centre.

By the other hand, the estimate for stability of the system reduces to determination of a functional relation between non-dimensional load parameter (Sommerfeld number), shaft angular velocity and the fixed position of the shaft centre on the trajectory of her movable equilibrium [2, 3]. To this end the solution of the stability problem presupposes determination of the critical stability of the dynamic system in the plane of indicated parameters.

2. EHD MODEL AND STABILITY STUDY

Considering the fluid local inertia forces, the momentum equations and continuity equation for a journal bearing are

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \upsilon\frac{\partial^2 u}{\partial y^2}\,;\; 0 = \frac{\partial p}{\partial y}\,;$$

$$\frac{\partial w}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + \upsilon\frac{\partial^2 w}{\partial y^2}\,;\; \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

At the considered case, the partial differential equation that governs hydrodynamic lubrication for two-dimensional incompressible thin fluid films can be written as

$$\frac{\partial}{\partial x}\left(\frac{h^3}{\eta}\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(\frac{h^3}{\eta}\frac{\partial p}{\partial z}\right)=6\omega r\frac{\partial h}{\partial x}+ \\ +12\frac{\partial h}{\partial t}-\frac{1}{\upsilon}\left[\frac{\partial\left(h^3 a_{x,av}\right)}{\partial x}+\frac{\partial\left(h^3 a_{z,av}\right)}{\partial z}\right] \quad (2)$$

where $a_{x,av}=\frac{1}{h}\int_0^h\frac{\partial u}{\partial t}dy$ and $a_{z,av}=\frac{1}{h}\int_0^h\frac{\partial w}{\partial t}dy$ represent averaged accelerations across the film on x and z directions.

The final form of this modified Reynolds can be presented in a form as in [6]

Because of the elastic deflection of the journal liner, the film profile between contact surfaces is represented by:

$$h(x,z,t)=c+e\cos\theta+\delta_y= \\ =c+e\cos\theta+\frac{(1+\mu)}{2\pi E}\int_0^{x_1}p(\xi)\ \Psi\left(\frac{x-\xi}{d}\right)d\xi, \quad (4)$$

where the last term expresses the elastic layer distortion. The liner surface point radial displacements are calculated in accordance with non-linear approach [7], which is based on the Papkovitch and Neuber stress functions.

Considering small plane oscillation about a position of equilibrium corresponding to the own weight of the rotor, the differential equations of motion of the shaft centre can be written in the form:

$$M\ddot{x}+R_x+S_x=0;\ M\ddot{y}+R_y+S_y=0, \quad (5)$$

where M - mass of the rotor; $R_x=C_1x-D_1y$, $R_y=C_2y+D_2x$ are the components of the HD forces and $S_x=\psi_{xx}\dot{x}+\psi_{yx}\dot{y}$, $S_y=\psi_{yy}\dot{y}+\psi_{xy}\dot{x}$ are damping forces components.

With application of standard approach to solve the last equation, the relevant characteristic equation is obtained. From its coefficients the modified stability criteria (which are based on the Hurwitz and Ljapunov theorems) are worked out:

$\bar{\Delta}_1=\alpha_1>0$; $\bar{\Delta}_2=\alpha_1\alpha_2-\alpha_3>0$;

$\bar{\Delta}_3=\alpha_3\bar{\Delta}_2-\alpha_1^2\alpha_4>0$; $\bar{\Delta}_4=\alpha_4\bar{\Delta}_3>0$.(6)

Detailed determination of HD and damping forces, as well as determination of modified stability criteria are presented in [8].

3. SOLUTIN TECHNIQUE,RESULTS AND DISCUSSION

The critical stability of considered tribological system is accomplished by specially created adaptive calculating procedure. An adequate algorithm and program system, which is developed in MATHCAD 2000 PROFESSIONAL environment, are founded to verify the stability of dynamic system by introduced criteria.

Solution of the stability problem with consideration of the investigated effects must include a solution of the EHD part of the complex problem (Fig. 2). To this end the HD pressure and basic bearing characteristics are calculated by simultaneous solution of the modified Reynolds equation and elasticity equations. The partial differential equation is solved numerically by successive over-relaxation technique on a finite difference grid. The calculated values of Sommerfeld number S and corresponding load W represent initial data for the program system, which verifies the stability of the dynamic system "lubricant-shaft".

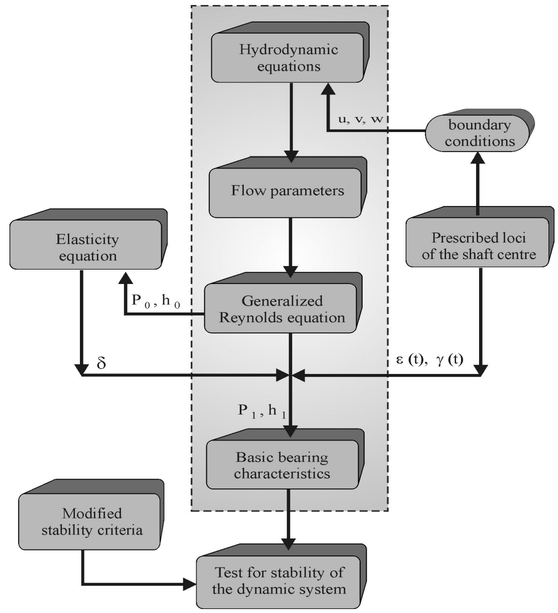

Fig. 2 Solution scheme

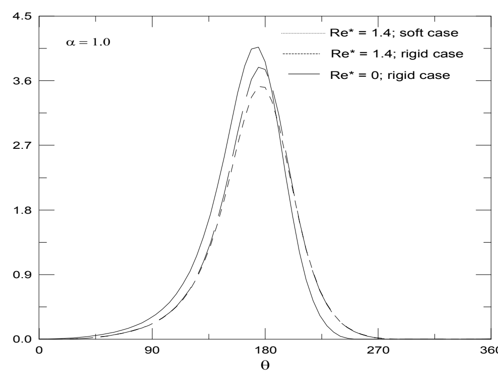

Fig. 3 Pressure distribution

Figure 3 illustrates the pressure distribution in the case in which the local inertia forces and elastic deformations of the shaft liner are taken into account. On the next Figure 4 is given the time variation of pressure for two basic cases - with and without inertia terms. The dependence of Sommerfeld number on the generalized Reynolds number is presented on a Fig. 5.

Along with that to see the effect of shaft's deformation and lubricants local inertia forces on the system stability the total load W values are plotted against the eccentricity ratio ε in last Fig. 6. The obtained results are concerned to three considered cases: (a) $\mathrm{Re}^*=0$, rigid case; (b) $\mathrm{Re}^*=1$, rigid case; (c) $\mathrm{Re}^*=1$, soft case ($\delta_y\neq 0$, $E=1{,}63.10^8$ [Pa], $\mu=0{,}38$).

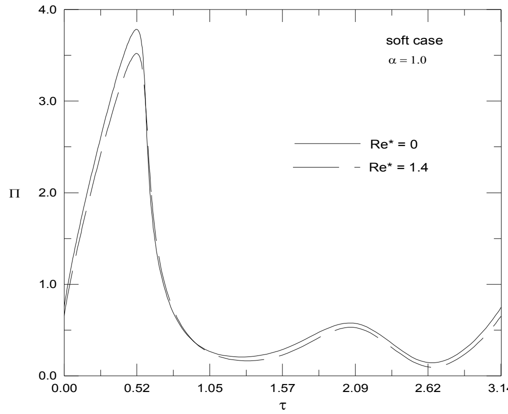

Fig. 4 Time variation of pressure

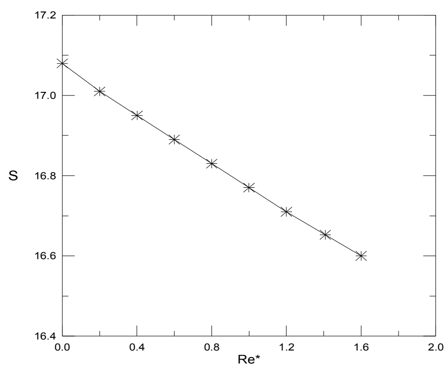

Fig. 5 Sommerfeld number vs Re*

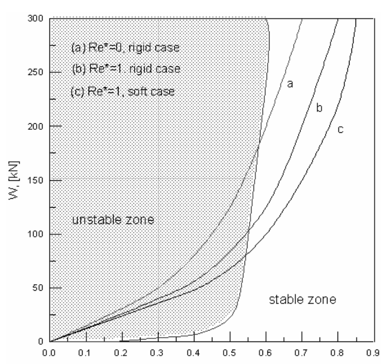

Fig. 6 Load versus eccentricity ratio

The results on this figure show that for the concrete value of load the system can be located in a stable zone if layer's deformations are considered (for example → $W = 90$ [kN]) and/or the lubricants accelerations are taken into account (for example → $W = 150$ [kN]), as the stable zone expanding at heavier loads.

4. CONCLUSION

It was found that consideration of the bearing surfaces deformation and lubricant's inertia forces are conducive to the stability state of the system. This phenomenon can be explained as result of the HD pressure (and respectively Sommerfeld number) change at rendering an account of the above mentioned effects.

5. REFERENCES

[1] Pincus, O. and Sternlicht, L.: *Theory of Hydrodynamic Lubrication*, Mc Grow-Hill Co, New York (1961)

[2] Voskresenskii, V.A., Djakov, V.I.: *Calculation and design of journal bearings*, Mashinostroenie, Moscow (1980)

[3] Hebda, M., Chichinadze A.B.: *Tribotechnics reference book*, Mashinostroenie, Moscow, (1990)

[4] Majumdar, B.C., Brewe, D.E., Khonsary, M.M.: *Stability of a rigid rotor supported on flexible oil journal bearings*, ASME, J. of Tribology, Vol. 110, (1988) 181-187.

[5] Kakoty, S.K., Majumdar, B.C.: *Effect of fluid inertia on the dynamic coefficients and stability of journal bearings*, Proc. Inst. Mech. Engrs., Vol. 214-J, (2000) 229-242

[6] Javorova J.G.: *One solution of the non-stationary problem of the EHD theory of lubrication*, PhD Thesis, University of Transport, Sofia (1998)

[7] Alexandrov, V.A., Javorova, J.G.: A more precise method of determination of the contact surfaces deformation in case of EHD friction, Proc. Jub. Sci. Conf. - UACEG, Sofia, (2002) 181-191

[8] Javorova, J.G., Alexandrov, V.A.: *Journal bearing instability and modified criteria for stability*, Proc. Intern. Conf. "Bultrib'03", Sofia, (2003) 81-89.

[9] Javorova J.G., Alexandrov V.A., Stanulov K.G., Zaharieva I., Chelu P.: *Effect of fluid inertia on the stability of journal bearings*, Proc of 5-th Int. Conf on Tribology "Balkantrib'05", Kragujevac, Serbia, (2005), 521-525.

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COUNTER PRESSURE EFFECTING ON COMPACTED BRIQUETTE IN PRESSING CHAMBER

Abstract: *The aim of this contribution is to present designed methodology of calculation of counter pressure effecting in pressing chamber at compacting process. Counter pressure is very important for compacting machines engineers because if they know counter pressure they are able to calculate radial pressure and length of pressing chamber. These parameters are needed for design of pressing chamber. Also lonely counter pressure helps at compacting process increase the briquette density – which is the main indicator of final briquette quality.*
Key words: *compacting process, briquetting process, counter pressure in pressing chamber, briquette quality*

1. INTRODUCTION

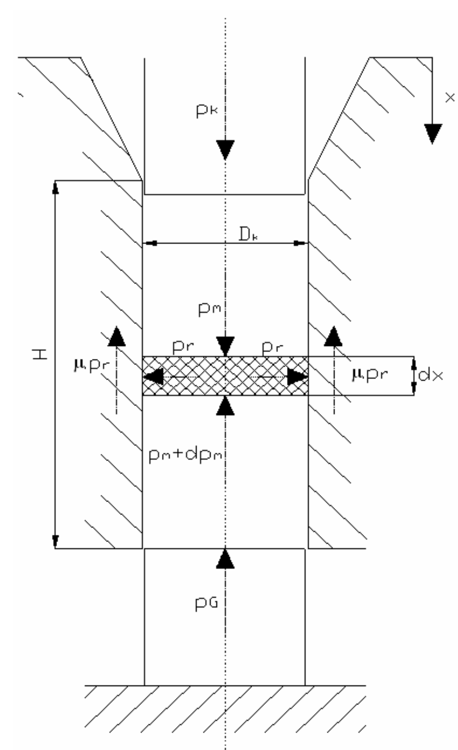
Counter pressure effecting on compacted briquette in pressing chamber is very important parameter at compacting process. Disallows material to leave the pressing chamber before compacting and helps with briquette compacting in pressing chamber. Counter pressure can be at horizontal way and also at vertical way of compacting generated: by counter pressure plug, by collet at the end of chamber with adjustable choking, by friction coefficient between briquette and chamber, by shape of pressing chamber (conicalness) and by length of compacted column consist from briquettes. For design of pressing chamber is very useful to know the value of effecting counter pressure.

2. KNOWN MATHEMATICAL MODELS OF COMPACTING

On our department we have done experiment for main influencing parameters evaluation. We know that at compacting process are more important pressing temperature (T), compacting pressure (p), fraction largeness (L) and input material humidity (w_r). We designed mathematical model which describes influence of all named parameters on final briquette density (ρ). This model is very useful at counter pressure calculation because we know definitely dependence ρ = f (p) [1].

The second mathematical model which we need at counter pressure calculation is model describing pressing conditions in closed pressing chamber by single-axis pressing on vertical press (Fig.1). By this compacting process is counter pressure generated by counter pressure plug. Maximal compacting pressure p_k which is rising by pressing depend on pressing chamber length and shape; depend on friction relations between pressed material and wall of the chamber. Drag friction is backward assigned by radial pressure p_r, applied to chamber wall, by friction coefficient μ and length of pressed briquette H. Equation (1) describes Fig.1.

$$\left[p_m - \left(p_m + dp_m\right)\right]\frac{\pi D_k^{\,2}}{4} - \mu p_r \pi D_k dx = 0 \qquad (1)$$



p_k – axial pressure of press (MPa)
p_G – counter pressure in chamber (MPa)
p_r – radial pressure (MPa)
p_m – axial pressure on the briquette (MPa)
D_k – diameter of pressing chamber (mm)
μ – friction coefficient (-)
H – length of pressed briquette (mm)

Fig. 1. Pressing conditions in pressing chamber by single-axis pressing on vertical press [1]

By equation (1) solving and by border conditions substituting they get equation (2) and (3).

$$p_k = p_G . e^{\frac{4.\lambda.\mu.H}{D_k}} \text{ (MPa)} \qquad (2)$$

Equation (2) specifies relation between axial pressure p_k and counter pressure effecting on compacted briquette p_G.

$$p_G = p_k . e^{-\frac{4.\lambda.\lambda.\mu}{D_k}} \text{ (MPa)} \qquad (3)$$

3. COUNTER PRESSURE CALCULATION

Counter pressure value with value of radial pressure influencing length of pressing chamber. Next calculation will show you how important are founded dependence ρ = f (p) and equation (3) for calculation of counter pressure which effecting on compacted briquette. For calculation we use as an example dimensions of our experimental pressing stand. This stand supplies closed vertical way of compacting. If we want calculate the counter pressure from equation (3) we have to know other parameters in this equation. We chose axial pressure p_k according to Fig. 2 (p_k = 120 MPa). With this pressure we are able to compact briquettes by Standard given quality [2 ,3, 4].

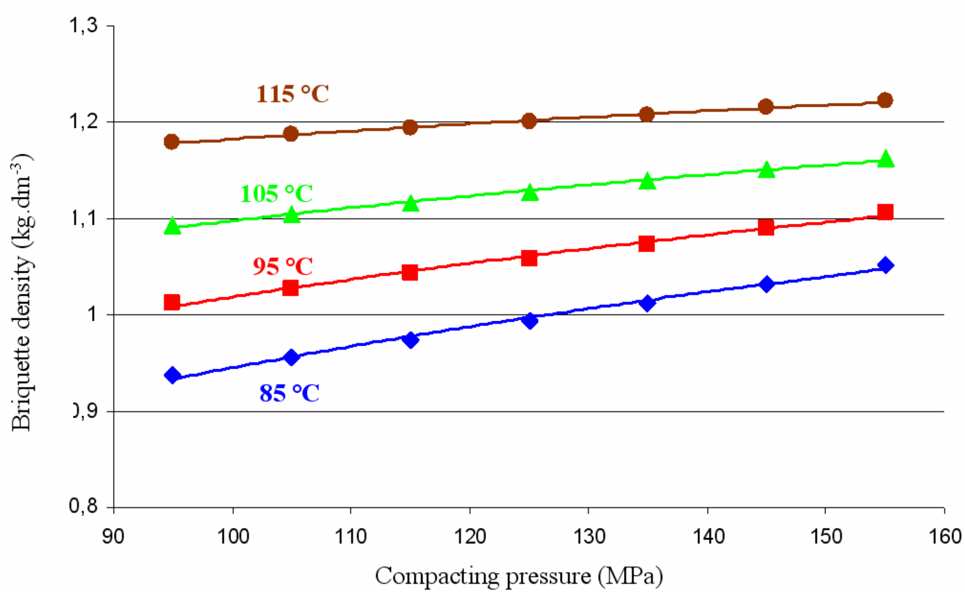
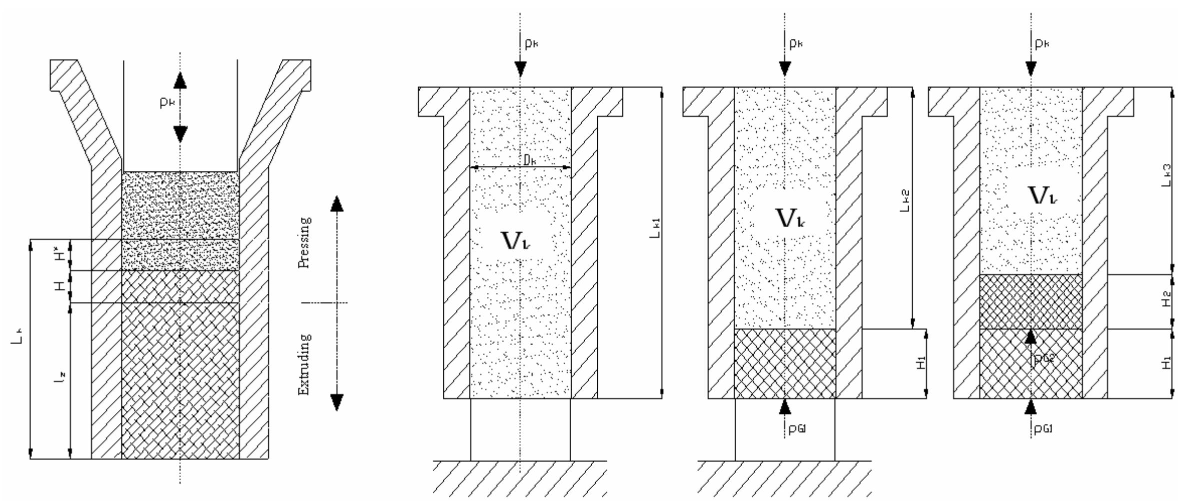


Fig. 2 Dependence of briquette density on compacting pressure at various pressing temperatures (w_r=10%; L=2 mm)



a.) b.) c.) d.)

Fig.3 Single-axis pressing process on vertical press (a.) and individual phases of compacting – b.) filling of pressing chamber; c.) pressing of the 1st briquette + filling of pressing chamber; d.) pressing of the 2nd briquette + filling of pressing chamber

Friction coefficient between pressed material (wood) and wall of pressing chamber (steel) is μ = 0,35. λ is ratio of main strains σ_r/σ_m (Fig. 1). For dispersive materials is this ratio from interval $0<\lambda<1$. Diameter of pressing chamber is given by construction of pressing stand, therefore D_k = 20 mm. For calculation of length of pressed briquette (H) we need also compacting ratio for wood. This ratio is ratio of volume before compacting and after compacting. This ratio was calculated from briquette density (by pressure 120 MPa and temperature 105 ºC) and from length of pressing chamber L_k. The compacting ratio is 1:8. Know we can calculate length of pressed briquette after each pressing on the pressing stand. Note, that in our case, in case of closed chamber, has each briquettes various length. On the figure 3 you can see what is situation in closed chamber at compacting. In the table 1 you can see calculated each length of pressed briquettes. After than we can calculate according to equation (3) and values in Tab.1 searched counter pressure (p_G). These calculated values you can find also in Tab.1. We can say that value of counter pressure increasing with reduction of the length of pressed briquettes. In closed system of pressing is pressed briquette after each pressing shorter because after each pressing is volume of pressing chamber reduced. According to these results we can say that value of counter pressure will decrease with increasing of length of pressed column. Now we can try to apply this theory to horizontal continuous way of pressing. On the figure 4 you can see what is situation at horizontal continuous pressing. Figure 4 describes the compacting process and effecting of counter pressure at horizontal continuous pressing. The main difference is that the length of pressed briquette is equal for each briquette. Briquettes which were pressed sooner will continuously move through the full pressing chamber until to the end of chamber. We use again dimensions of experimental pressing stand at calculation but with considering of continuous way of pressing.

i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
L_{ki} (mm)	140	122,5	107,19	93,79	82,07	71,81	62,83	54,98
H_i (mm)	17,5	15,31	13,40	11,72	10,26	8,98	7,85	6,87
p_{Gi} (MPa)	39,84	45,74	51,59	57,35	62,87	68,15	73,18	77,84

Table. 1 Table of calculated parameters for counter pressure calculation [3]

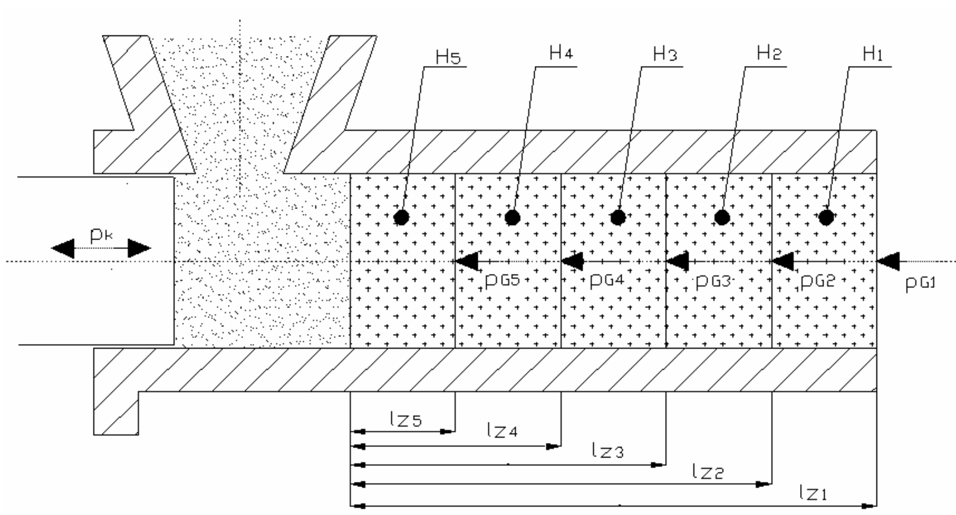


Fig.4 Counter pressure effecting at horizontal continuous pressing

In the table 2 you can see the calculated values of counter pressure at continuous way of pressing. We can say that counter pressure decreasing with increase of length of pressed column or with increase of length of pressing chamber. With other experiment in the future we have to verify this claim. Also is much needed to find the optimal length of pressing chamber in dependence on compacting pressure or counter pressure. Optimal length of pressing chamber is when the briquette reaches by Standard given density, when is able to overrun the counter pressure and when it is able to leave the pressing chamber without fall to pieces. Optimal length of pressing chamber will change in dependence on effecting compacting pressure or counter pressure. Optimal length of pressing chamber will depend also on radial strains. Radial strains we can calculate from the ratio of main strains λ (radial / axial). It will be very useful if we could execute experiment for radial strains find out.

i	**1**	**2**	**3**	**4**	**5**
l_{zi} (mm)	87,5	70	52,5	35	17,5
p_{Gi} (MPa)	0,48	1,45	4,39	13,23	39,84

Table.2 Table of calculated values of counter pressure at continuous way of pressing

On the figure 5 you can see the dependence of effecting counter pressure in pressing chamber on length of pressed column of briquettes. This figure comes from previously calculations. You can see that the counter pressure is higher when the length of pressed column is shorter and vice versa.

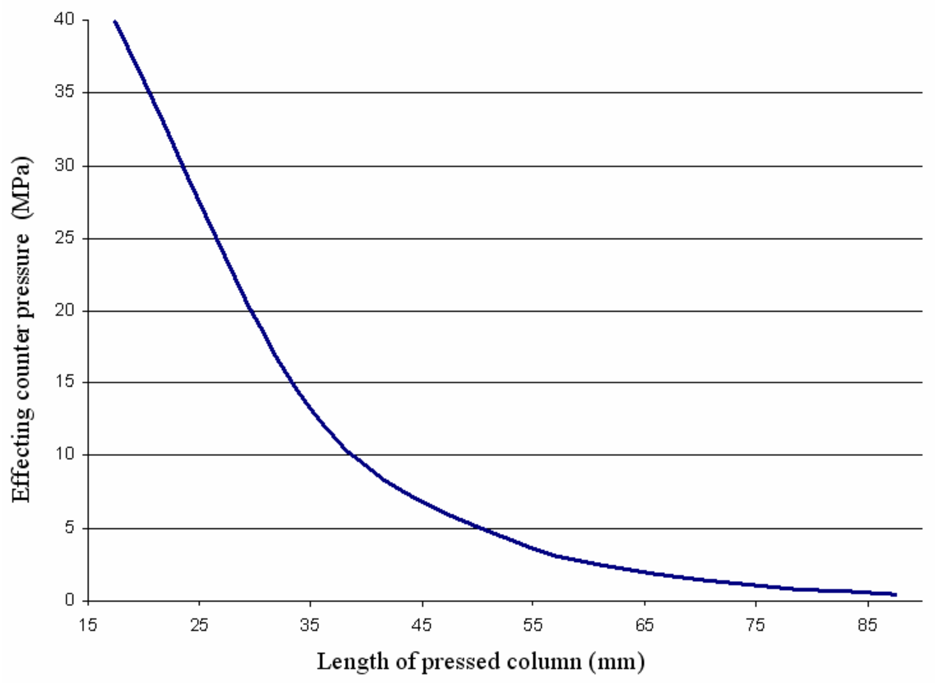


Fig.5 Dependence of counter pressure effecting on briquette in pressing chamber on length of pressed column

4. CONCLUSION

This presented methodology and calculations are very useful for design of pressing chambers. We are able to design the shape and dimensions of pressing chamber. When we will know the value of effecting radial strains we can calculate the place in pressing chamber when the briquette can leave the chamber without fall to pieces. Every design and calculation has to be according to briquettes density which is given by Standards.

5. REFERENCES

[1] Holm, J.; Henriksen, U.; Hustad, J.; Sorensen, L.: *Toward an understanding of controlling parameters in softwood and hardwood pellets production*, American Chemical Society, published on web 09/09/2006.

[2] Šooš, Ľ., Križan, P.: *Analyze of forces interaction in pressing chamber of briquetting machine (in Slovak)*, In.: Proceedings from 11. International conference TOP 2005, pp. 299-306, Častá - Papiernička, Slovakia, FME STU, ISBN 80-227-2249-9, 29.06.-01.07.2005.

[3] Križan, P.: *Wood waste compacting process and conception of presses construction (in Slovak)*, Dissertation thesis, FME STU in Bratislava, Slovakia, 2009

[4] Križan, P.; Vukelić, D.: *Shape of pressing chamber for wood biomass compacting,* In.: Quality Festival 2008: 2nd International quality conference, Kragujevac, Serbia, ISBN 978-86-86663-25-2, 13.-15. May 2008.

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ONE CAI MODEL IN THE DIGITAL FACTORY

Abstract: *Manufacturing Engineering is developing in the direction of on-line digital factory, where all engineering activities are integrated and simulated before the real production process. On the other hand, our industry after total degradation begins to develop again, where a key role in this process has the quality of products. This paper presents research, development and implementation of CAI-model, as a basic concept of the digital quality, in the concrete factory ``IVA 28`` from Obrenovac. Also, this paper presents computer integrated inspection and measurement in the final control of product quality. The slider is specific part that was measured on DEA measuring machine, and PC DMIS is used as software.*
Key words: *CAI, metrology, quality, PC DMIS, DEA.*

1. INTRODUCTION

Application of computer technologies in the industrial metrology, more specific in coordinate metrology is very important in terms of product quality. Poor product quality is mostly realized in the production phase and it's necessary to pay more attention to quality control. Accordingly, CAI (**C**omputer **A**ided **I**nspection) model undoubtedly has a great role where measurement and inspection process are performed on the numerically controlled measuring machine using specialized software.

Factory „IVA 28“ from Obrenovac is engaged in the production of precision parts for machine building industry. Product range is categorized within following groups: sliders, spindle housings, tailstocks and other parts. Tolerance of these parts are very small (a few µm) and is required in the production process to achieve high accuracy production. For quality control of these parts the factory is using coordinate measuring machine “DEA Global Performance” which has the possibility of measuring large and complex parts.

2. MEASURING MACHINE DEA GLOBAL PERFORMANCE WHIT SCANNING PROBES

2.1 Basic characteristics of measuring machine

New generation of DEA measuring machines is developed in 2005. when the Global line serie is introduced with three new models: Classic, Performance and Advantage. Great flexibility of this measuring machine enables using of Touch-trigger and Scanning probes for measuring complex parts weighing up to 2t. DEA Global Performance is 3D coordinate measuring machine (Figure 1), with the following technical characteristics[4]:

- Stroke X=1200mm, stroke Y=2200mm, stroke Z=1000mm
- Granite table
- Optical measuring system
- Accuracy: $MPE_E = 2.5 + L/333$
- Air bearings
- FB2 control system (3+2 axes control)

Figure 1. DEA Global Performance

2.2 Scanning probes

Along with the measuring machine, factory "Iva 28" is using touch-trigger and scanning probes from renowned Renishaw company. Renishaw motorized probe head PH10MQ is also used, which allows measuring machine to work with five axes.

Very significant is the use of Scanning probes which can determine shape defects of given area, besides its measuring position and size. Scanning probe used in the factory is SP25M, with three scanning modules SM25-1,SM25-2, SM25-3 and three stylus holders SH25-1, SH25-2, SH25-3, shown in Figure 2[3].

Figure 2. Scanning probe SP25M

3. DEVELOPMENT OF CAI MODEL FOR A SLIDER

The first step is the part modeling which defines the nominal form. CAI model is developed for slider, which is built in special-purpose lathe. Slider is modeled in SolidWorks 2007 (Figure 3).

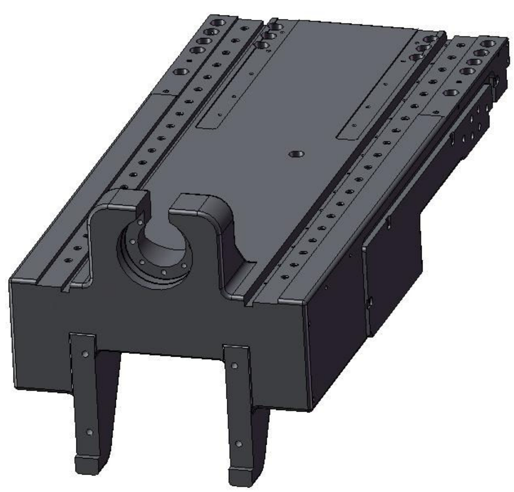

Figure 3. Slider model in SolidWorks

Integration process CAD-CAI-NUMM (Figure 4) is accomplished in the first place by modeling of the part, which is in the STEP format and recognizable to software PC DMIS. For inspection process software PC DMIS CAD++, version 4.2 is used, which is a standard programming language for numerically controlled measuring machines.

Instructions (measuring operations) defined in software PC DMIS are transferred to the control system, which specify the movement of drive system of machine (for movement of linear axes) or probe head (for movement of two axes). Measurement signals represent feedback and measurement results can be processed on a computer [2].

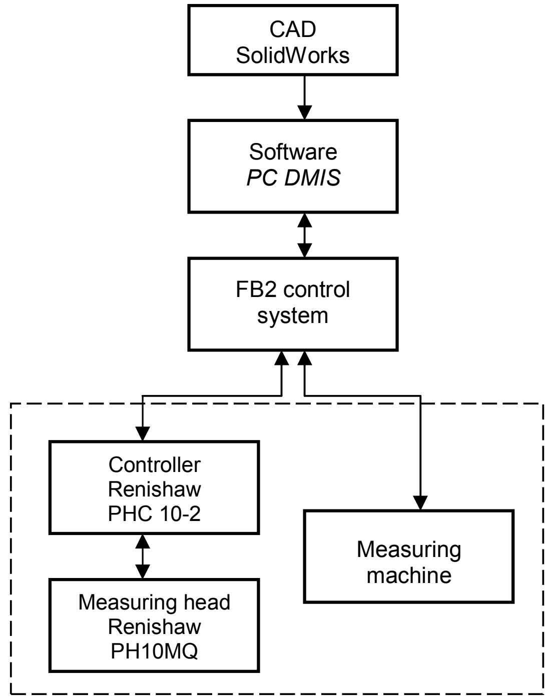

Figure 4. CAD-CAI-NUMM integration

The process of measurement can be conducted in one or more operations, depending on the number of preparations, number of machines, number of positions in which the part is measured. Since only one machine was used in the process of slider control and the part was placed in only one position, the process of measuring was conducted in one measuring operation.

4. MEASURING PROGRAM

The programming of measuring machine implies array of activities which need to be carried out for the specific measuring operation in order to gather all the needed informations for realising the measurement. On basis of these informations, measuring machine is prepared for the start of measuring process and then, in automatic regime, realizes measuring operation or measuring cicle. This leads to measuring report – on the basis of measuring results [1].

4.1 Defining the position of the slider

The measurement program should first define the position of the part on the machine. Due to the large dimensions and weight, the part is placed on the machine without restriction. Placing the slider on it's side is conditioned by the paths. Roller guides that require high quality of fabrication are placed on top of these paths. Also, the part is placed longitudal on the machine so the measuring sensor could easily reach the place where measuring is conducted, in order to avoid collision.

4.2 The choice of the probes

In order to accomplish the measuring operation it is necessary to define the scanning probe. For measuring the slider, measuring head PH10MQ and scanning probe SP25M are used, with scanning module SM25-2 and stylus holder SH25-2. This type of probe has sufficient length of stylus holder which allows measuring of the part without changing the probe. Defining of measuring tools is conducted in the program PC DMIS, in Probe Utilities window (figure 5).

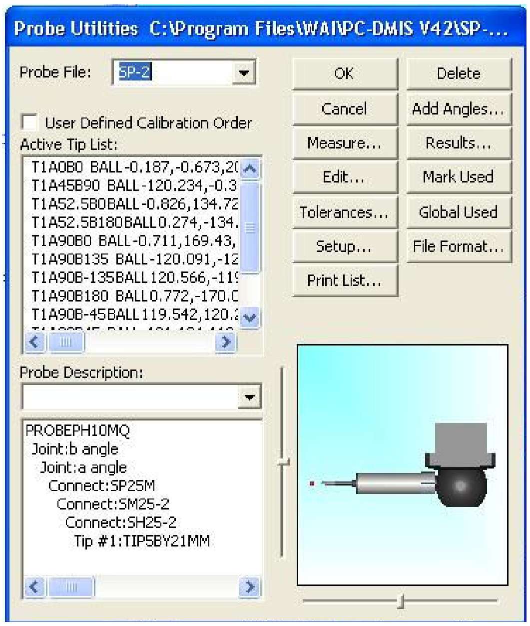

Figure 5. Scanning probe defined in PC DMIS

4.3 Program measuring report

Program measuring report describes the controlling program through the orders which are written in common language, understandable to the user. Controlling program contains data which defines stylus holders route, stylus holders speed, getting the styli in the right position etc. [1].

Starting point in the program is defining the ground zero and leveling out, which defines the origin of the measuring subject's coordinate system, so the machine has the idea about subject's position and orientation on the machine table. After defining the position of the coordinate system, defining of all the geometrical entities is conducted (lines, planars, circles etc.) which are necessary for later control of shape and position tolerances.

Process of defining geometric entities consists of choosing the optimal number of points which precisely describe the entity, so the measuring process would not take long. It is also necessary to define the referral planars. Figure 6. shows the window from PC DMIS software. Controlling program is shown on the left side. The right side graphically shows the slider with all the geometrical entities marked.

After the measuring of geometric shapes, determining their mutual relations and relations based on tolerance defined in the drawing is performed. Relations between geometric shapes are inserted by using Feature Control Frame, which is activated when selecting types of tolerance.

Figure 7. shows input values such as tolerance for parallelism required geometric shape.

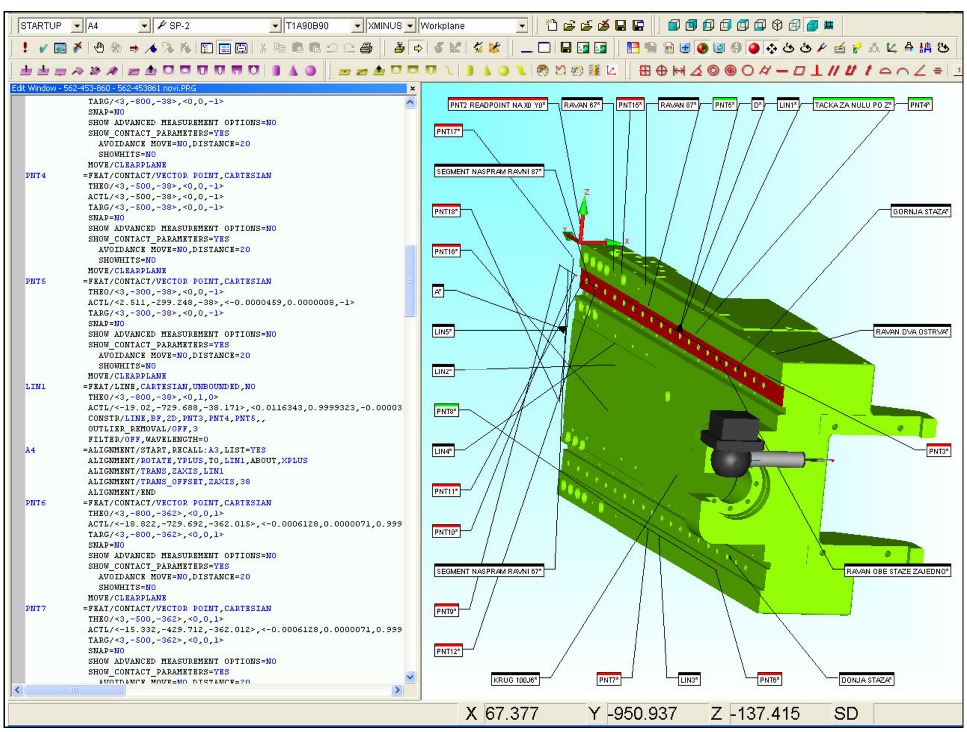

Figure 6. Control programme for slider in software PC DMIS

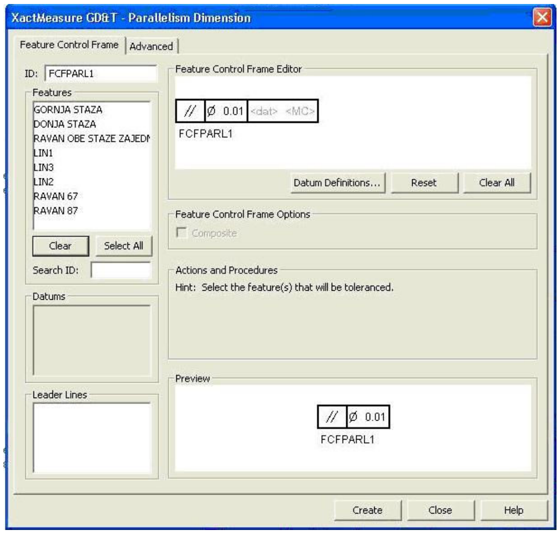

Figure 7. Window *Feature Control Frame* for defining tolerance

Feedback in the form of a report is obtained after the end of the measurement process and slider control. Report contains name of the part, serial number, control date and all types of demanded tolerances presented in detail. Along with the label of tolerance, nominal value of the measure (NOMINAL), upper and lower tolerance (+TOL, -TOL), actual value of measure (MEAS), deviation from the nominal value of the actual measure (DEV) and also the value exceeding the actual measure in relation to the permitted (OUTTOL) are defined.

One part of the report, obtained after measuring the slider is shown on Figure 8. Report shows that the measuring values are within allowed limit. Fulfillment of tolerance field is colored green. If some measures exceed the allowed value, the part is submitted to finishing until the set value is reached.

Additional control of the slider is done by placing the roller guides via comparator. Slider paths on top of which roller guides are placed must have high accuracy in terms of parallelism and flatness.

pc-dmis	PART NAME :	562-453-860			maj 14, 2009	21:40
	REV NUMBER :	-752	SER NUMBER :	9504	STATS COUNT :	1

	MM	FLAT5 - RAVAN DVA OSTRVA TO THE ORIGIN				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0.000	0.010	0.000	0.003	0.003	0.000
	MM	DIST2 - RAVAN 67 TO RAVAN DVA OSTRVA (XAXIS)				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	95.000	0.000	0.020	94.990	-0.010	0.000
//	MM	PARL3 - RAVAN 67 TO RAVAN 87				
AX	NOMINAL	+TOL	-TOL	MEAS	DEV	OUTTOL
M	0	0.0100	0	0.006	0.006	0.000

Figure 8. Report obtained by measuring slider

5. CONCLUSION

Numerically controlled measuring machines are the basic element of production metrology. Implementation of the measuring machine and the software requires high costs, but also provides many benefits and savings in time.

"IVA 28" is an example of digital factory in our industry, where with CAI model manages to maintain product quality at a high level. Also, efficient and fast measurement of parts using CAI model allows that all customer requirements be met, both in terms of quality and in time of delivery.

6. REFERENCES

[1] Majstorović, V., Hodolič, J.: *Coordinate measuring machines,* (on serbian language),FTS, Novi Sad, 1998.

[2] Hexagon Metrology, *FB2 Control system – User's manual*, Switzerland, 2007.

[3] Renishaw, *Probing systems for co-ordinate measuring machines*, United Kingdom 2003.

[4] Hexagon Metrology, *DEA GLOBAL Coordinate Measuring Machines*, Switzerland, 2009.

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ORGANIZATION OF THE TRYBOSYSTEM “TOOL – PART” AFTER MAGNETIC-ULTRASONIC TREATMENT

Abstract: *The overall analysis of the facts of thorough laboratory and industrial investigations allowed concluding that the increased resistance capacity of the ferromagnetic materials (cutting tools and parts), treated after the combined magnetic-ultrasonic technology arises by two processes, in two consecutive stages: i. formation of a new surface (with improved structural and physico-chemical characteristics), in the treated materials; ii. change in the friction conditions, i.e. contact interactions, leading to structural adaptability, trybosystem self-organization(SO), resulting from the properties acquired during the first stage.*
To avoid doubts about the magnetic-ultrasonic treatment’s ability to induce changes in the cutting conditions and “tool – part” contact interaction, longterm comparative analyses aiming to study drilling were independently conducted at the Department of Manufacturing Technologies, Technical University at Prague, the Czech Republic
Key words: *activation energy, reserve energy, self-organization.*

1. INTRODUCTION

According to the first principle of thermodynamics, the work of friction forces, A_{fr}, is principally converted into heat, Q, and a minute portion, ΔE, is applied to the materials in the trybosystem: $A_{fr} = Q + \Delta E$. Investigations on the energy balance of friction with precise methods allowed understanding that the conditions of friction influence not only the overall magnitude of the friction work, but also the relationship between the basic quantity of reserve energy and quantity of dissipated heat. This relationship, characterizing the trybosystem’s work capacity, is determined by the normal load, P, the speed of relative displacement – ν, and the vector of friction parameters – $\dot{C}$ (material properties, environment, temperature and so forth) (Gourevich, 1975): $\Delta E/Q = f(P, \nu, \dot{C})$. The major component of the energy balance of friction is the reserve energy. The magnitude of ΔE is of critical importance during the generation of friction forces, determines the laws of formation of new structures, and the magnitude and nature of their subsequent destruction. Analysis of the laws of the energy balance, concomitant with the analysis of the structure and elementary content of the surfaces involved in friction, allows concluding, that all friction processes are actually the result of two basic phenomena – activation, i.e. increase in the free energy of the materials in the trybosystem, and passivation, the system’s decrease in free energy.

The simplified representation of the friction force as function of the normal load appears to be invalid in the theoretical and empirical plan. It was shown that the friction force is actually not a function of the normal load, but rather the operator in the system, arising during a combination of normal load, sliding speed and vector of the friction parameter (Ivanov, 1975).

The problems associated with the SO process during friction relate to the domain of “highly parametrical” materials condition, i.e. high concentration of energy, high speed, high pressures, and anomalous physical conditions. The process is accompanied by the creation of structural and phase conditions, absent in the diagrams of systems in equilibrium. Under investigation of the process of secondary structure formation, carried out with electronic - transmitive and raster microscopy, roentgen – spectral and ojespectral analysis, electronography, roentgenography and radioactive indicators, it was found that the traditional mechanisms of volume plastic deformation under metal friction in the conditions of trybosystem SO are totally excluded. The kinetic phase transition leads to new mechanisms of plasticity, deformation and destruction (Zorev *et al.*, 1971). It is essential to note, that the kinetic phase transition during SO regimen and formation of secondary structure is not random, but rather governed by minimal principles. All interactions during friction in SO regimen are localized in the thin surface layer. Major changes take place. It was found that the secondary structures are resistant and possess SO properties (Gourevich, 1976; Kabaldin, 1981). A fundamental energy condition of the trybosystem’s material SO is such dynamic equilibrium of the processes of the tryboactivation and passivation, under which the active part of the activation energy, G_{Aef}, is equivalent to the reserve energy, ΔE, found in the limit energy values, necessary for the formation of the secondary structure, G_{BC}: $G_{Aef} = G_{BC}$. As a result from the violation of this condition, damage occurs. The relationship of G_{Aef} with the overall activation energy $G_{Aoverall}$ (the friction work – A_{fr}) is evaluated by the coefficient of reserve energy, K_r. The magnitude of K_r determines the SO diapason (SOD), and significantly influences the level of self-organization (LSO), under the optimal solution $K_r \rightarrow \min$. A major means of minimization of K_r is the application of *methods for surface strengthening.*

2. EXPERIMENTAL SETUP

To explore the influence of the combined magnetic-ultrasonic treatment of the dependent variables during drilling (axial force F_o and twisting moment M_B), investigations on the drilling process were carried out in the conditions of the TU - Prague, department of “Manufacturing technologies” (Ziad, 2007). The used drills, with ф = 2,3 mm, are made of high-speed steel – HSS 02 ČSN221121. A part of the drills was subjected to the combined magnetic-ultrasonic treatment in the tool “MUS – 1”, in the conditions of the TU - Sofia, using a treatment regimen, which has been previously associated with a significant increase in the durability of helical drills, namely H = 157 kA/m – intensity of the constant magnetic field; τ = 60s – treatment duration; and constant frequency of ultrasonic oscillations – F = 20 ± 1 kHz (Makedonski, 2005).

Steel M45 was used as billet material. The experiments conducted on a cutting machine model FV25 with CNC, using three cutting regimens (see table 1), with a constant depth of the drilled holes at L = 3d, and without the use of lubricating - cooling fluid. During the cutting process, the axial force and the twisting moment were measured with a four-component dynamometer model Kistler – 9272 connected to the processing software Dinoware. Five holes were always made with each drill, the processing software drawing the graphical dependencies for axial force and twisting moment, with a subsequent results averaging of the repeated experiments. The latter is done in order to minimize the influence of random factors on the final investigation results. Furthermore, optic microscope ZEISS equipped with a digital camera was used to document the wear at each 10^{th} drill made, and the work of each drill was carried out until reaching a wear of one of its posterior surfaces VB_{max} = 0,5 mm, or until the drill was broken. Microsoft Excel 2007 platform was used to process and compute the results from the obtained graphical dependencies.

Number drilled holes	**Ø 2.3 mm; V_c=25 m/min; f=0.05 mm/tour**				**V_c=30 m/min (4152 mm^{-1}); f=0.06mm/ tour**				**V_c=35 m/min (5000 min^{-1}); f=0.07 mm/ tour**			
	Normal		Treated in MUS-1		Normal		Treated in MUS-1		Normal		Treated in MUS-1	
	M_B	**F_0**	**M_B**	**F_0**	**M_B**	**F_0**	**M_B**	**F_0**	**M_B**	**F_0**	**M_B**	**F_0**
1	23	312	12	193	24	219	15	200	23	321	13	149
5	34	284	18	220	50	179	13	192	33	269	12	165
10	29	363	15	211	31	277	12	186	62	265	14	173
15	40	303	14	216	38	211	12	194	46	389	16	239
20	32	345	14	209	32	207	16	203	42	324	12	181
25	35	303	13	165	36	255	19	222	–	–	12	160
30	27	275	14	200	–	–	–	–	–	–	11	192
35	46	365	13	189	–	–	–	–	–	–	12	191
40	22	314	13	185	–	–	–	–	–	–	12	231
45	37	298	11	207	–	–	–	–	–	–	13	170
50	76	310	15	200	–	–	–	–	–	–	12	219

Table 1. **M_B : [N.mm]; F_0 : [N].**

After number of holes	**Wear of the drills**			
	Normal		**Treated in “MUS – 1”**	
	VB_K	**Vbmax**	**VB_K**	**Vbmax**
1	20	48	25	24
5	80	157	64	65
10	109	216	65	95
15	130	351	68	117
20	160	450	70	141
25	168	480	75	166
30	177	495	79	186
35	210	504	85	194
40	225	506	90	223
45	245	509	95	237
50	263	515	110	265

Table 2. **VB_{max} and VB_k are in μm.**

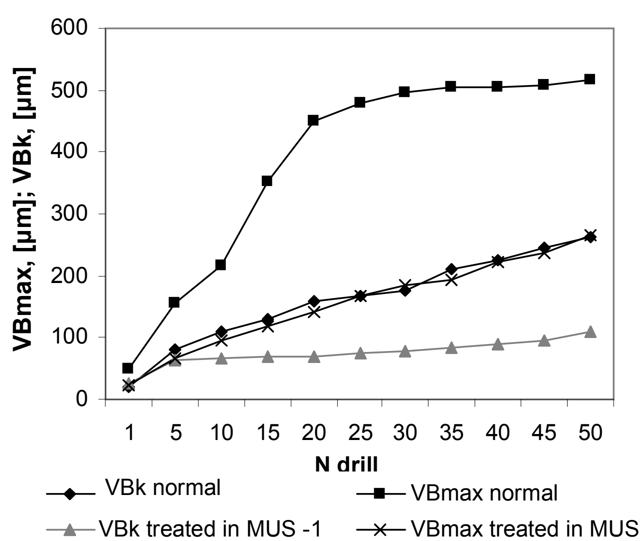

Fig. 1. Wear curves for normal and subjected to magnetic- ultrasonic treatment drills.

3. RESULTS

Summarized in Table 1 are results for the twisting moment and axial force in the applied experimental cutting conditions during work with normal drills and for drills, identical to the latter, but previously subjected to treatment with the indicated regimen in "MUS – 1". The recorded values for the average and maximal wear, VB_k and VB_{max} respectively, with the drilling of 50 holes with a work regimen of $V_c = 25$ m/min and f = 0,05 mm/tour, are exposed in Table 2 (see also Fig. 1 for graphical representation). The results show, that as a whole, the work with the preliminarily treated drills and for the three cutting regimens is conducted under significantly eased manufacturing conditions, favoring the technological system "machine – adaptation – tool – part", concretely expressed in: 1) a decrease in the twisting moment from 89 to 50 percent and in the axial force from 14 to 79 percent; 2) a decrease in the wear from 1,94 to 2,39 times; 3) significantly decreased breaking of the drills.

4. CONCLUSIONS

The above results allow concluding that the work with tools subjected to magnetic-ultrasonic treatment is accompanied with a change in the cutting conditions and in the "tool – part" contact interaction. The level of the obtained effect is directly dependent on the applied positive changes in the tool's material from the treatment itself, and namely the increased dislocation density, and the occurred intensive relaxation processes of the accumulations of a larger number of atoms in the Kotrel's atmospheres around dislocations (Makedonski, 2005).

5. REFERENCES

[1] Gourevih, D.M. (1975). Износ твердосплавного инструмента при високих скоростях резания. *Вестник машиностроения*. No. 5, 68-69.

[2] Gourevich, D.M. (1976). Причины образования экстремума стойкостной зависимости твердосплавного инструмента. *Вестник машиностроения*. No. 12, 30-33.

[3] Ivanov, M.K. (1975). Исследование связи износостойкости с эдс, возникающей при трении металлов *Автореф.канд.дис., Ростов-н/Д*

[4] Kabaldin, J.G. (1981). Хрупкое разрушение режущей части инструмента-*Вестник машиностроения*. No. 7, 41-42.

[5] Makedonski, A.I. (2005). Електрофизична технология за повишаване износоустойчивостта на феромагнитни материали, *Дисертация д.т.н.*, София.

[6] Ziad Nabih Abdou. (2007). Experimentální výzkum šroubovitých vrtáků, *Diplomová práce* , ČVUT- Fakul strojní, Praha.

[7] Zorev N.N, Klauch .DH, Batiorev B.B et al. (1971). O процессе износа твердосплавного инструмента. *Вестник машиностроения.* No. 11, 70-73.

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ANALYSIS OF GEAR CHARACTERISTICS AND SERATION PROCESSING IN "KOLUBARA - METAL" FACTORY

Abstract: *The introduction of modern technology in the production of profiled gear milling cutters requires a complete analysis of the application of the tools in the industry of our country. This paper presents the analysis of the application of the aforementioned tools in the company 'Kolubara-Metal '. With regard to the fact that a wide assortment of gears is produced in this company, the analysis included different types of serration machines as well as various profiled gearing tools utilised in the gear production.*
The paper includes some tool-related issues, i.e. producer, geometry, tool materials and tool sharpening as well as workpiece-related ones, i.e. material, dimensions, complexity, quality of manufacture and scale of production.
Key words*: serration machines, profiled gear milling cutters, serration, tool exploitation, tool sharpening.*

1. INTRODUCTION

Despite the bad economic situation some fields must work, because other economic and social fields depend on them. There are commercial organizations that still produce something for others, but they primarily work for their own needs. One such factory is "Kolubara-Metal" which has in own program wide variety of production gear. Given the wide range of different gear, size (dimensions up to 2 m), shape (cylindrical and conoid), with real teeth, screw ,..., has a number of special machines with intended usege.

It is pleasure to see all machines in the plant for serration work. After having different machines for making gears of different sizes and dimensions, this paper presents the machine with their characteristics

2.ANALYSIS OF THE PRODUCT ON WHICH SERRATION PROCESSING

Working piece or gear that are processed may be of soft material: bronze, brass, cast iron or steel, usually Č.4732 steel alloy steel for improvement (improved from 25 to 27 HRC) is used.

Working gear diameter: maximum without support pillar 2000 mm, maximum with extra column 1200mm minimum 300 mm. The maximum length of milling of straight-teeth and slant-teeth gears: with vertical milling is 560 mm and with radial milling 760 mm.
For sharpening of milling machine for this purpose is used. This machine is of Russian descent. On this machine are sharpened milling all the modules from the smallest to the largest one (from 5 to 24 mm). Milling cutter sharpened by face area until the sides to be clean of the damage. Sharpening depends on the quality of the work peace, and the quality of tools. If the work peace which already thermally enhanced is processed, tool will be more weared, and have to be often sharpen more often or more milling cutters are used. average sharpening milling cutter for 24 hours is three times.

Milling machine is placed on the spindle, the number of teeth put dividing plate that match the number of teeth of milling cutter. The grindstone is introduced into hollow between, teeth under certain angle and approach to sharpening. When sharpening is done by cooling to prevent heating of milling, which would lead to changes in the structure of material tools, and thus change the hardness. Wear depends on the type of material analyzed, the number of teeth and the shift in average after a sharp tool 16 to 32h of work .

Fig. 1 Sharpening of milling cutter.

3.ANALYSIS OF MACHINES FOR PROCESSING OF SERRATION

Semiautomatic milling machine 5K32P mill is designed for rough and fine gear seration with straight and oblique teeth. The highest productivity of machines is given in terms of serial production, but on it can produce and gears in small batches and in very broad limits. The machine 5K32P can be make gear with straight and oblique teeth of the core module $0.5 \div 10^{th}$. Its structure is designed for larger modules. Working length of the machine is 250 mm and maximum diameter of the work piece is 800mm. This machine uses milling cutters. The choice depends on the mode of processing modules, the diameter and length of gears that are made.

For example, a gear module 8 is made with the three passages, where 1mm is left for the final passage to the final measures. Rotation per minute (Rpm) of milling cutter must not be below 56 rpm, and shift 0.8 mm.

Fig.2. Semiautomatic milling machine 5K32P

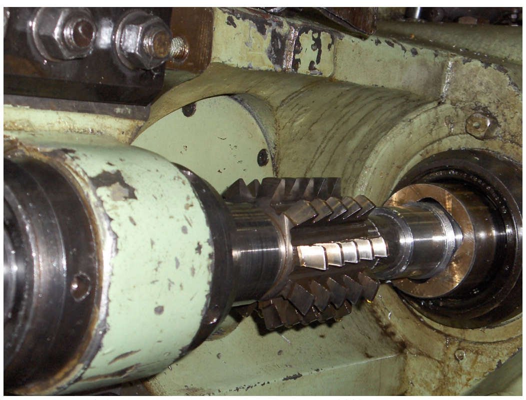

Fig.3. Machine 5K32P uses gear milling cutter.

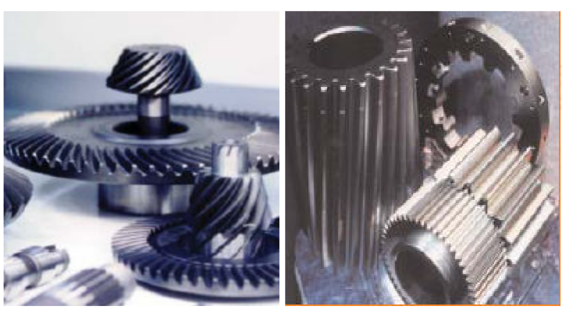

Fig.4. Different types of gears, which are produced on the machine 5K32P

Universal milling machines for serration, model 5A342, is provided for processing of serration of cylindrical gears, applying the method of relative rolling milling cutter method and individual sharing and milling, with squamous or spindle gear milling cutters.

The machine can process serration the following types of gears: the gears with traight and oblique teeth for external coupling, gears with straight and oblique teeth for internal coupling, worm gears, gears with teeth arrow channel and no channel for output of milling, with the right gears teeth, with a small angle cone at the top.

Universal milling machines for serration uses various tools, thus modes of treatment are broad spectrum, which depends on the material that is processed if the processes softer materials-bronze, brass, cast iron, use the higher modes of processing, which in turn depends on the module gears. Processing of serration of steel are used less cutting conditions.

The main motion is circular and it is made by a tool that processes serration of gear; also mounting tools can have two extra movements that are linear; addition of further movement of the same circular that working piece is performed which depends on the type of milling cutters that are used for certain gear.

Fig.5. Development of different gears on the universal milling machines

Milling machines for serration model ZFWZ3150 / 3 is provided for processing of serration of cylindrical gears.

There are three types of processing: sharing unit, relative motion and tangential milling.

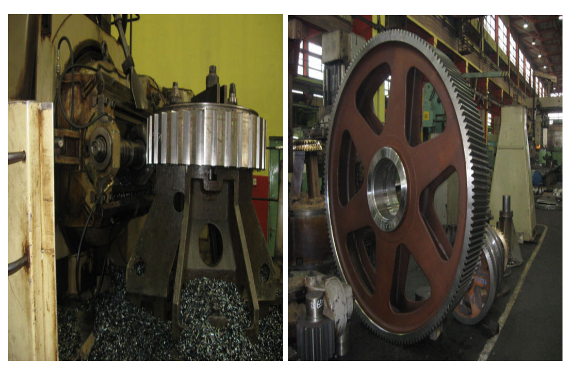

Fig.6. Production of cylindrical gears on the machine ZFWZ3150 / 3

3.1. Wear and sharpening of milling cutter

The wear process of milling cutters affects many factors (Figure 1). Increased wear of milling cutter first milling machine operator perceives first. It can observe the worn cutting edges of teeth of milling cutter, and is characterized by a blunt sound of the milling, which also attracted attention. In this case the cause of blunt edge of milling cutters, the occurrence of sand in the cast of worm wheel. Other common reasons for wearing of milling cutters are: hardness of gears and the phenomenon of great chip, chip on deposits milling cutter . Asynchronous speed of milling cutter and work piece, fraying blade due to periodic variable load certain stages of creating a chip, separation parts of tools with periodic separation deposits from tools (Figure 5). In Figure 6 gives a general form of wear and tear of the process of cutting elements of milling cutter are given.

Depending on the damage or blunt of cutting edge of milling cutters, it needs to be sharpen. Frequently damage and wear of milling cutter ranges from 0.1 to 0.7 mm in normal use, ie. normal regime. Focuses on the mill until the damage can not leave the wings and head milling. Side and head of milling get from factory sharpened by the module and profile, and be sharp while retaining module and profile, ie. until it remains only back part of milling. Each sharpening of milling cutter increases the space between the radical-relief angle and rake angle

Fig.7.The traces of wear on milling cutter

When sharpening specifical oil for cooling of milling cutter called "RIZOL" is used. On this machine 46 grain grinder granulation is used. Less modules is easier and faster sharpen than of the larger modules. Milling cutter can sharpen whet approximately 50 sharpening with normal modes of serration. The process of sharpening milling briefly looks like this: grinder goes straight to hollow between teeth of milling to sarpen rake angle, a machine with guitars that fixed for that milling machine adjusts coil (step) by taking every passing from 0.03 to 0.01 mm depending on the module. Smaller modules to m_n - 10 can sharpen for about 90 minutes of normal mode sharpening. Module 24 for 4 hours with normal wearness. This machine sharpens the largest module, m_n - 24

The machine is semi-automatic, by preparing and fixing for necessary milling cutter. The machine itself divides automaticly the number of teeth-by-step perform feed of sharp stone (grinder), and the number of passages in one cycle is about 20 passages.

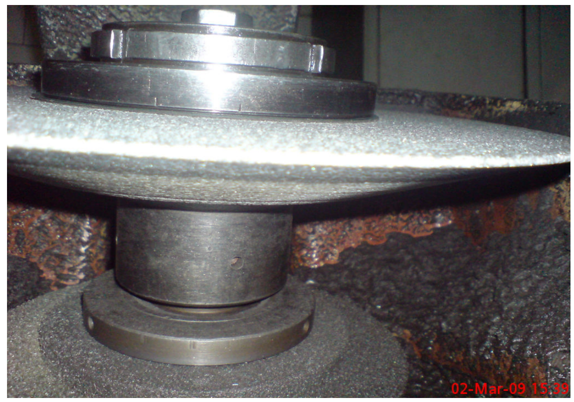

Fig.8. Grindstone for sharpening of milling cutters

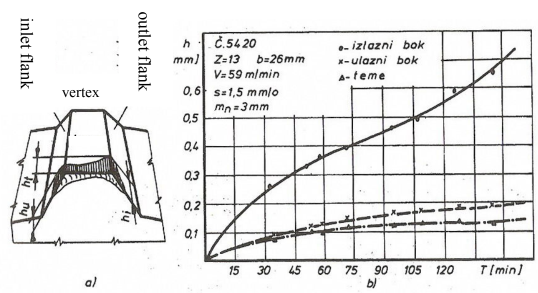

Fig.9.The general form of wear (a) and development of wear processes (b) cutting element milling cutter

4. CONCLUSION

In this paper analysis of application of gear milling cutters for making gears in the factory "Kolubara-Metal" is given. The machines that are used for serration are included. The characteristics of machines, tools, and gear that are produced on them are given. All machines in the factory work, mostly produced gears for its own purposes, for maintenance of excavators working in the mines. Sometimes they work on the order for other customers. Continuous production of gears includes tools for serration consumption. From the aspect of consumer of tools, the introduction of modern technology in the production of profiled gear milling cutters makes sense.

5. REFERENCES

[1] Kimer, J.: Tehnološki postupci i alati, I deo-Alati za obradu rezanjem, Novi Sad, 1973.

[2] Nikić, Z., Radonjić, S., Jugović, V. , Jovanović, B.: *Eksploatacione karakteristike PFAUTER glodala presvučenih slojem TiN*, Zbornik radova, 24. Savetovanje proizvodnog mašinstva Jugoslavije, Redni broj strane 127-133, Novi Sad, 1992,.

[3] Nikić, Z., Radonjić, S.:*Exploiting characteristics of Pfauter Milling cutte coated with TiN layers*, 12th ICPR – International Conference on Production Research Preliminary Programme, Finland, 1993.

[4] Radonjić, S., Nikić, Z., Jovanović, B.: *Tajlorovi izrazi pri ozubljenju Pfauter glodalom*, 25. Savetovanje proizvodnog cmašinstva Jugoslavije, Redni broj strane 45-50 Beograd, 1994.

[5] Radonjić, S., Sovilj, B., Sovilj-Nikić,I., Analiza leđnog struganja zuba odvalnih glodala klasičnim postupkom, 32. Savetovanje proizvodnog mašinstva Srbije sa međunarodnim učećem, Novi Sad, 18.-20. septembra 2008.

.

[6] Sovilj. B.: *Identifikacija triboloških procesa pri odvalnom glodanju*, Novi Sad, IPM, FTN, 1988.

[7] Sovilj, B.,Prapotnik, B., Mitrović, R., Todić, V.: *Influence of gearing process on the occurence of cutting edge break by hob milling tools*, Tribology in industry, Vol. 21, No. 2, Redni broj strane 53-58, 1999.

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Sovilj, B., Radonjic, S., Sovilj-Nikic, I.

ANALYSIS OF APPLICATION OF PROFILED TOOLS FOR SERATION IN "KOLUBARA - METAL" FACTORY

Abstract: *The introduction of modern technology in the production of profiled gear milling cutters requires a complete analysis of applying these tools in the domestic industry: In the paper the analysis of application of profiled gear milling cutters for serration in the factory "KOLUBARA-METAL" Vreoci. Considering that in this factory a wide range of gears is produced, the analysis included the type and performance of profiled milling cutters used in the manufacture of gears.*
Keywords: *gear profiled milling cutters, milling cutters, disc-shaped milling cutters and palmate milling cutters.*

1. INTRODUCTION

Profiled milling cutters with the backstroke teeth are very widespread in the processing of profiled parts. These are: convex milling cutters, concave milling cutters, gear cutters, splines of splined shafts of straight-line profiles, tapping as well as milling cutters for special applications designed to process the most complex profiles. The biggest advantage of profiled milling cutters comes to the fore when processing parts with greater length by the width of the profiled surface. Other advantages of profiled milling cutters are:
- Ease of manufacture, processing by back surface profile is performed only with a knife without grinding and applying of special auxiliary tools;
- Ease of sharpening that is done by face surface, while retain the original profile is retained "KOLUBARA-METAL" in its program has a wide variety of gear production , both in form and size.

2. ROLE AND IMPORTANCE OF HOB MILLING CUTTER DURING GEAR SERRATION

Hob milling, as one of the most complex processing cutting, is the broadest application of processing cylindrical gear teeth due to high productivity process. Complicated kinematical and geometric relationship between hob milling workpiece and cutting tool creates a series of difficulties and problems that prevent optimal use of tools and machines, such as: determining the optimal cutting speed and displacement, determining the existence of rational hob milling, the maximum and evenly to use as multi tooth tools, which determines the geometry of productive hob milling etc.[1].

Improving the process of hob milling is significant and useful for manufacturers of gears as well as manufacturers of hob milling cutters. Because of the complicated process, high values of gears, especially the tools, research of backgrounds for hob milling process optimization and optimization of geometrical parameters require considerable financial resources and the significant efforts of researchers. There are many factors that influence the process of hob milling. Numerous factors and their interaction make the wear process difficult for the study

Figure 1 presents the factors which influence the wear during hob milling process

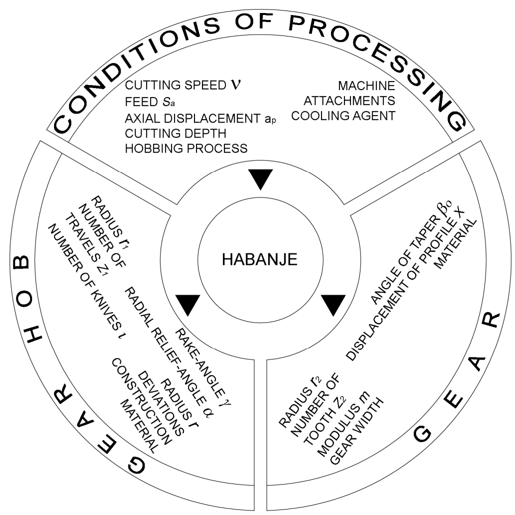


Fig. 1 Factors influencing wear during hob milling process

Hob milling process is one of the most important link in the chain of mechanical processing because of it has great impact on productivity, the final geometric accuracy and the quality of serration surface. By development of hob milling technology hob milling, hob milling is successfully applied for the rough machining as well as fine machining of serration. Therefore, the demand for the optimization process increased as from the standpoint of surface quality, and from the standpoint of productivity. A prerequisite for the successful optimization and adaptive management of the process is its identification, and identification of phenomena arising in hob milling. Therefore, research activities in this field are directed to to development of new hob milling cutters and technological improvements in machinery as well as completely new methods for identifying a credible description of the processes and phenomena arising during hob milling [6].

Hob milling cutters are used for making gear serration with straight, oblique and helical teeth and making worm wheels for external conjugation with involute profile (Figure 2).

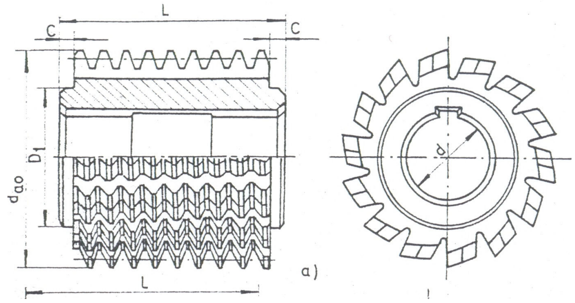


Fig. 2. Integral gear hob

Hob milling cutters is usually made as single-thread especially if they are used for fine machining. For the rough and previous machining are made with two or more threads due to faster and less processing. Construction of milling cutter with inserted teeth (Figure 3) allows savings in material costs over 50%, greater durability of tools for over 60%, cost reduction of serration for over 25%, and increased process productivity 1.5 times compared to the integral hob milling cutters.

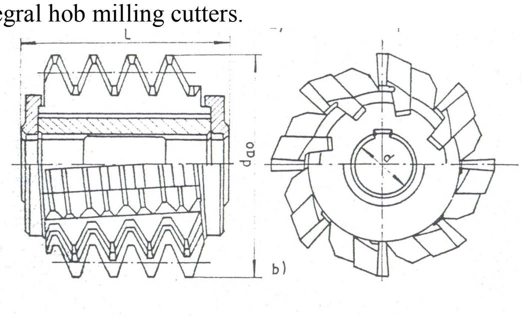


Fig.3. Milling cutter with inserted teeth

3. TYPES PROFILED GEAR MILLING CUTTERS USED AT 5A342 MACHINE

Hob milling cutter is an indispensable tool for processing gear serration by hob milling method. It is made out of high-speed steel as one piece or of hard metal with inserted teeth.

There is different classification of hob milling cutters. Direction of milling is essential for setting machines, there are schemes of setting in which the relationship (direction) miller – gear is presented.

In Figure 4 is a milling head with engraved signs: module, angle of milling cutter, steel, etc is shown.
Hob milling cutters are differed in module size. It is from 0.5 to 30 depending on the required gear that serrated. There are milling cutters with multiple starting points.

Fig. 4. Milling head with engraved signs

Fig. 5. Hob milling cutter

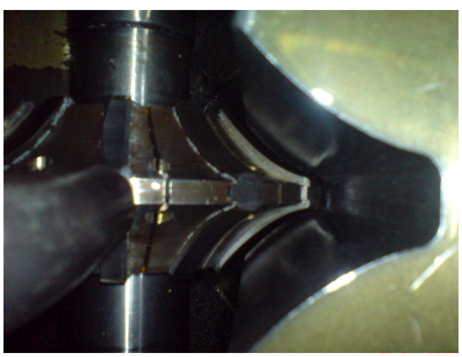
Fig. 6. Hob milling cutters for making fluts

Hob milling cutters are marked divided by the tooth profile. Three basic profiles can be differentiated that are marked with Roman numerals I, II, III . Profile I is outside standards, i.e. it has a short profile of the teeth and it gives shallower teeth, or it is made as the template - to be used for dedicated tasks. Profile II is a standard profile that is used mostly. Profile III is profile of milling cutter used for making gears with predimension for grinding. This profile leaves deeper hollow between teeth because of passage of abrasive grinding wheel grinder at machine for grinding the gears. This type of milling cutters has a wider head because of end of the grinding wheel. There are also more milling cutters for serration processing that have different profiles (Figure 6.).

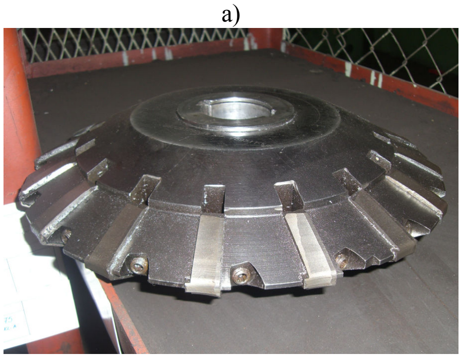
Milling machine for making chain wheel whose cogs have radius shape is shown in Figure 7. This milling cutters are defined by pitch and diameter of rolls or cylinder, also with profiles I, II and III.

Fig. 7. Milling cutters for making chain wheel

Most of the milling cutters has cutting angle of 20 degrees.



a)



b)

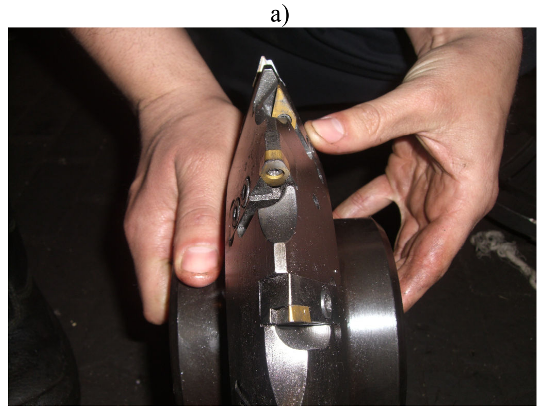
Fig. 8. Disc-shaped milling cutters (a,b)

Disc-shaped milling cutters(Figure 8.) are mainly used for processing of gear serration with large module. These milling cutters are made of high-speed steel: Č9780, Č7880, Č7680. Hardness of cutting piece is $63^{\pm 1}$ HRc.

Disc-shaped milling cutters have all the modules. Some milling cutters are made by made or sharpen by patterns. Templates are mounted on the machine for sharpening.

Disc-shaped milling cutters with variable hard metal plates are used in processing of gear serration gear on predimension When the gear is mounted on the machine, previous processing is performed by disc-shaped milling cutter with removable plates, and then it is taken off and milling cutter of high-speed steel is put which is used for fine machining. Milling cutters with removable plates are generally used. With such type of milling cutters productivity is much higher, achieving a much higher cutting speed and without cooling. When milling cutter of high-speed steel are used cooling is necessary and cutting speed is less.

a)



b)

Fig. 9. Disc-shaped milling cutters with changeable inserts (a,b)

There are all types, profiles and modules from -5 to larger modules 40 of palmate milling cutters. It is used in special cases when other milling cutters can not be applied. It is used by serration of arrow gears where arrow on the double gear is not separated by the or there is a small space where the arrows of double gears are broken. The palmate milling uses a special head which has a cone of acceptance in which it fixed.

a)

b)

Fig.10. Palmate milling cutter (a,b)

4. CONCLUSION

One of the factories which in its production program making different gears, as in shape and size, on different machines is factory Kolubara-Metal ". It uses a different profiled gear milling cutters. Their production is focused on their own needs, related to the system for the production of coal, which is a continuous process in making gears.

The paper made a summary of tools for use in the factory "KOLUBARA-METAL. The characteristics of some tools for serration used in their production are given.

5. REFERENCES

[1] Kimer, J.: Tehnološki postupci i alati, I deo-Alati za obradu rezanjem, Novi Sad, 1973.

[2] Nikić, Z., Radonjić, S., Jugović, V. , Jovanović, B.: *Eksploatacione karakteristike PFAUTER glodala presvučenih slojem TiN*, Zbornik radova, 24. Savetovanje proizvodnog mašinstva Jugoslavije, Redni broj strane 127-133, Novi Sad, 1992,.

[3] Nikić, Z., Radonjić, S.:*Exploiting characteristics of Pfauter Milling cutte coated with TiN layers*, 12th ICPR – International Conference on Production Research Preliminary Programme, Finland, 1993.

[4] Radonjić, S., Nikić, Z., Jovanović, B.: *Tajlorovi izrazi pri ozubljenju Pfauter glodalom*, 25. Savetovanje proizvodnog cmašinstva Jugoslavije, Redni broj strane 45-50 Beograd, 1994.

[5] Radonjić, S., Sovilj, B., Sovilj-Nikić,I., Analiza leđnog struganja zuba odvalnih glodala klasičnim postupkom, 32. Savetovanje proizvodnog mašinstva Srbije sa međunarodnim učećem, Novi Sad, 18.-20. septembra 2008.

[6] Sovilj. B.: *Identifikacija triboloških procesa pri odvalnom glodanju*, Novi Sad, IPM, FTN, 1988.

[7] Sovilj, B.,Prapotnik, B., Mitrović, R., Todić, V.: *Influence of gearing process on the occurence of cutting edge break by hob milling tools*, Tribology in industry, Vol. 21, No. 2, Redni broj strane 53-58, 1999.

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10th INTERNATIONAL SCIENTIFIC CONFERENCE
Novi Sad, Serbia, October 9-10, 2009

Trakic, E., Avdic, S., Saric, B.

REVERSE ENGINEERING OF STATOR WINGS OF VARIABLE TURBO CHARGER

Abstract: *In the process of reversible engineering of complex geometrically demanding forms of products there is significant influence of laser methods of triangulation to preciseness of the product digitalization process. The aim of the process of reengineering of stators wings of turbine as functionally responsible component of turbocharger of very small size is the analysis of geometric relations of aerodynamic profile generally protected by the manufacturer.*
Digitalized model of wings of turbocharger is still used as the basis for computer control of products, "CAI inspection "which represents new concept in the field of insurance of quality of the products
Key words: *reversible engineering, 3D digitalization, CAI inspection*

1. INTRODUCTION

Reversible engineering (RI) of the products is applied with the aim of analysis of functionality, identification and multiplication of existing part, composition or whole product, when schemes, technical documentation or CAD model are not available. It is known that tree-dimensional verification and control of parts is the most usually slow and expensive and it represents the element that disturbs production process. Manufacturing companies spend great part of their resources in order to develop 3D CAD models that serve as the basis for the definition of the design. But, efficiency of 3D CAD model is not transferred into the process of verification and control of the product. The term CAI-inspection comprises verification of the deviation of geometry of wing blade of turbocharger (on the basis of its digitalized model) from nominal geometry, defined by CAD model.

It is possible to separate two basic segments of CAI-inspection:

- 3D-digitalization and
- Verification of deviation

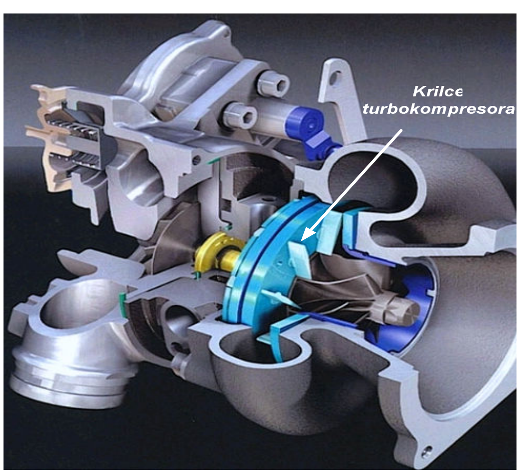
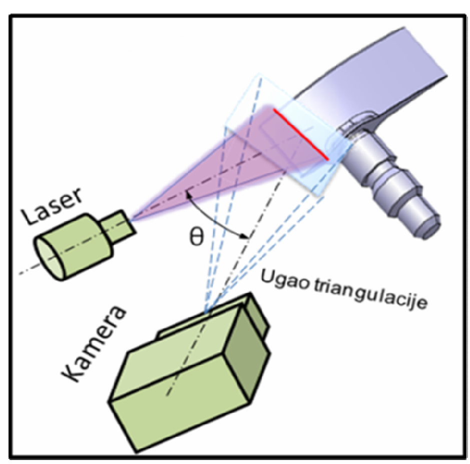


Fig. 1. Wing of turbocharger

2. SPATIAL 3D DIGITALIZATION OF THE OBJECT

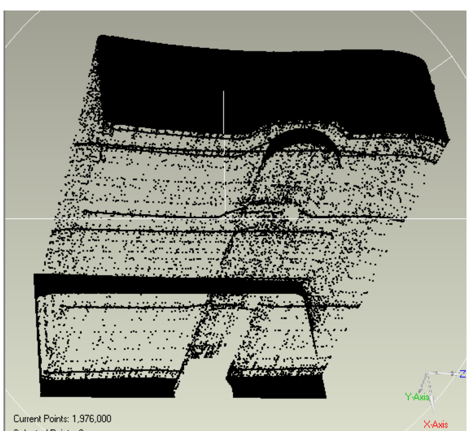
Within 3D digitalization data on coordinate points are collected from the surface of physical object and their translation into digital form. This is the origin of the term 3D digitalization. The result of 3D digitalization is assembly of points, defined through coordinates, which are often referred in the literature as *the cloud of points*, due to the shape which occupy in the space.

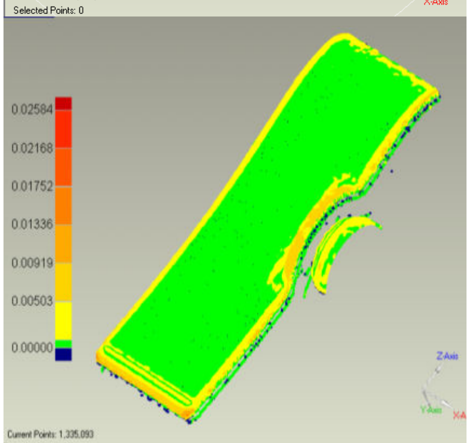


This phase is considered as the most important in the process of RI, having in mind that in the biggest number of cases, the quality of results of 3D digitalization determines the quality of the resulting CAD model.

Fig. 2. Digitalization of the object through application of the laser

Thanks to this system of application of the laser the Picture 1. large number of 3D measure points of the object are generated. Also, fast and efficient digitalization of the product is preformed. This process is faster, more detailed and more précised in comparison with some other traditional methods. The advantage is in the possibility of generation of thousands and millions of points in short time through application of 3D scanner.





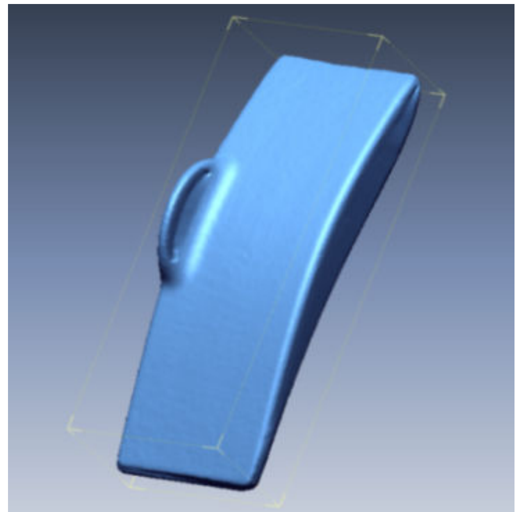


Fig. 3. Post processing of digitalized model

After the process of 3D digitalization, there is a lot of practical problems related to the cloud if points – Picture 3a., such as presence of disturbances, that is measuring mistakes and and peaks, (too) large number of (needless) points, as well as lack of data systematization. The basic task of the process of reduction of scanned data Picture 3b., (post processing), is getting of characteristic points which present the basis for (re)construction for the curve or the surface, with the aim of developing of geometric model in the satisfactory timeframe, which with sufficient quality approximates the original object. Reconstruction of the surfaces on the basis of polygonal approximations is based on generation of the network of polygons (the most generally triangles), and the very procedure is much more precise if the result of the digitalization is more complete and of a higher quality. When whole surface is mathematically described that is closed, surface model is being transferred into the body (*"solid"*) – volume model Picture 3c.. Than, it is appropriate for work with common and widespread CAD systems.

3. ANALYSIS OF CAI RESULTS

The process of getting of verification results starts with selection of surfaces where there is a need for inspection. The CAI process (Picture 4), is composed of the spatial digitalization of the sample which is taken during production process or as the inspection object. Produced digitalized model (so called *the cloud of points*) is entered into some of specialized software for CAD inspection, together with corresponding CAD-model. After that orientation of digitalized model towards CAD-models being preformed with the aim of their mutual overlapping. Afterwards, calculation of the level of deviation of digitalized model from CAD-model is preformed. The other possibility, due to lack of CAD model, is mutual comparison of “the *cloud of points* “for two samples of the same shape. When *the cloud of points* corresponds to some CAD network, the distance between transformed cloud of points and CAD network has to be irrelevant in order to perform exact

CAI procedure.

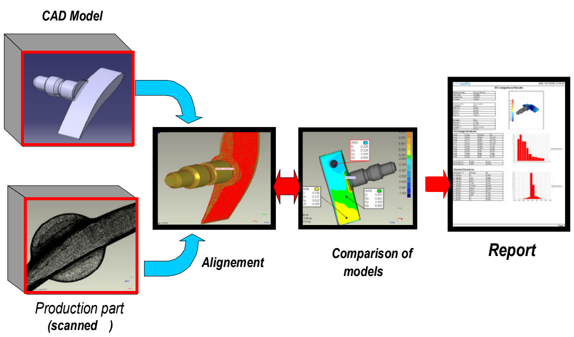


Fig. 4. Procedure of computer supported CAI-inspection

Analysis of deviation of products in 2D and 3D space (Picture 5) is the greatest contribution of this CAI method, since all possibilities of fast analysis and control of the product are subordinated to the possibilities of software applied programs. It is very important to show geometric relation of wing profile which is the fundamental goal in the process of reengineering. The analysis can serve afterwards in the process of production of duplicates or in upgrading through redesign.

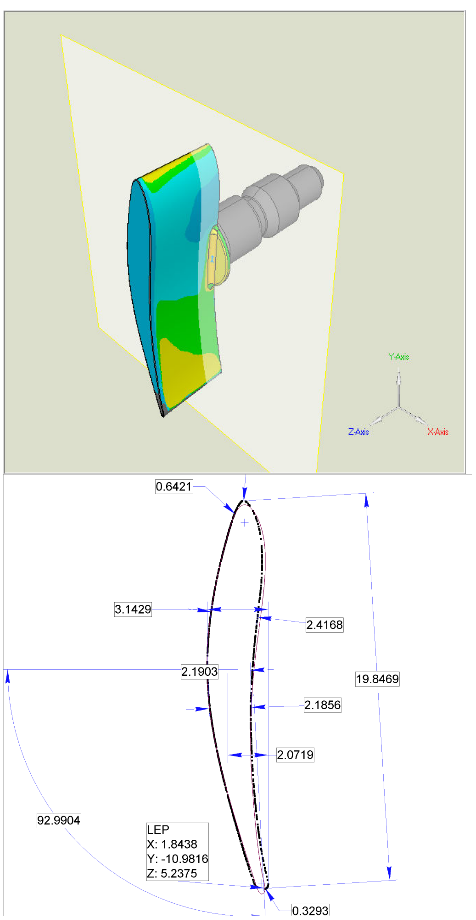


Fig. 5. Analysis of product in 2D and 3D space

4. CONCLUSION

In the present competitive market conditions, reduction of time from the development to the delivery is of crucial importance for survival in market. Digitalization of model of complex form through application of laser significantly accelerates the possibilities of innovation or development of the products in comparison to the classic approach. 3D technologies of digitalization provide significant time reduction for measurement, increase of preciseness, reliability and productivity of the process of information identification about dimensional precision of parts, especially parts of high technological complexity. Digitalized model of wings is suitable for simulation studies, production through application of modern techniques, production of tools and fast analysis in the sense of innovation of products. That enables the manufacturers to reach higher goals and to be competitive in the market.Application of CAI technology represents the process of verification and inspection in 3D digital environment, which is completely integrated in already existing CAD/CAM/CAE system.

5. REFERENCES

[1] M. Lukac, T. Perhavec, J. Diaci, ; *Comparison of Er:YAG and Er:Cr:YSGG Dental Lasers,* Presented at the SOLA International Dental Laser Conference Bangalore, Feb. 8-9, 2008

[2] K. H. Lee and H. Park, “Automated Inspection of Free-Form Shape Parts by Laser Scanning”, *Robotics and Computer Integrated Manufacturing 16*, pp. 201-210, 2000.

[3] Weish T.W.: *Introduction to CAD-Driven Reverse Engineering*, Designing With Reverse Engineering, Society of Manufacturing Engineers IMTS Conference, 2000.

[4] Vergeest J.S.M., Horváth I., Kuczogi G., Opiyo E.Z., Wiegers T.: *Reverse Engineering For Shape Synthesis In Industrial Engineering*, Delft University of Technology, The Netherlands, 2000.

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Zuperl, U., Cus, F.

AUTOMATION OF MILLING FIXTURE VERIFICATION PROCESS

Abstract: *The paper presents the automation of analysis and verification process of clamping devices, suitable for fixing of thin-wall workpieces. These workpieces will likely undergo deformations due to clamping and cutting forces during machining, which are the result of inconsiderate fixture design. An automation program has been made for the evaluation of fixtures intended for clamping of prismatic and rotational products, for determination of the optimum magnitude and positioning of clamping forces, required to enable the workpiece to be safely clamped during machining. The automation procedure ensures reduction of fixture planning process and prevention of defects and deformation during the machining process.*
Key words: *fixtures, milling, automation, clamping force.*

1. INTRODUCTION

The developed system is of great importance for designing fixtures since it can routinely determine within a short time the optimum sizes, direction and application points of clamping and locating forces for different cases of clamping. The purpose of the procedure is to improve the design of fixture and thus to increase the geometrical accuracy of the thin-wall product made. Designing of fixtures is a complex and intuitive process for which an experienced technologist is required. For each workpiece there are several possible solutions of the design of modular fixtures, therefore the scope of possible solutions is large.

The development of the artificial intelligence has contributed to limiting the scope of possible solutions and, consequently, to achieving better designs. Developed automation procedure (Figure 1) contains the fixture design, analysis, optimization and simulation module. The highly capable structure offers also the possibility of rationalization and visualization of the fixture solution obtained. It is important to consider the cutting forces, the clamping forces, the friction forces and the dimensions and availability of fixtures as well as the space on the machine limiting the possibility of clamping. The designing and manufacturing costs of the fixture amount even to 18 % of the total production costs [1]. In addition to searching for the mathematical solution for positioning and clamping of workpieces the development is oriented towards searching for the solutions by means of the computer routine. Researches [2] proposed the model “workpiece-fixture” based on the screw theory and used the linear programming method for determination of clamping forces. By the use of the non-linear programming method the quadratic model for verification of the fixture configuration is derived [3]. Mittal [4] proposes the dynamic model “fixture-workpiece” for the determination of the required clamping forces ensuring the equilibrium of the workpiece during machining. All the above mentioned methods use simplified models which do not take the friction into account in their calculations [5].

2. ASSUMPTION IN MAKING THE AUTOMATION PROCESS

When making the automation programme it was assumed that the workpiece would be fixed by a flexible modular fixture ensuring clamping of workpieces of different shapes. The worked out programme works on the (industrial computer) IPC and is programmed in the C++ programme language. The developed programme determines [6]:

- Minimum number and position of locating and clamping elements,
- Motion allowed by locating elements,
- Reactions at the places of the contact “workpiece-fixture” (locating forces),
- Minimal clamping forces required for balancing of cutting forces,
- Collision detection system,
- Fixture cost calculation system,
- The cost of fixture automation (pneumatic in combination with hydraulic) [7],
- Animation of fixture assembling, machining [8],
- Visualization of clamping control.

The clamping forces on the workpiece must not create internal stresses and must not damage or deform the workpiece surface. This argument affords great importance to the model made since it specifies the minimum required clamping forces, their application points and orientations with which the workpiece is still safely clamped. The purpose of the Force analysis is to find out whether the workpiece will lose the contact with the locating and positioning elements during machining due to cutting forces and moments.

3. CLAMPING SCHEME ANALYSIS AND OPTIMIZATION

The scene is more complex when friction between the workpiece and fixture is taken into account (Fig. 2).

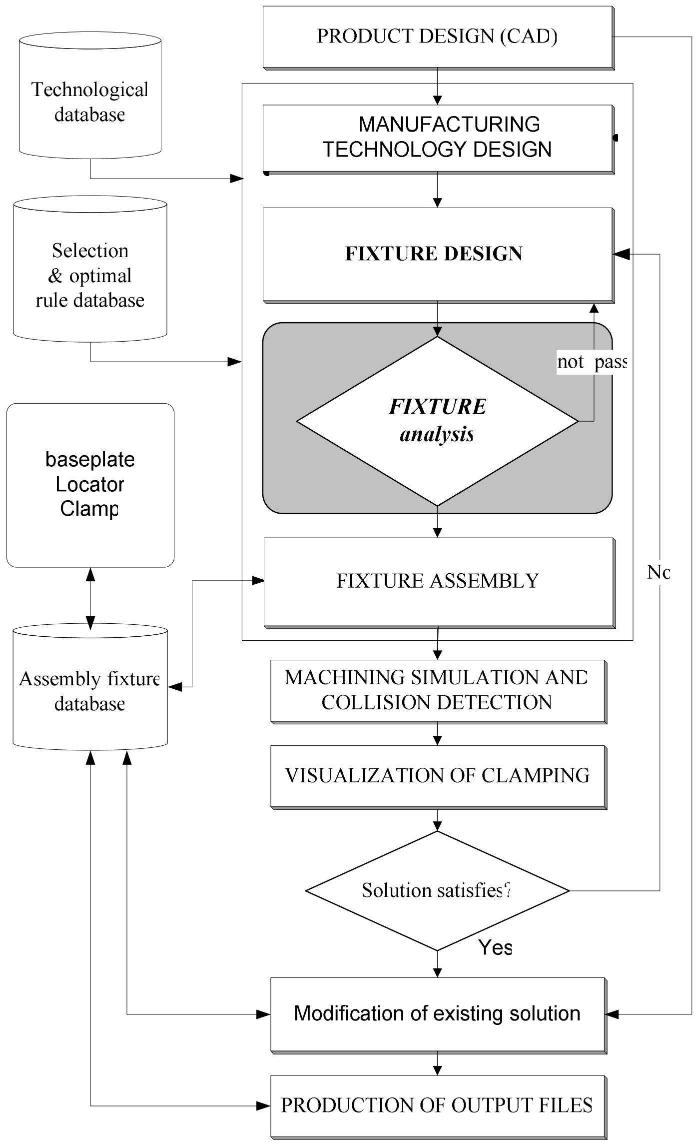

Fig. 1. Block diagram of the automated system for selection, analysis, optimization and visualisation of fixtures.

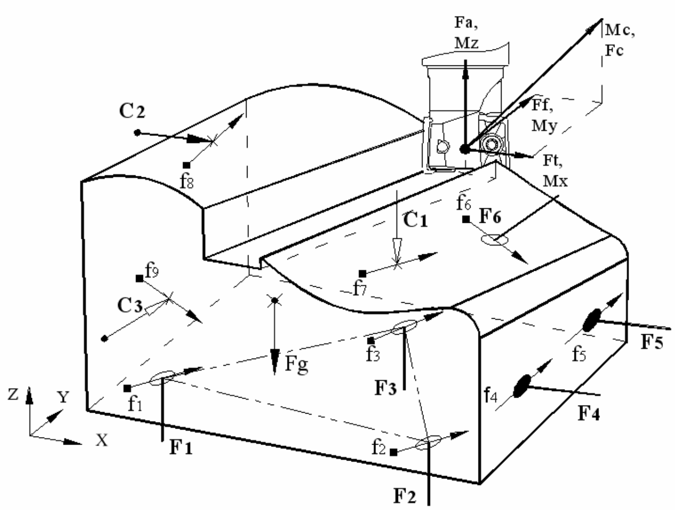

Fig. 2. Forces on workpiece during the milling process

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Where:

- (F_1 - F_6)- reactions acting on locating elements (N)
- (C_1, C_2, C_3)- clamping forces acting in the direction of the normal onto positioning planes (N)
- (F_t, F_a, F_f - components of cutting force F_c (N)
- (M_x, M_y, M_z)- components of cutting moment M_c (Nm)
- f_i, (i=1...6)- resulting friction forces in contact points (N)
- F_g- force of workpiece weight (N)
- μ - friction coefficient

In general when the friction forces are taken into account, the number of unknowns is far more than that of the equilibrium equations. In order to solve for clamping forces the case must be simplified, and an iteration method is used in the force analysis routine. The workpiece is located on the six-point P_1-P_6, and is held by three clamping forces C_1, C_2, C_3 at points P_7, P_8, P_9, respectively. The resulting force of friction f_i between the locator and workpiece is $\mu \cdot F_i$ and between the fixing element and the workpiece it is $\mu \cdot C_j$, ($j=1...3$). The reactions on the locating elements must be positive because otherwise the contact between the workpiece and the fixture is lost.

4. MATHEMATICAL SYSTEM FOR CALCULATION OF CLAMPING AND LOCATING FORCES

To achieve static equilibrium and dimensional accuracy in machining the resultant force and moment on the workpiece must be zero. The equations of equilibrium are:

$$\sum \mathrm{F_i} = 0$$

$$\left(\sum_{i=1}^{6} \mathrm{F_i}\right)_x - \mathrm{R_x} = \left(\sum_{i=1}^{6} \mathrm{F_i}\right)_y - \mathrm{R_y} = \qquad (1)$$

$$= \left(\sum_{i=1}^{6} \mathrm{F_i}\right)_z - \mathrm{R_z} = 0$$

$$\sum \mathrm{M_i} = 0$$

$$\left(\sum_{i=1}^{6} (\mathrm{F_i} \times \mathrm{r_i})\right)_x - \mathrm{M_x} = \left(\sum_{i=1}^{6} (\mathrm{F_i} \times \mathrm{r_i})\right)_y - \mathrm{M_y} = \qquad (2)$$

$$= \left(\sum_{i=1}^{6} (\mathrm{F_i} \times \mathrm{r_i})\right)_z - \mathrm{M_z} = 0$$

Where: r_i- the vectors defining the locating points, (R_x, R_y, R_z) - components of the resultant cutting force F_c.

Because of the numerical solving of the problem the equilibrium equations are written in matrix form:

$$[A]_{lok} \cdot [F]_{lok} + [w_e] = 0 \qquad (3)$$

The normalised geometrical matrix $[A]_{lok}$ is as followed:

The vector of supporting forces $[F]_{lok}^T$:

$$[F]_{lok}^T = [F_1 \quad F_2 \quad F_3 \quad F_4 \quad F_5 \quad F_6] \qquad (5)$$

When the coefficient of the friction between the workpiece and the clamping elements is equal to zero, the above equation is simplified. After entering the geometrical matrix $[A]_{lok}$ and the vector of external forces $[w_e]$ into the Equation 3 the clamping and locating forces are calculated.

The normalized geometrical matrix $[A]_{lok}$ and the vector of external forces $[w_e]$ are as followed:

$$[A]_{lok} = \left[\begin{array}{cccccc}
f_{1x} & f_{2x} & f_{3x} & -1 & -1 & f_{6x} \\
f_{1y} & f_{2y} & f_{3y} & f_{4y} & f_{5y} & -1 \\
1 & 1 & 1 & -f_{4z} & -f_{5z} & -f_{6z} \\
\hdashline
r_{1y} & r_{2y} & r_{3y} & \begin{pmatrix} -f_{4y}\cdot r_{4z} - \\ -f_{4y}\cdot r_{4y} \end{pmatrix} & \begin{pmatrix} -f_{5y}\cdot r_{5z} - \\ -f_{5z}\cdot r_{5y} \end{pmatrix} & \begin{pmatrix} -f_{6z}\cdot r_{6y} + \\ +r_{6z} \end{pmatrix} \\
-r_{1x} & -r_{2x} & -r_{3x} & \begin{pmatrix} -r_{4z} + \\ +f_{4z}\cdot r_{4x} \end{pmatrix} & \begin{pmatrix} -r_{5z} + \\ +f_{5z}\cdot r_{5x} \end{pmatrix} & \begin{pmatrix} f_{6x}\cdot r_{6z} + \\ +f_{6z}\cdot r_{6x} \end{pmatrix} \\
\begin{pmatrix} -f_{1x}\cdot r_{1y} + \\ +f_{1y}\cdot r_{1x} \end{pmatrix} & \begin{pmatrix} -f_{2x}\cdot r_{2y} + \\ +f_{2y}\cdot r_{2x} \end{pmatrix} & \begin{pmatrix} -f_{3x}\cdot r_{3y} + \\ +f_{3y}\cdot r_{3x} \end{pmatrix} & \begin{pmatrix} r_{4y} + \\ +f_{4y}\cdot r_{4x} \end{pmatrix} & \begin{pmatrix} r_{5y} + \\ +f_{5y}\cdot r_{5x} \end{pmatrix} & \begin{pmatrix} -r_{6x} - \\ -f_{6x}\cdot r_{6y} \end{pmatrix}
\end{array}\right] \qquad (4)$$

$$[w_e] = \begin{bmatrix}
f_{7x} + f_{9x} + C_2 + R_x \\
f_{7y} + f_{8y} + C_3 + R_y \\
-f_{8z} - f_{9z} - F_g + R_z \\
-f_{7y}\cdot r_{7z} - f_{8y}\cdot r_{8z} - f_{8z}\cdot r_{8y} - f_{9z}\cdot r_{9y} - C_1\cdot r_{7y} - C_3\cdot r_{9z} - F_g\cdot r_{gy} + M_x \\
f_{7x}\cdot r_{7z} + f_{8z}\cdot r_{8x} + f_{9x}\cdot r_{9z} + f_{9z}\cdot r_{9x} + C_1\cdot r_{7x} + C_2\cdot r_{8z} + F_g\cdot r_{gx} + M_y \\
-f_{7x}\cdot r_{7y} + f_{7y}\cdot r_{7x} + f_{8y}\cdot r_{8x} - f_{9x}\cdot r_{9y} - C_2\cdot r_{8y} + C_3\cdot r_{9x} + M_z
\end{bmatrix} \qquad (6)$$

The Equation 3 is suitable for further numerical solving. The system has the non-trivial solution when the determinant of the system is: $\det|F_{lok}| \neq 0$.

By the iteration procedure the Equation 3 is solved; thus the minimum required clamping forces are calculated. The iteration starts with the initial value of clamping force $C_j=0,\ j=1,2,3$, afterwards this value gradually increases incrementally, until all forces F_i are positive. In this way we reach the basic-fundamental solution of the problem. The obtained values of C_1, C_2 and C_3 will be the first set of possible solutions. The basic solution can be optimised in this following way: The value of the basic solution is adapted to the first clamping force whereas the values of the others are gradually increased incrementally until all the calculated locating forces are positive. Then the procedure is repeated for each clamping force.

5. RESULTS AND MODEL EVALUATION

The tests confirmed correctness of the results of the propose automated system. The deviation of the predicted forces from the actual forces is slightly greater only in case of very little coefficient of friction ($0.01 \leq \mu \leq 0.2$) between the workpiece and the fixture. We tried to compensate the deviation of the predicted results in the mathematical model itself, but the corrections made did not improve significantly the values of the predicted forces. Therefore the required correction was made by introducing the artificial neural network into the model.

By using the artificial neural network (ANN) all the influencing factors, not taken into account in the equilibrium matrix equation, are included [9]. Five-layer feed-forward neural network was used. It contained 18 neurons in the input layer, and 9 in the output layer. The input vector consists of components of cutting forces, co-ordinates of point of machining, co-ordinates of position of the clamping and supporting parts, workpiece weight and friction coefficient. The output vector contains 9 corrections factors by which the values of the calculated forces are multiplied. Training was performed with the help of the error back-propagation. The training was supervised; the desired outputs (the nine clamping / locating forces) of the ANN are also being supplied during training.

Training of the ANN was made with experimental data of 1500 full training examples. Additional 800 examples were used to test the trained network.

The data for training and testing are obtained from the experimental measurements on the fixtures already made. Due to the introduction of the ANN the accuracy of the predicted forces was improved for 94% in case of $\mu \leq 0.3$ and for 4% in case of $\mu > 0.3$. The average estimation error was about 7.4% which is low compared to the 12,7% estimation error of the analytical model.

6. CONCLUSION

A automation system is presented that considered the effect of frictional forces for verification, rationalization and improvement of a fixture design.

A new iteration method is introduced for determining the clamping and locating forces at more reasonable level. By the system developed we have significantly reduced the time of conceiving the fixture (18%) and we have reached a greater manufacturing accuracy.

By the described model it is possible to anticipate and prevent the defects on the workpiece, fixture and cutting tool during the clamping and machining process.

In the research it has been found out that by taking the friction into account the value of the required clamping force as well as the number of the required clamping elements are strongly decreased.

Automated procedure enables even the inexperienced technologist to prepare high-quality (optimal) fixturing schemes.

7. REFERENCES

[1] Ma, W., Li, J., Rong, Y.: *Developement of automatzed fixture planning system*, Int. J. Adv. Manuf.Technol., Vol. 15, p.p. 171-181, 2006.

[2] Senthil, A., Subramaniam, V., Seow K.C.: *Conceptual design of fixtures using genetic algorithms*, Int. J. Adv. Manuf. Technol. Vol. 15, p.p. 79-84, 2004.

[3] Cus, F., Kopac, J.: *Inclusion of geometrical shape of cutter into optimization of milling process*, Metall, Vol. 10/11, p.p. 602-610, 1998.

[4] Mittal, R.O.: *Dynamic modeling of the fixture-workpiece system*, Robotics Computer-Integr Mfg Vol. 8, p.p. 201-217, 1998.

[5] Li, Y., Liang S.Y.: *Cutting force analysis in transient state milling processes*, Int. J. Adv. Manuf. Technol., Vol. 15, p.p. 785-790, 2001.

[6] Zuperl, U.: *Development of systems for computer-aided design of modular fixtures*. Proceedings of the 11th International DAAAM, Opatija, 19.-21. October 2000.

[7] Zuperl, U., Cus, F.: *A determination of the characteristic technological and economic parameters during metal cutting*, Stroj. vestn. 50(5), p.p. 252-266, 2004.

[8] Milfelner, M., Cus F.: *System for simulation of cutting process*, International Scientific Conference on the Occasion of the 50th Anniversary of Founding the Faculty of Mechanical Engineering, Ostrava, September 2000.

[9] Zuperl, U., Cus, F., Mursec, B., Ploj, A.: *A Hybrid analytical-neural network approach to the determination of optimal cutting conditions*, J. mater. process. technol. 157/158, pp. 82-90, 2004.

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Invited Paper

Borojevic, S., Jovisevic, V., Jokanovic, S.

MODELING, SIMULATION AND OPTIMIZATION OF PROCESS PLANNING

Abstract: *Designing of production systems from the standpoint of necessary resources for carrying out the production process for many years present an important set of engineering tasks. In the scope of design of production systems, in addition to design of process planning, it is necessary to make the determination of normative parameters, by which the effectiveness of the production process will achieve a high level. This is possible using application of the software system Tecnomatix Plant Simulation. This software system implementation is one step closer to the automation design of process planning, by modeling and simulation of technological processes. In this paper it process planning was a modeled and simulated in concrete conditions, applying this program system, in 2D and 3D environment and also determining optimal parameters of production.*

Key words: *Tecnomatix Plant Simulation, Design, Modeling, Simulation.*

1. INTRODUCTION

Designing of production systems from the standpoint of necessary resources for carrying out the production process for many years present an important set of engineering tasks. This process is determined by a number of influential factors of different degrees of intensity, direction and effect direction. In terms of growing competition the procedures of optimization of process planning are gaining in importance.

Process planning in metal manufacturing industry has variety of characteristic solutions in all its phases, i.e. operations. These characteristics were caused by the input data, which are encompassed with drawings and volume of production, the available technological equipment and raw materials, as also techno-economical conditions and subjective commitment of technologists.

In general, process planning variants of making a certain product are arising as a result of conventional design from technologist or application of automated systems design.

No matter which way of design is used, each adopted variant of the process planning is a logical set of appropriate technology development operations, whose solutions depend as from solutions of previous operations, as from solutions of the following operations.

Thus, the j-th variant of the process planning of production can be represented as a set of corresponding operations, i.e.:

$$(TP)_j = \{O_{j1}, O_{j2}, O_{ji}, \ldots, O_{jp}\} \tag{1}$$

where letter p is the number of manufacturing operations, for the observed variations of the process planning.

Within the design of the manufacturing process planning, in addition to designing technologies of production, it is necessary to make the determination of norms (standards of time, materials, areas, etc.), by which the effectiveness of the production process will achieve a high level. During this, the most important role has work needs norms of production systems that are closely related to the time of production and quantity of products (parts).

To achieve high performance of the production systems, it is necessary to optimize process planning. Optimization in most cases is performed by applying some of the known methods and it taking into account the processing time , hold time, off time, preliminary-final time, set-up time, extra time and etc.

This paper contains presentation of computational system Tecnomatix Plant Simulation, which allows one step closer towards automation design processes of production, by modeling and simulation of process planning.

2. SIMULATION OF PROCESS PLANNING

The aim of the simulation is to achieve results that can be transferred into the real world. In addition, the simulation defines the preparation, execution and evaluation of carefully targeted experiments in a projected simulating model. Simulation of process planning is executed using the following steps:

- Assessment and collection of data from real production processes, which are necessary for designing simulation models,
- Determination of simulation studies goals and creation of simulation models in accordance with defined goals,
- Running experiments to perform the simulation, in context of simulating model. This gives a certain number of results, such as: how often the machines in the state of failure, how often are blocked, setting of machine, process times, utilization of the machines, etc.,
- Interpretation of simulation data.

In the process of defining tasks and goals of the simulation studies, usually we need to ask the following questions:

- What kind of bandwidth and the output can be expected?
- What is the optimal number of resources (machines, workers, tools)?
- Where buffer zones are required?
- What is the optimal size of buffer zones?
- What optimal number of working pieces can be processed?
- What strategies are most appropriate for the task?
- How to combine and interact some or all of these factors to produce different results?

After all that, it is necessary to decide on the scope of simulation: only process plan or other areas of production (receiving, storage, delivery, etc.).
Developing a simulation model is cyclic and evaluation process. The simulation is executed on the first or initial model, and then with its improvement and enhancement, model becomes operational to provide optimum results after completion of the process simulation. Finally, after several cycles of improvement and enhancement, optimum simulation model is reached. Thus defined optimal simulation model represents a real process plan in the production system, for which is necessary to conduct needed research and analysis.

In general, the process simulation technology is applied in cases:

- where new production system is planning,
- for improving the existing production system and
- for introducing a plan that is defined in practice.

3. OVERVIEW OF PROGRAM SYSTEM TECNOMATIX PLANT SIMULATION

Tecnomatix Plant Simulation is a software system which is designed for modeling, simulation and optimization of manufacturing process planning. Optimization of manufacturing process planning using this software system is based on time-oriented simulation and event-oriented simulation.

Time-oriented simulation takes into account a wide range of different types of production time, while event-oriented simulation takes into account only these points in time which events have an impact, within the simulation model.

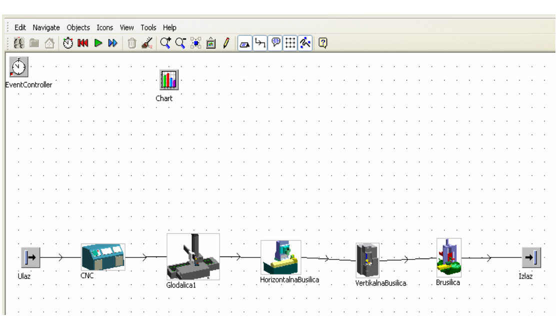

Fig 1. Modeling of process planning in 2D environment

Modeling of technological processes and the creation of simulation models of real production processes by applying the system Tecnomatix Plan Simulation can be performed in 2D and 3D environments.

Modeling in 2D environment, shown in Figure 1, is applied to complex optimization problems, related primarily to the time balancing the technological process, i.e. analysis of the production process from the point of time (production times, extra and additional times, a preliminary-final time, cycles production, etc.).

Modeling in 3D, shown in Figure 2, is primarily used for monitoring the distribution of technological systems and devices, which is necessary to spatially arrange in the appropriate production system.

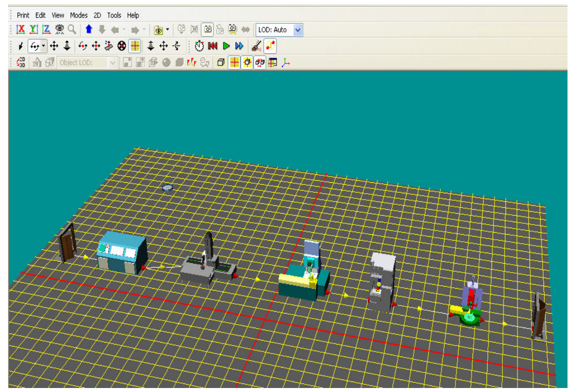

Fig 2. Modeling of process planning in 3D environment

Modeling in 2D and 3D environments is possible to connect, so when model in 3D environment is being created, model in the 2D environment was generated automatically.
The course of creating simulation models is carried out as follows:

- Generation of the 2D or 3D models of appropriate technological systems, devices, methods of transport material, inputs, outputs, etc. from the database of mentioned technological units,
- Development of spatial distribution of selected technological units and their adjustment to the conditions related to real production processes,
- Connecting the appropriate technological units in the production line. Thus defined product lines represent the actual product flows, which occur in the appropriate production system,
- Setting of parameters for each of the selected technology unit, which is a part of appropriate production flows. Data which are being entered in this step, should correspond as much as possible to the values of the real production process,
- Defining the appropriate objects, in the form of diagrams, tables, histogram, etc., which have the function of monitoring and presenting the results of simulations of the production process,
- Modeling of the production process and its setting in order to create conditions for the execution of process simulation, i.e. testing of the simulation model,

- If the designer is not satisfied with the results of model simulations, he/she correct the input parameters until he/she get a model that gives satisfactory simulation results.

Capabilities of the system Tecnomatix Plan Simulation from the aspect of objects and methods of simulation are reflected through the simulation and modeling of:

- Process plan with a number of different strategies of production,
- Production process using the process planning,
- Condition: in malfunction, in work, in pause, etc.,
- Participants in the work and tasks they perform,
- Working shifts systems,
- Transportation systems etc.

4. APPLICATION OF PROGRAM SYSTEM TECNOMATIX PLANT SIMULATION

4.1 Process plan model

Application of the program system Tecnomatix Plan Simulation in this paper is shown on the model of process plan for production and assembly of crankshafts for production of motor saws. The production process in the specific situation involves making a three parts of crankshafts: one half of the magnet, one half clutch and piston rod.

Following data was used as input parameters for process of simulation and modeling using program system Tecnomatix Plan Simulation: the manufacturing process plan for parts of crankshafts (sequence of operations, production time, extra time, list of machines) and the number of pieces crankshafts annually.

4.2 Process plan simulation

Simulation of manufacturing process plan and assembly for crankshafts using the system Tecnomatix Plan Simulation in 2D environment consists of several steps:

- Defining the spatial model and generation of individual processes, which represent the operations in the production process from the process plan,
- Defining the distance between the individual technological systems in order to effectuate the simulation time which is lost during transportation of parts prior to the following operations,
- Linking individual processes in the flows of materials processing according to designed process plan,
- Defining the required time for individual processes,
- Defining the methods and rules of the transition work pieces during processing of materials,
- Defining objects for monitoring and recording the results of simulations
- Performing initial process simulation,
- Analysis of the results of simulation,
- Modification of simulation models and
- Performing the final process simulation.

Simulation of manufacturing and assembly process plan for crankshafts by the system Tecnomatix Plan Simulation in 2D environment is shown in Fig. 3

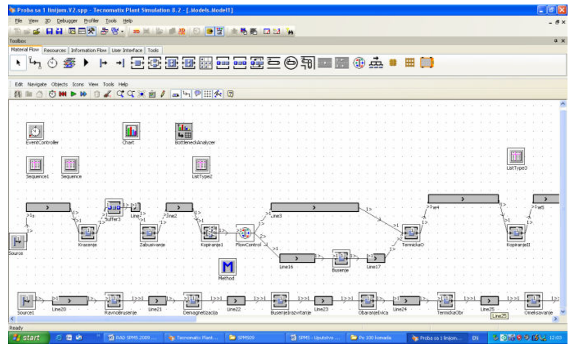

Fig. 3. Segment from simulation model shown in 2D

After designing satisfactory model of the manufacturing and assembly process plan for crankshafts in the 2D environment, it is being made a modeling of process plan in 3D environment. The purpose of modeling the 3D environment is primarily to determine the spatial layout of machinery and equipment in the production plant.

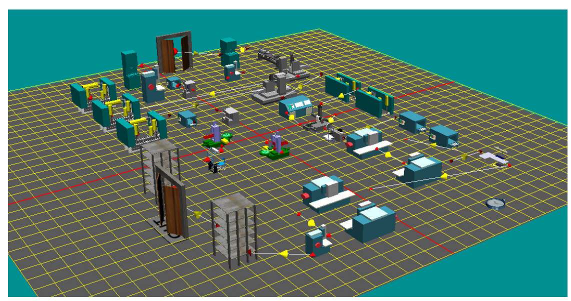

Fig. 4. Simulation model shown in 3D

By placing the machines and devices in precise defined locations in the production plant in 3D environment it is determined the precise distance between the machines that affect optimization for earlier designed models.

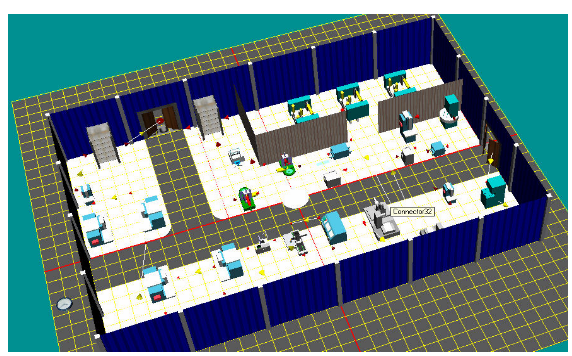

Fig. 5. Simulation model located in the corresponding production plant

Simulation model and production plant of the manufacturing and assembly process plan for crankshafts by the system Tecnomatix Plan Simulation in 3D is shown in Figure 4 and Figure 5. This model is founded on the basis of previous information on the number, layout and positions of the necessary technological systems and equipment.

4.3 Simulation results

Improving the simulation model is performed through initial process simulation and analysis of simulation results. In the model after the analysis of results, bottlenecks of production are being identified and accumulation of working pieces of precisely defined operations of the process plan. Efficiency of machines performing the initial process of simulation, i.e. before performing the optimization process, is unsatisfactory as shown in Figure 6.

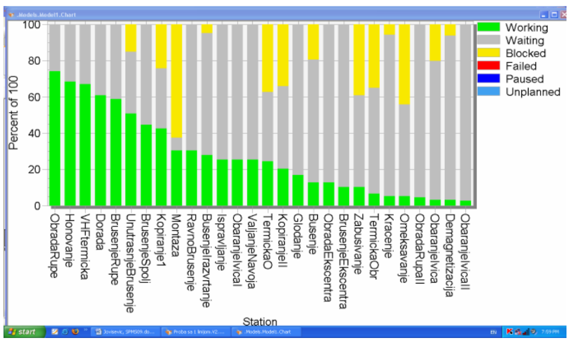

Fig. 6 Efficiency of machines before optimization

After analysis of influential factors, process optimization of process plan was performed, where goal is set as a function of high efficiency machines and minimum time duration of the cycle of production, while the limits were defined by the process plan. Resolving the above-mentioned shortcomings, introduction of buffer zones and increasing the number of machines, it was achieved a significantly shorter production cycle time. For example batch of 100 pieces of crankshafts, saving time in manufacturing process after the simulation was about 40%.After completion of design and simulation of process plan in the 3D environment, it was determined the exact location of machines and devices in the spatial layout of production facilities. Based on this information manufacturing cycle is reduced by 5% as a result of savings in time in transport parts between machines.

Based on the layout and location of machines and devices, it was designed a preliminary solution for production plant with the appropriate characteristics (departments, roads, entrances, exits, etc.).

Within results from execution of simulation of process plan, cycle times were generated for the appropriate size of batch parts and percentage utilization of machines in the manufacturing process. According to optimal designed simulation model, for the case of simulation of process plan and for the batch of 100 pieces crankshafts, the percentage utilization of machines is shown in Figure 7.

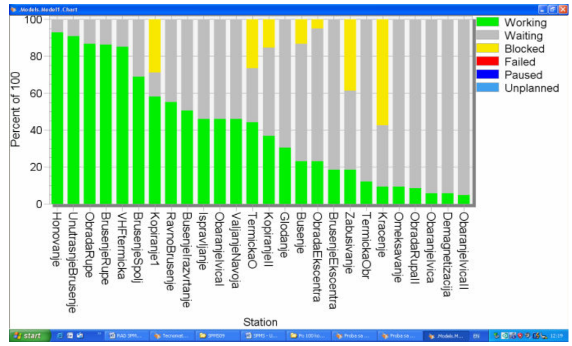

Fig. 7 Efficiency of machine after the optimization

5. CONCLUSION

Process plan modeling and simulation allows creating of models that represent adequate production processes, which generates the following benefits:

- Improving the productivity of existing production systems,
- Reduce investment in planning new production facility and capacity,
- Reduce inventory and flow time,
- Optimization of production systems dimensions, including backup size,
- Reducing investment risk through early proof of production concept,
- Maximizes utilization of productive resources,
- Improvement in design and layout of production line and machines.

In the example, final result of performing simulations showed data related to the duration of the manufacturing cycle, utilization of resources, as well as the required dimensions of the production plant that meet the set requirements from process plan.

6. LITERATURE

[1] Jokanović, S.: *Geometrijsko modeliranje*, Mašinski fakultet Banjaluka, Banjaluka, 2006.

[2] Jovišević, V.: *Projektovanje tehnoloških procesa,* Mašinski fakultet Banjaluka, Banjaluka, 2005.

[3] Programski sistem *Tecnomatix Plant Simulation* – UGS Corporation - Siemens Product Lifecycle Management Software Inc., 2009.

[4] Zelenović, D.: *Projektovanje proizvodnih sistema*, Fakultet tehničkih nauka, Novi Sad, 2003.

[5] Zelenović, D., Ćosic, I., i dr.: *Automatizovani postupak za oblikovanje proizvodnih sistema* – APOPS 08, Novi Sad 1990-92.

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Invited Paper

Budak, I., Sokovic, M., Hodolic, J., Kopac, J.

POINT DATA REDUCTION BASED ON FUZZY LOGIC IN REVERSE ENGINEERING

Abstract: *Contemporary 3D-digitization systems for Reverse Engineering modelling are characterized by increased scanning speed and also by the possibility to generate large number of points in a short time. Generally, this improves the efficiency of the RE-modelling process. In practice however, a large number of points in the stage of generation of the CAD model may become a serious problem. Therefore, lately considerable attention is focused to the problem of point data reduction in the 3D-digitization results. This paper presents an approach for point data reduction based on fuzzy logic, along with the results of its practical application.*
Key words: *Reverse Engineering, 3D-digitization, Point data reduction*

1. INTRODUCTION

Contemporary 3D-digitization systems which are applied in Reverse Engineering (RE) modelling are characterized by increased scanning speed and also by the possibility to generate large number of points in a short time. Generally, this improves the quality and efficiency of the RE-modelling process. In practice however, later in the stage of CAD model generation, a huge number of points which are generated in the stage of 3D-digitization may become a serious problem [1,2].

Considering all the above mentioned, the stage of pre-processing the results of 3D-digitization which includes error filtering, data smoothing and the most sophisticated process of data-point reduction, becomes inevitable in almost any RE system [3,4].

In the multitude of data-point reduction approaches that were developed, it is possible to identify three dominating groups of approaches for pre-processing the results of 3D-digitization: methods of point sampling, methods of polygon reduction and grid methods [5, 6].

It should be noted that there are frequent attempts to integrate the methods of artificial intelligence into the process of pre-processing, i.e. into point data reduction above all, in order to achieve better quality and process efficiency [1].

Within the framework of this article, a novel approach for point data reduction is introduced, designated primarily for RE modelling systems based on the "cross-sectional" approach.

2. THE NOVEL APPROACH FOR POINT DATA REDUCTION

The main features of an approach for point data reduction presented here are integrated deviation analysis and fuzzy logic reasoning. This constitutes the main difference in comparison to the approaches developed so far.

Building on the weak spots and deficiencies of current approaches to reduction of point data by sampling methods - i.e. the lack of information on the level of deviation in reduced point clouds and necessity to employ parameters which are abstract to user [4,5] - a novel approach was developed for analysis of the level of deviation of the reduced point cloud in comparison with the initial point cloud. This novel approach introduces an additional parameter termed maximum allowed reduction error (MARE), in the reduction-related decision process with the sampling-based methods.

In order to improve the process of reduction, the novel approach was enhanced by implementing fuzzy logic in the process of reduction-related decision making. Beside the additional improvement of the deviation/mean level of reduction ratio, implementation fuzzy logic allowed a more user-friendly and intuitive application. The reduction process is controlled by simply entering the deviation tolerance, allowing the user to gain better insight into the quality of the reduced point cloud [6,7].

The key feature of the novel approach to sampling-based point data reduction, proposed here, is the *procedure for analysis of deviations* of cross-sectional curves, which are the result of point data reduction.

Practical realization of procedure for analysis of deviation is based on computation and analysis of maximum deviation of the resulting cross-sectional curve relative to the original cross-sectional curve generated from initial point cloud. *Least squares method*, modified to meet specific requirements of the problem in hand, was used to compute maximum deviation - designated *MRE (Maximum Reduction Error)* in this paper. In this case, the key parameter of *MRE* is the absolute value of maximum deviation of a cubic spline curve generated through an array of scanned and reduced points - relative to the spline curve generated through original point array. In other words, *MRE* is computed after each point elimination by finding maximum deviation $\varepsilon_i(x_i, y_i)$ of the spline curve generated after elimination of j-th point $T_j(x_j, y_j, z_j)$ - relative to the spline curve generated through originally scanned point cloud (Fig. 1).

$$MRE = \max(\varepsilon_i) \ ; \ i = 1,2,...,n \, . \tag{1}$$

Deviations $\varepsilon_i(x_i, y_i)$ are calculated at points defined by resolution ν (Fig. 1) which can be varied to suit the length of the scanned curve, i.e. the density of scanned points within array.

Beside parameter *MRE*, the procedure also employs the *ARE* (*Average Reduction Error)* – an additional parameter which allows assessment of deviation of the resulting cross-sectional curve. *ARE is* a mean sum of deviations computed at points defined by resolution v (Fig. 1) and can be expressed as:

$$ARE = \overline{\sum_{i=1}^{n} \varepsilon_i} \, . \qquad (2)$$

The methods for reduction of point data by sampling, were improved by implementing fuzzy logic into procedure for decision-making on which elimination of points is based.

To eliminate the problems which stem from the specific values of decision-critical input parameters entered by the user, and create a more user-friendly system, a new, synthetic parameter was introduced under the name reduction coefficient (RC), and its maximum allowed value was defined as maximum allowed reduction coefficient (MARC). For all three methods the RC parameter was derived based on method-specific parameters, and an additional input parameter maximum reduction error (MRE), i.e. the maximum allowed reduction error (MARE). MARE was introduced to allow the maximum reduction error to be controlled.

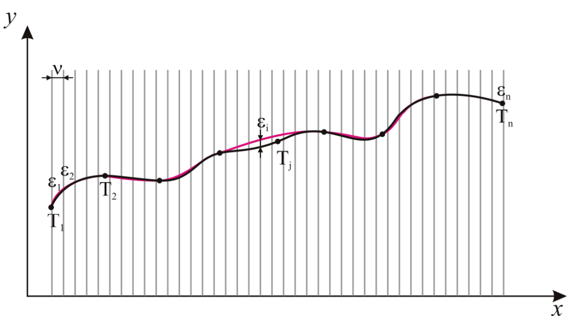

Fig. 1. Graphical interpretation of MRE and ARE

Details of the novel approach for point data reduction are presented here for the case of spatial method. The spatial method for point data reduction is based on the parameter of spatial (Euclidean) distance (d_E) [7] which, together with *MRE*, was used as input parameter for the fuzzy-logic-based decision-making system. Shown in Fig. 2 is the structure of this fuzzy system which consists of three modules – input, knowledge base and output.

The input is formed by two state variables – d_E, and *MRE*, whose values are fuzzified into fuzzy sets with appropriate input spaces, while the fuzzy sets of input values are defined by their membership functions [9]. Due to its simplicity, triangular membership function was chosen for all state variables. It should be noted that the input space for d_E (0 to 2 [mm]) was defined based on practical experience, while for the state variable *MRE,* this input space is defined on the basis of real-application experience with *MARE* = 0,05 [mm] as the pivotal parameter. The input space was segmented in the following way - for d_E it was sectioned into three segments with appropriate linguistic terms (*shorter*, *medium,* and *longer*), while for the *MRE* it was segmented into three fuzzy sets (*slight, moderate and significant*). The output from this fuzzy system is variable RC (a non-dimensional value) which, for simplicity sake, has been allotted an output space from 0 to 100, and the parameter MARC must fall within that space. To allow finer control of *RC parameter*, the input space was segmented with finer resolution, resulting in a total of nine fuzzy sets denoted with linguistic qualifiers - *minor, very low, low, medium-low, medium, medium-high, high, very high*, and *huge*.

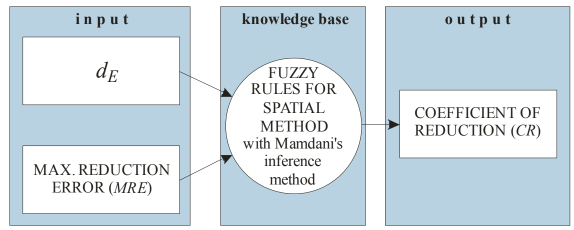

Fig. 2. Structure of fuzzy system for point data reduction using spatial method

Using the defined fuzzy variables (d_E, *MRE,* and *RC*) and their belonging fuzzy subsets with their membership functions, fuzzy control rules were defined which represent the knowledge base of the proposed fuzzy system. A total of nine fuzzy rules were defined which are presented in Table 1.

1. If (d_E is *Shorter*) and (*MRE* is *Slight*) then (*CR* is *Huge*)
2. If (d_E is *Medium*) and (*MRE* is *Slight*) then (*CR* is *Very-high*)
3. If (d_E is *Longer*) and (*MRE* is *Slight*) then (*CR* is *High*)
4. If (d_E is *Shorter*) and (*MRE* is *Moderate*) then (*CR* is *Mid-high*)
5. If (d_E is *Medium*) and (*MRE* is *Moderate*) then (*CR* is *Mid*)
6. If (d_E is *Longer*) and (*MRE* is *Moderate*) then (*CR* is *Mid-low*)
7. If (d_E is *Shorter*) and (*MRE* is *Significant*) then (*CR* is *Low*)
8. If (d_E is *Medium*) and (*MRE* is *Significant*) then (*CR* is *Very-low*)
9. If (d_E is *Longer*) and (*MRE* is *Significant*) then (*CR* is *Minor*)

Table 1. Control fuzzy rules of the fuzzy system for point data reduction using spatial method

The system was modelled using reference values of output variable, according to which the membership functions of input variables were adjusted. As criterion for adjustment of the membership functions, mean square deviation was adopted [8]:

$$E = \sqrt{\frac{\varepsilon_1^2 + \varepsilon_2^2 + \ldots + \varepsilon_n^2}{n}} \, . \qquad (3)$$

using the three sigma rule:

$\left|\varepsilon_{\max}\right| < 3E$ => *acceptable level of adjustment*

$\left|\varepsilon_{\max}\right| > 3E$ => *unacceptable level of adjustment*

The mechanism of fuzzy decision-making is based on the *Mamdani* method. This method uses the *minimum of operation, i.e. the minimum of* intersection, to form the fuzzy implication function [9]. The procedure of fuzzy reduction is presented in Fig. 3.

3. RESULTS

The developed approach has been tested through its practical application. Here results of the application on case study of a sports glasses lens (Fig. 4) are presented.

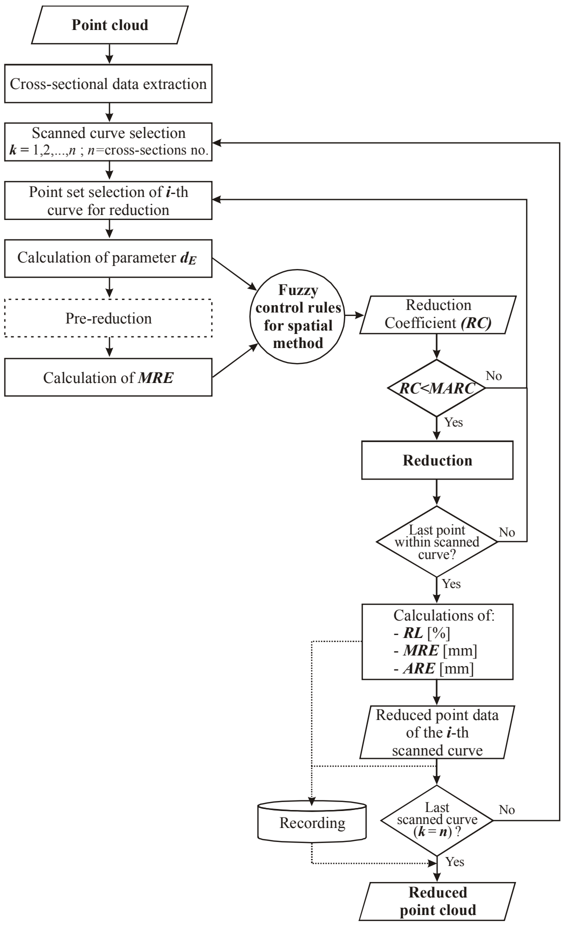

Fig. 3. Algorithm of the proposed fuzzy-logic-based software application for point data reduction by the spatial method

The choice of this part, which due to ergonomic intent is of a relatively simple geometry, was motivated by the complexity of digitized data (Fig. 5) which requires adequate fixture and locating. 3D digitization was performed by a contact system Cyclone II - Renishaw, resulting in a total of 412,111 points, of which a large number represent error-points which actually belong to the fixture and measuring table.

Fig. 4: Sports glasses and a lens

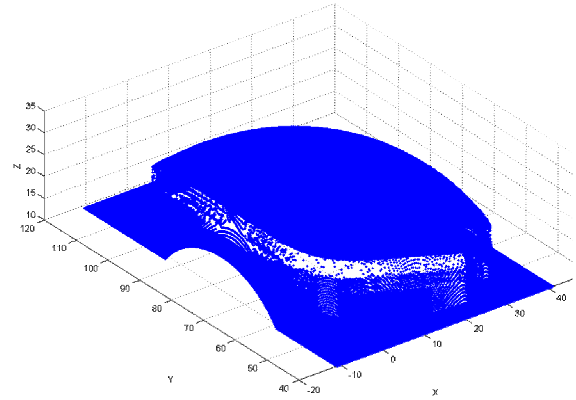

Fig. 5. The results of 3D-digitization

The pre-processing included 3D filtering (volumetric filtering, filtering by segmented line, and elimination of individual points), cross-sectional filtering/smoothing of point data (elimination of end points), change of resolution and reduction of point data. The point cloud subject to reduction, contains 109,528 points in 214 cross-sections. Fuzzy-chordal reduction method was chosen, with MAD=0.03 [mm]. The results of reduction are presented in Table 2 and in Fig. 6.

MAD [mm]	0.03
Maximum error [mm]	0.02835
Average error [mm]	0.00265
No. of eliminated points	107,466
Reduction level [%]	97.82
No. of resulting points	2,062

Table 2. Results of point data reduction

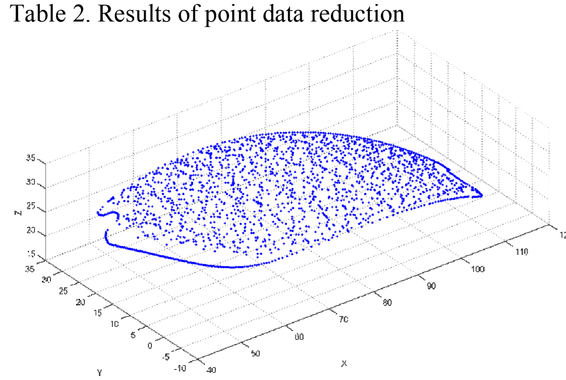

Fig. 6. *Graphical representation of reduction results*

Surface model was generated in Pro/ENGINEER Wildfire 4 by automated generation of cross-sectional curves on the bases of reduced point cloud in IBL format (Fig. 7).

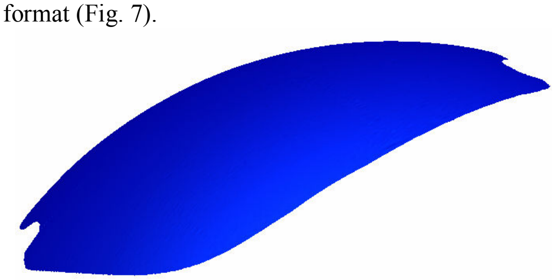

Fig. 7. Surface model generated from “reduced” point cloud

Verification of the generated surface model from “reduced” point cloud has been conducted through comparison of the deviation of the “reduced” and “original” surface models from the “original” point cloud (used as input in reduction process). Deviations have been analysed by the application of CAD inspection technique. The results are shown in Fig. 8. Numerical values for maximum positive and negative deviations are given in Table 3.

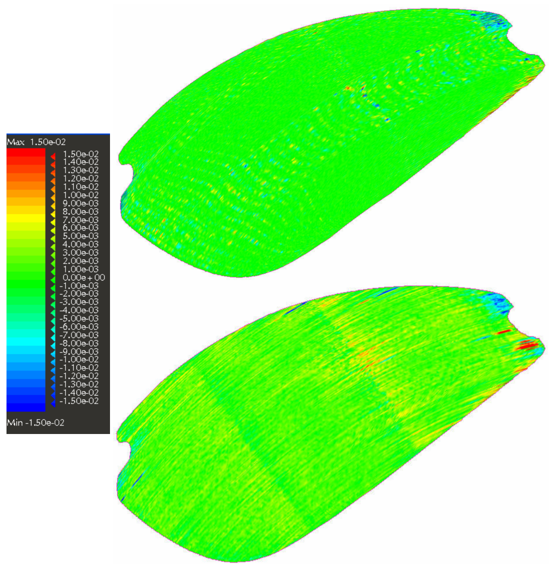

Fig. 8. Results of CAD-inspection of surface models defined by 0,015 [mm] tolerance

Model	Deviation [mm]	
	Min.	Max.
“original”	-0.0279	0.0283
“reduced”	-0.0291	0.0280
Difference:	+0.0022	-0.0003

Table 3. Results of CAD inspection of generated surface models

4. CONCLUSIONS

Within this paper a novel approach for point data reduction, designed for use in systems for Reverse Engineering modelling based on cross-sectional methodology, has been presented.

This paper also provides practical results of application of the developed approach. Judging by the graphical output from CAD inspection and the maximum values, one can conclude that the level of deviation of the “reduced” surface model is very close to that of the “original” surface model. More regions with deviations within the “reduced” surface model are direct consequences of the approximate surface generation on the bases of reduced point data. According to this it is obvious that the developed approach, although still in the experimental stage of work, shows satisfying results.

Future researches will be directed towards analyzing parameter relations, i.e. adequate functions of affiliation in fuzzy procedures with the goal of fine-tuning the performance of the reduction process.

REFERENCES

[1.] Wu J. et al. (2008) A Hybrid Fuzzy Heuristic for Point Data Reduction in Reverse Engineering, The 2008 International Congress on Image and Signal Processing (CISP2008), pp 615-619.

[2.] Sokovic, M., Kopac, J. (2006) RE (Reverse Engineering) as necessary phase by rapid product development, Journal of Materials Processing Technology (175), pp.398–403.

[3.] Huang, M.C., Tai, C.C. (2000) The pre-processing of data points for curve fitting in Reverse Engineering, International Journal of Advanced Manufacturing Technology, (16), pp. 635–642.

[4.] Chang, D.Y., Chang, Y.M. (2002) A freeform surface modelling system based on laser scan data for RE, International Journal of Advanced Manufacturing Technology, (20-1), pp. 9–19.

[5.] Lee, K.H. et al. (2001) Data reduction methods for reverse engineering, International Journal of Advanced Manufacturing Technology (17-10), pp. 735–743.

[6.] Budak, I. (2009) Development of the System for Intelligent Pre-Processing of 3D-Digitization Results from Free-Form Surfaces, Doctoral dissertation, University of Ljubljana, Faculty of Mechanical Engineering Ljubljana, Slovenia.

[7.] Budak, I.; Soković, M.; Hodolič, J. (2007) Implementation of innovative procedure for error estimation in cross-sectional data-point reduction in reverse engineering, Proceedings of the 4th International Working Conference "Total Quality Management", Belgrade, Serbia, pp. 201-206.

[8.] Vukadinović, S.V. (1981) Elements of the probability theory and of mathematical statistics, Economic review, Belgrade. (in Serbian)

[9.] Balič J. et al. (2003) Intelligent Manufacturing Systems: Programming and Control, University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia.

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10th INTERNATIONAL SCIENTIFIC CONFERENCE
Novi Sad, Serbia, October 9-10, 2009

Invited Paper

Milosevic, M., Todic, V., Lukic, D.

MODEL DEVELOPMENT OF COLLABORATIVE SYSTEM FOR PROCESS PLANNING

Abstract: *With competition in global markets, more and more enterprises seek to make up virtual enterprise or cooperate with each other in the manufacturing process in order to reduce cost of product and increase competitive abihty. For this reason, some of the key technologies are developing in the field of collaborative work between enterprise, besides collaborative design, the collaborative process planning also very important among them. With process planning collaborative platform engineers whom belong to the different enterprise may be work more efficiently than before, and the manufacturing resource of virtual enterprise will be utilized more optimized. In this paper the model of system for process planning in collaborative environment are shown.*
Key words: *Collaborative systems, PLM, Process planning, CAPP*

1. INTRODUCTION

Manufacturers are facing increasing challenges of better product quality with tighter delivery requirements for customers. Global competition is increasing with pressure on prices, smaller orders, shorter life cycles, more suppliers and increasing material and energy costs. These new business drivers make manufacturers follow more competitive manufacture model, such as collaborative manufacturing, to closely collaborate with their customers, suppliers, manufacturers and partners for the most advanced competitiveness by leveraging core competencies throughout the entire product lifecycle.

PLM systems support the management of data for products, processes and services from initial concept, through design, engineering, launch, production and use to final disposal. They coordinate and collaborate products, project and process information throughout the entire product value chain among various levels, internal and external to enterprise. They also support a product-centric and process-centric solution that unifies product lifecycle by enabling online sharing of product and process knowledge and applications [1].

In the age of heterogeneous markets, rapid expansion of technologies and excessive reductions in product life cycle, collaborative engineering has been recognized as a strategy for the total life cycle. This collaborative engineering is getting more and more important as manufacturing activities require more expertise and more involvement from a lot of people on networks, including design engineers, production managers, process planners, production engineers, delivery managers, customers and expert advisors.

2. COLLABORATIVE ENGINEERING

The traditional approach to product development and production is *Sequential Engineering , SE*. In this method, works are divided into many sub-tasks, and the optimization is defined by these task sequences (Fig. 1).

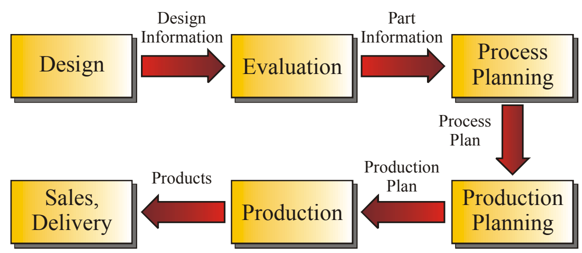

Fig. 1. Product development and production activities in Sequential Engineering approach

The opposite method is *Concurrent Engineering, CE*. It is a systematic approach to the integrated and concurrent design of products and their related processes. In the concurrent engineering approach, a complex, dependent and diverse model is used, and optimization is determined by task dependency, organization behavior and uncertainty.

One of the key words in current researches in concurrent engineering is *Co-operation*. This co-operation means *Collaboration* and it is becoming more and more important. Consequently, *Collaborative Engineering* means co-operating, sharing information and knowledge of global and multi-company engineering (Fig. 2) [2].

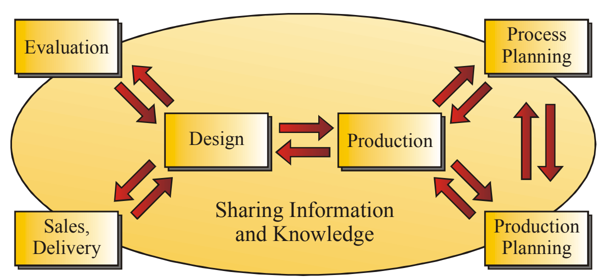

Fig. 2. Product development and production activities in Collaborative Engineering approach

According to the functions and roles of users participating in a collaborative design activity, a collaboration product development system can be organised in either a ‘horizontal’ or a ‘vertical’ mode.

The *horizontal collaboration* puts the emphasis on gathering a design team from the same or different disciplines to carry out a task systematically.

The *vertical collaboration* can establish an effective communication channel between the upstream design and the downstream manufacturing simulation and optimisation tools, and it can enrich the principles and methodologies of concurrent engineering to link diversified engineering tools dynamically. Due to these different levels of collaboration and interaction between users, the collaboration can be generally categorised into three types (Fig. 3):

- Visualisation-based collaboration,
- Co-design collaboration and
- CE-based collaboration.

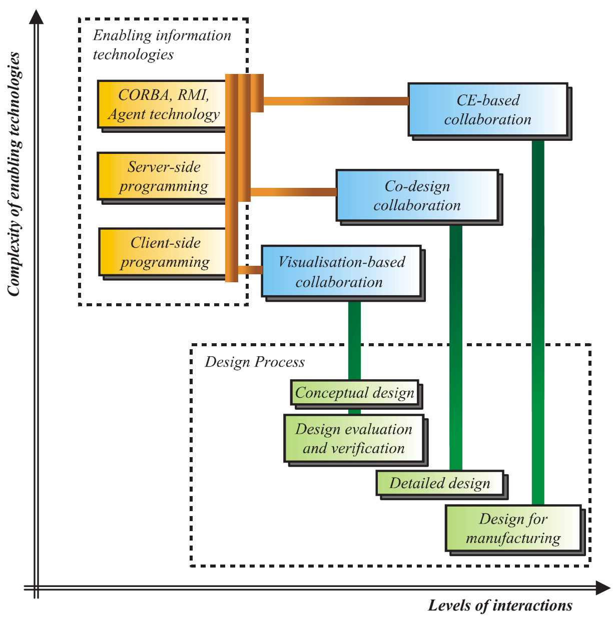

Fig. 3. Different design processes with different collaborations [3]

2.1 Visualisation-based collaboration

Visualisation-based collaboration has the advantage of facilitating collaborative and distributed product or process preview/review. In such an environment, a multi-disciplinary team involving a manager, designer, process planner, customer, etc., can be formed to look at or review the same visualised design model, which is often steered by a chief designer or chief planner. To alleviate the sluggish transfer of large-volume design models over the Internet, concise 3D formats for Web applications, such as virtual reality modelling language (VRML) or Extensible 3D standard (X3D), have been launched to simplify the models as triangular meshes for visualisation purposes. Under this collaboration, the communication can be maintained through either an asynchronous manner or a synchronous manner.

2.2 Co-design collaboration

Co-design collaboration targets a more interactive collaboration activity for a conceptual or detailed design with more complex requirements of co-ordination and organisation among users. Co-design can be conducted either asynchronously or synchronously. An asynchronously collaborative Technologies and methodologies for collaborative product development systems activity can be organised in a hierarchical assembly structure, through which a chief designer outlines the assembly configuration and the detailed component design tasks are assigned to individual designers to carry on separately. Managements, co-ordination and project review of tasks, which can be assisted by some advanced project management or PDM systems, are vital to the whole process. A synchronous collaborative activity is conducted in a way such that a group of designers are dedicated to the same task actively. Teamwork techniques, such as user commitment, roles and responsibilities, are crucial to guarantee this simultaneous co-design activity.

2.3 CE-based collaboration

CE-based collaboration extends the CE principle, which is based on the integration of design and the related manufacturing processes for a life-cycle consideration, to support distributed applications, and geographically dispersed users, systems and resources can be integrated in an Internet/Intranet environment beyond the traditional boundaries of physical and time zones. In a CE-based collaborative system, product design systems and some evaluation or simulation service tools diversified in terms of functionalities, communication protocols, programming languages and data structure representations are integrated as a multi-disciplinary environment for optimising design. In such a system, application services in product design, process planning, engineering analysis and simulation, can be conveniently embedded as *Application Service Providers* (ASPs) for remote invoking and manipulation.

2.4 Product lifecycle collaboration

As such, a new technology solution, called, ‘‘product lifecycle collaboration’’, is required. Functions of to enable product lifecycle collaboration include, but not limited to (Fig. 4) [1]:

- Product portfolio management,
- Collaborative product customization,
- Collaborative product development,
- Collaborative product manufacturing,
- Collaborative component supply and
- Extended product service.

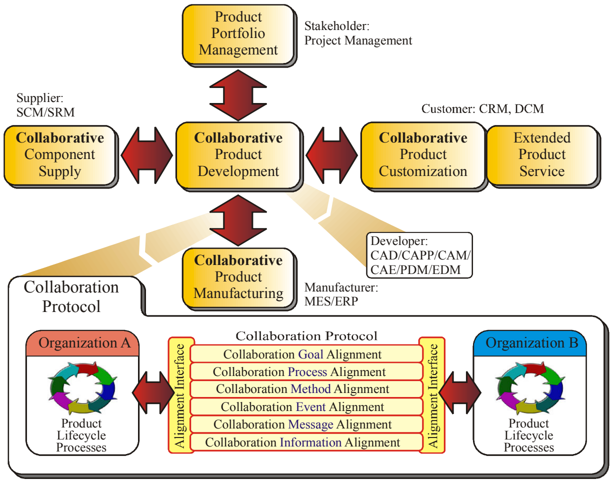

Fig. 4. Product lifecycle collaboration

In particular, the collaboration protocol, which provides different companies with general regulation to facilitate real time collaboration throughout the entire lifecycle, is imperatively required. This collaboration protocol includes different layers of collaboration alignment, such as goal, process, method, event, message and information.

3. FRAMEWORK OF COLLABORATIVE PROCESS PLANNING SYSTEM

An integrated manufacturing process planning framework includes process planning activities and integration with other application systems (Fig. 5).

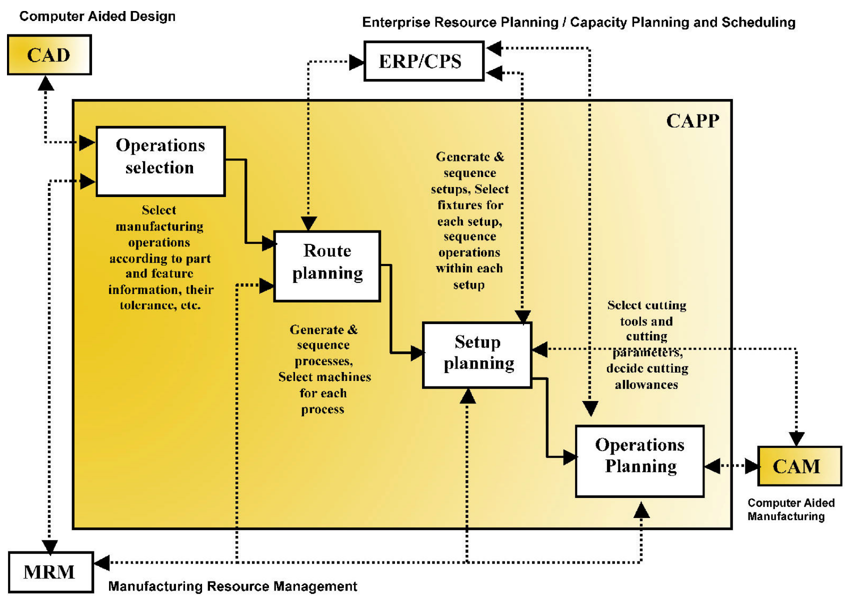

Fig. 5. Framework of an integrated CAPP system [1]

Operations selection function selects manufacturing operations according to part and feature information, material, tolerance, etc. Routing planning function generates and sequences processes, selects machines for each process. Setup planning generates and sequences setups, selects fixtures for each setup, sequences operations within each setup. Operations planning function selects cutting tools and cutting parameters, etc. Manufacturing resource management module provides the necessary capabilities to define the required resources and the capabilities to enable the implementation of the operations selection, route planning, setup planning and operations planning functions. Operations selection function normally integrates with the CAD system to retrieve the defined manufacturing features and select the corresponding manufacturing operations. Route planning, setup planning, and operations planning functions usually interact with the ERP/CPS systems by providing the necessary manufacturing process routings, setups, and operations for project, production and shop-floor scheduling. Setup planning and operation planning functions communicate with the CAM system by providing setups, and operation information, which includes cutting tools and cutting parameters to generate the NC codes.

The conceptual framework of process planning collaborative system are shown in the Fig. 6. On the server side, a collaborative server program is running for the entire request from the client side. It composed of process planning module, collaborative simulation module and collaborative discussion and optimization module.

At the beginning, the process plan for the part is created within the CAPP system that uses an internal Knowledge Base and Manufacturing resource Database. After that, the process planner engineers are operating on the client side to do process planning work, they can collaborative discuss the process plan of the part, and finally select suited equipment, machine tools, cutting tools, fixtures, cutting parameters from the manufacturing resource database.

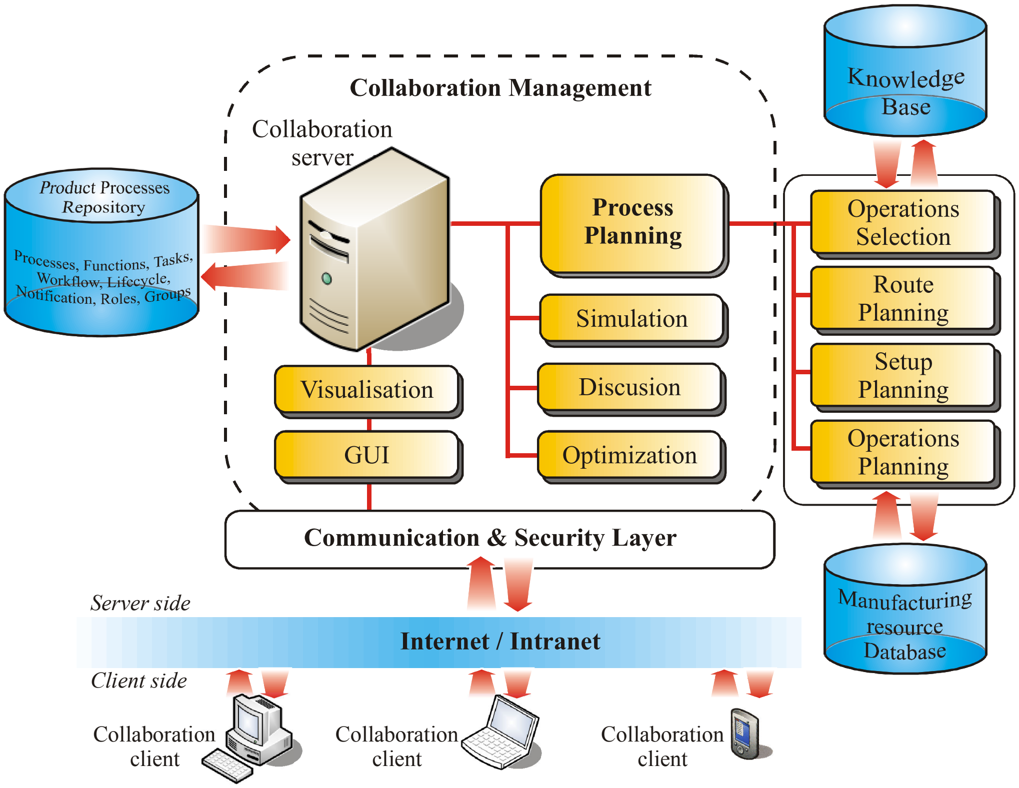

Fig. 6. Conceptual view of Collaborative process planning system

On this way, process engineers collaboratively make optimized manufacturing process of the part. When the proccess plan is finished and optimized then it is stored on the Product Process Repository in order to future use.

4. CONCLUSION

To satisfy new collaborative business requirements in modern e-manufacturing era, particularly, the increasing needs in collaborative product lifecycle management, a model of collaborative process planning system has been proposed. This model provides a platform for engineers to view, evaluate and optimize a process plan through dynamically invoking remote collaboration system.

With this system the young engineer will be advantaged from the system and other professional engineer, on the other hand, the partners of the enterprise will be benefited from the view and sharing manufacturing resource.

5. REFERENCES

[1] Ming, X.G., Yan, J.Q., X.H. Wang, et.al.: Collaborative process planning and manufacturing in product lifecycle management, Computers in Industry No.59, pp.154-166, Elsevier, 2008.

[2] Sangado, N.: Networked Virtual Manufacturing System for Collaborative Engineering, A Dissertation Submitted to the Department of Mechanical Design and Production Engineering of Seoul National University, 1999.

[3] Li, W.D., Ong, S.K., Nee, A.Y.C., Integrated and Collaborative Product development Environment: Technologies and Implementations, World Scientific Publishing Co.Pte.Ltd, 2006.

[4] Zhou, Z., Li, M., Shen, L.: Manufacturing Resource Management For Collaborative Process Planning, Intemational Federation for Information Processing (IFIP), Vol. 207, Knowledge Enterprise: Intelligent Strategies In Product Design, Manufacturing, and Management, Boston: Springer, pp. 926-931., 2006.

[5] Todic, V., Lukic, D., Stevic, M., Milosevic, M.: Integrated CAPP System for Plastic Injection Mold Manufacturing, The Journal Revista de Materiale Plastice, Vol. 45, No. 4, pp. 381-389, Romania, 2008.

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Invited Paper

Petrovic, B., P., Jakovljevic, Z., Pilipovic, M., Mikovic, Dj, V.

IN PROCESS IDENTIFICATION OF WORKPIECE/SYSTEM GEOMETRICAL DEVIATIONS BASED ON GENERAL PURPOSE ROBOTS AND LASER TRIANGULATION SENSORS – PART 1: CONCEPTUAL FRAMEWORK

Abstract: *This paper gives a conceptual framework of a new class of metrological systems based on integration of general purpose industrial robot with laser triangulation sensor for contactless dimensional metrology. The paper has two parts. Part one considers conceptual framework where the system architecture is given, key aspects of the interface between two subsystems are considered, as well as a new methodology frames for signal processing and generation of partial or complete 3D digital model of scanned object with complex spatial geometry. For verification of practical applicability, laboratory installation is developed and experiments and practical functional testings are carried out. This paper also gives recapitulation of two feasibility studies: huge assemblies welding process robotization and forging press serving in the scope of flexible manufacturing cell for forging on MAXI presses. Evaluation and practical implementation are in the second part of this paper.*
Key words: *Industrial robot, laser triangulation sensor, 3D digitalization*

1. INTRODUCTION

Nowadays product quality standards impose the need for identification of geometrical properties for practically every part/component, subassembly or final assembly which is assembled using an automated system, where the deflections from nominal values should be recognized and corrective interventions carried out when needed. In the scope of mass customization manufacturing which leads to extreme increase of product variations and decrease of batch size, the demand for metrology system high flexibility and applicability in plant conditions emerges.

Installation of an optical sensor on general purpose industrial robot, usually of an anthropomorphic configuration, gives a powerful metrology system with remarkable flexibility and high accuracy with potential for realization of huge class of technological tasks in dimensional metrology and inspection in industrial conditions, directly on manufacturing line. Obvious potential which emerges from this symbiosis opens up a series of engineering tasks and challenges. These tasks can be classified into following groups:

- The choice of optimal sensor system
- Planning of optimal trajectory and velocity profile, especially the development of interactive tools for trajectory generation based on virtual geometry model of the scanned object
- Creation of virtual metrology model of the robot-sensor-object-to-be-scanned system for simulation of robot and sensor system task
- Sensor signal processing and generation of planar or spatial model of scanned object
- Autonomous compensation of the position and orientation deflection of the scanned object
- Identification of metrological performances of the system, system calibration, mapping and compensation of robot deflections

Technology of contactless optical sensors suitable for observed application gives following possibilities: 1)spot CCD or PSD laser systems based on single or multiple optical triangulation, 2)confocal spot laser systems, 3)linear CCD or CMOS triangulation systems – profilometers, and 4)triangulation systems with structured (coded) light source. A review of specified sensor technologies is given in [1] and [2]. All of these systems have compact construction and are suitable for installation on robot. From metrological point of view, industrial robot in such a metrology system has a function of programmable platform for moving/manipulation of sensor system in workspace.

This paper, which consists of two parts, reports a part of results obtained within project MA14035 INTOSA[1] where the conceptual bases for one robotized system for 3D digitalization of objects with complex geometry based on CCD laser sensor with spot optical triangulation is developed. Practical applicability of this concept is verified and demonstrated in laboratory conditions in the Center for New Technologies at Faculty of Mechanical Engineering in Belgrade.

2. CONCEPT OF THE SYSTEM

Metrology system consists of: 1)universal industrial robot with appropriate kinematical configuration, 2)laser triangulation sensor and 3)acquisition system for data conditioning and acquisition (Figure 1). Sensor is attached to the robot end point *P* using appropriate adapter. Although generally it is possible to attach sensor arbitrarily, due to practical reasons it is appropriate to build in sensor in such a way that colinearity and/or orthogonality with main axes of symmetry of robot terminal plate is achieved.

[1] Project MA14035: **Application of Intelligent Sensor Systems in Development of Integrated Automation of Real and Virtual Processes in Manufacturing Enterprises - INTOSA**, financed by the Government of the Republic of Serbia, Ministry of Science and Technological Development, Grant 14035, (2008-2010)

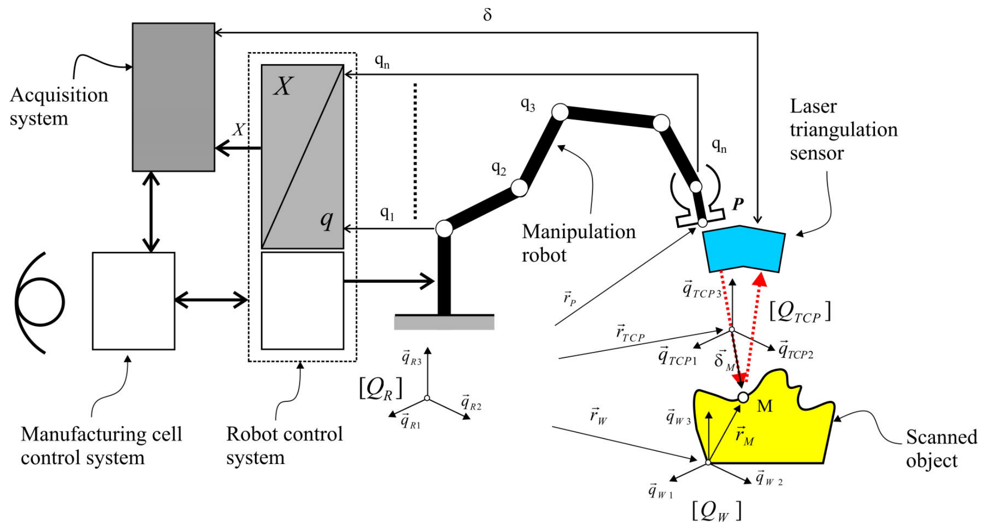

Fig. 1: Robotized measuring system concept

2.1. Triangulation sensor

Typical configuration of laser sensor with optical triangulation is shown in Figure 2. Semiconductor low power laser, usually with maximal power not higher then 1mW generates monochrome coherent light which is trough primary optical system collimated on the surface of scanned object. Optical axis of primary optical system is significant because one of the axes of local coordinate frame is coincident with it. Emitted light beam with diameter of 10 to 100µm is reflected in all directions according to Lambert's law of diffuse reflection [3]. One part of reflected light is reflected in the direction of optical axis of secondary optical system which focuses the overtaken part of light to optoelectrical transducer. The spot on which focused light falls depends on the distance of the surface of the scanned object. Applying triangulation geometry, based on information about location of this point in the local frame of linear transducer, the unknown displacement, i.e. momentary distance, is calculated:

$$\Delta d = f(\Delta z) \qquad (1)$$

Detail analysis of relation (1) is given in [3]. Appling linear CCD or CMOS digital transducers with high resolution together with appropriate algorithms for primary processing of sensor signal, the resolution of 14bits along measuring range (MR) is achieved. Scanning speed is in the range from a few hundreds of samples per second to a few tens of kHz. This kind of triangulation sensors is characterized by high robustness and metrology stability. Depending on the chosen optical system design characteristics, different measuring ranges as well as their projections from the sensor body (stand off distance) are achieved.

2.2. Robot TCP and triangulation sensor location

When robot TCP (Tool Center Point) is determined for particular application, it is convenient to coincide one of the axes with the principal axis of primary optical system and to choose the middle of the laser measuring range as the origin point of local laser sensor frame. This fact should be used when robot trajectory is planned – one should tend to keep TCP, that is origin of laser sensor local frame, always sliding over the surface of the scanned object, or to keep it as close as possible. Besides this one there are two additional requirements.

The first requirement, which is importanant for the accuracy of the measuring system as a whole, is connected to the constraint inflicted by the optical triangulation concept. Modeling and calibration of laser sensor are always carried out under the assumption that the principal axis of emitted laser beam is orthogonal to the surface of the object whose distance is measured – orthogonality requirement. The deflection of orthogonality degrades the accuracy of laser system which has its clear foundation in Lambert's law of diffuse reflection. Besides, measuring surface inclination puts down the energy of reflected light which in certain cases can have drastic repercussion to performance of sensor transducer set which due to insufficient excitation can stay without valid sample. Generally, inclination should be within interval of ±15º. This is especially important when object has highly reflective surface and/or surface with high texture. For the reference surface made of white paper inclination in given interval generates the error of 0.2% of measuring range, which is for the measuring range of 100mm as far as 200µm and can be regarded as significant error. If the inclination in both directions is in the interval of ±5º, than the error is not more then 0.12% of MR.

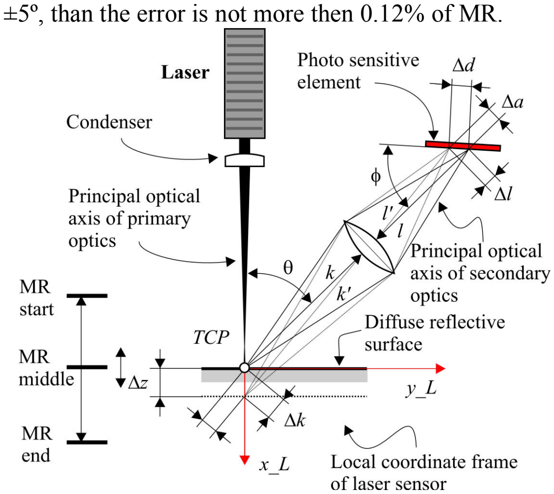

Fig. 2: Functional principle of laser triangulation sensor and definition of local coordinate frame

The second requirement refers to the problem of shadow, i.e., the occurrence of physical obstacle which totally or partially breaks the optical axis of secondary optical system - sensor can not generate valid result. **Optical visibility requirement** puts in additional constraint for the process of robot trajectory planning. Generally, this requirement can not be always fulfilled.

Considering these requirements/constraints in the application of laser triangulation sensors, the application of robots gets its full significance. Inherent manipulability properties enable to, choosing the right trajectory, one can always provide optimal metrology conditions: 1)location of the TCP on the surface of scanned object, 2)orthogonality of the principal optical axis to the surface of the scanned object, and 3)elimination of shadow problem always when it is physically feasible. The possibility to fulfill given three prerequisites makes the symbiosis of robot and laser triangulation sensor a technology entity of a high value.

2.3. Acquisition system

Integration of robot and laser sensor is carried out trough acquisition system. Acquisition system, i.e. PC or another microprocessor system supplied with corresponding interfaces and acquisition software must have the function of communication with robot control system and laser sensor microprocessor system. Acquisition system conducts synchronous acquisition of robots internal coordinates (values of actuator encoders) and measured distance to the scanned object. In successive time sampling instants acquisition system gets and memorizes the vector with (n+1) elements where n denotes the number of active robot DOFs. Position vector of arbitrary point M r_M on the scanned object, presented in local workspace coordinate frame is computed using relation:

$$\bar{r}_M = \bar{r}_{TCP} + \bar{\delta}_M - \bar{r}_W \qquad (2)$$

where r_{TCP} denotes robots TCP position (from robot control system), δ_M is the vector of measured distance generated by laser triangulation sensor, and r_W is the vector of position of the scanned object in workspace (Figure 1). Deflection (deviation) η of point M nominal position r_{Mo} defined by digital 3D CAD model from the real position obtained by measuring is then:

$$\bar{\eta} = \bar{r}_M - \bar{r}_{Mo} \qquad (3)$$

Point M position vector contains inherent error of manipulation robot end point position which comes as a consequence of imperfections of robots mechanical and control system. This error consists of stationary and nonstationary component (oscillation of robot end point, processes of stochastic nature and slow processes caused by nonstationary temperature field and wearing/deformation of kinematics chain elements). In the most cases stationary component has dominant influence and metrological performances of robotized measurement system can be significantly improved if this component is identified and memorized for total robot workspace or only for a part significant for application at hand. Reading the values of identified stationary component of robot end point positioning error from look-up table together with interpolation relations gives the values of current correction e_M and corrected values of point M position vector is given by:

$$\bar{r}_M^k = \bar{r}_M + \bar{e}_M \qquad (4)$$

This approach significantly improves metrological properties of robotized scanning system.

Scanning task is, as a rule, comprised of the sequences made of subsequences of scanning and subsequences of robot repositions. Each of these sequences gives, as a result, a vector of one contour, usually as continuous time series. This working principle assumes the existence of bidirectional communication between acquisition system on one side and robot control system and laser sensor on the other one. Acquisition system is required to have the function of discontinuous withdrawal of encoder signal and adjoined measured distance whenever it is demanded by measuring plan. Acquisition system can be a part of cell controller or it can be located in the layer right beneath it. Anyway it is superior to the microprocessor system of laser sensor and it is in hierarchy sense parallel to the robot control system.

A set of measured point position vector time series calculated from equations (2) and (4) by superposition, generates so-called nonstructured points cloud which caries the complete or partial information about real geometry of visible surface of scanned object.

3. SENSOR SIGNAL PROCESSING

Time series for each of scanned contours demands the appropriate processing before synthesized output, in the form of points cloud suitable for digital 3d model generation in CAD modeler, is generated. Primary signal processing assumes four tasks: 1)Removing the noise and microgeometry texture details in time domain; 2)Transformation of time into spatial domain; 3)Contour resampling in spatial domain and the reduction of number of points; 4)Compensation of robot positioning errors

Secondary signal processing is guided by concrete application, i.e. by the task put to the robotized measuring system. Here, two basic cases are possible:

1. Object is partially scanned and only a location of certain points or profiles of characteristic cross sections is checked. In this case from primary processed sensor readings the coordinates of required points or vectors of required cross section contour are extracted.
2. Object is totally scanned and corresponding point cloud is generated, and by further polygonization (Delaunay triangulation etc.) its virtual geometry model is generated [4]. In this case a synthesis of contours generated during primary signal processing is carried out, the redundancies are eliminated and virtual model of object is generated in the form of point cloud.

The key requirement for the choice of technique for primary processing of generated time series is the phase correctness and possibility of multiresolution analysis. Techniques based on wavelet transform fulfill both requirements including the possibility of partial or total reconstruction of starting vector.

Using discrete wavelet transform (DWT) [5] signal f is presented as sum of its approximation AJf at certain resolution J and details Djf, $j \in [1, J]$ taken from it during passing from higher resolution to lower one:

$$f = A_J f + \sum_{j=1}^{J} D_j f = \sum_n a_n^j \phi_{j,n} + \sum_j \sum_n d_n^j \psi_{j,n} \quad (5)$$

Ajf and *Djf* are represented by approximation a_n^J and detail d_n^j coefficients which represent the share of scaling functions $\phi_{j,n}$ and wavelets $\psi_{j,k}$ in signal. These coefficients are computed using fast onepass hierarchical algorithm –subband filtering scheme which enables reversibility of filtration and algorithm for inverse discrete wavelet transform (IDWT).

Using subband filtering scheme shown in Figure 3, d_n^j are computed from a_n^{j-1} by filtering it with highpass filter $\bar{G}$, and then downsampling by 2. Similarly, a_n^j are computed from a_n^{j-1} by filtering it with lowpass filter $\bar{H}$, and then downsampling by 2. Filters H, G, $\bar{H}$ and $\bar{G}$ are conjugate mirror FIR filters defined by selected wavelets. Algorithm for IDWT can be described by subband filtering scheme given in Figure 3b. a_n^{j-1} are computed by upsampling a_n^j and d_n^j by 2, convolving obtained sequences with filters H and G and summing it. Algorithm for IDWT can be used for computation of signal approximation at resolution (DWT level) $J - A_j f$ if detail coefficients d_j^n, $j \in [1, J]$ during computation are zeroed. Details $D_j f$ can be computed similarly.

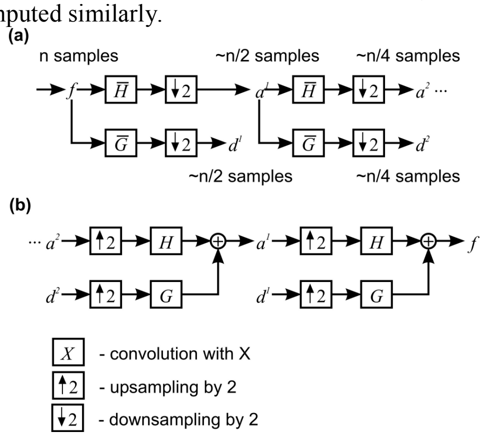

Fig. 3: Subband filtering scheme for: a)DWT, b)IDWT

The existence of IDWT is extremely significant for decoupling the noise, microgeometry of scanned object surface texture and its macrogeometry [6]. Adequate choice of wavelet used for DWT, as well as the choice of transformation level *J*, can lead to recognition of given components at certain levels of signal approximations or details.

Transition from time to spatial domain generally brings up the problem of contour spatial discretization uniformity. Depending on the shape of scanning trajectory as well as on the local properties of scanned object surface, the uniformity of sensor signal discretization in time domain is more or less deteriorated leading to cumulation of points in certain parts of contour and their rarifying in other parts. The problem is solved in such a way that initial contour vector in spatial domain is discretized again using interpolation algorithms [7]. This area is studiously researched for decades in the context of geometrical modeling of spatial objects and it is not the subject of research presented in this paper. Having the ringing in of developed concept as a goal, zero order interpolators are used living the room for application of advanced techniques in the phase of digital 3D model generation in CAD environment.

4. CONCLUSION

This paper gives a concept of a system for robotized digitalization of spatial objects with complex geometry based on application of spot laser sensors. The structure of system is shown and critical metrology details of symbiosis of general purpose manipulation robot and laser triangulation sensor are discussed. The concept of acquisition system is described and basic geometric equations for the synthesis of 3d digital model of scanned object in the form of unstructured point cloud are given as well as the relations for identification of deviation of empirical model from nominal digital model created in 3d CAD modeler. Basic definitions of laser triangulation sensor are given and it is shown that manipulation robot has very desirable properties, providing that, when working with complex geometry parts, orthogonality and optical visibility requirements can be fulfilled. For the primary sensor information processing, the application of DWT is suggested because it provides phase correct signal decomposition, gives the freedom in choice of time or spatial signal approximation in accordance to application conditions at hand and enables real-time applicability.

5. REFERENCES

[1] Schwenke, H., et al., *Optical Methods for Dimensional Metrology in Production Engineering*, Annals of the CIRP, Vol. 51(2), pp: 685-699, 2002

[2] D'Apuzzo, N., *Three-Dimensional Image Capture and Applications VI*, Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 6056, San Jose (CA), USA.

[3] Petrović, P., *Rubberized Cord Thickness Measur. Based on Laser Triangulation – Part I: Technology*, FME Transaction, Vol 35, pp: 77-84, 2007

[4] Aurenhammer, F., *Voronoi Diagrams - A Survey of a Fundamental Geometric Data Structure*, ACM Computing Surveys, Vol. 23(3), pp: 345-405, 1991.

[5] Mallat, S., G., *A Theory for Multiresolution Signal Decomposition: The Wavelet Representation*, IEEE Transaction on Pattern Analysis and Machine Intelligence, Vol II, No. 7, pp: 674-693, July 1989.

[6] Jakovljević, Ž., Petrović, P., *A New Approach to Rubberized Cord Surface Structure Identification Based on High-Resolution Laser Scanning and Multiresolution Signal Processing*, FME Transactions, Vol. 37(1) pp: 19-26, 2009

[7] Bernardini, F., Bajaj, C., L., Chen, J., Schikore, D., R., Automatic Reconstruction of 3D CAD Models from Digital Scans, International Journal of Computational Geometry and Applications, Vol. 9(4/5), pp: 327-369, August 1999

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Invited Paper

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IN PROCESS IDENTIFICATION OF WORKPIECE/SYSTEM GEOMETRICAL DEVIATIONS BASED ON GENERAL PURPOSE ROBOTS AND LASER TRIANGULATION SENSORS – PART 2: EVALUATION

Abstract: *This paper gives a conceptual framework of a new class of metrological systems based on integration of general purpose industrial robot with laser triangulation sensor for contactless dimensional metrology. The paper has two parts. Part one considers conceptual framework where the system architecture is given, key aspects of the interface between two subsystems are considered, as well as a new methodology frames for signal processing and generation of partial or complete 3D digital model of scanned object with complex spatial geometry. For verification of practical applicability, laboratory installation is developed and experiments and practical functional testings are carried out. This paper also gives recapitulation of two feasibility studies: huge assemblies welding process robotization and forging press serving in the scope of flexible manufacturing cell for forging on MAXI presses. Evaluation and practical implementation are in the second part of this paper.*

Key words: *Industrial robot, laser triangulation sensor, 3D digitalization*

1. INTRODUCTION

For illustration of practical applicability of the concept of robotized scanning of objects with complex geometry directly on production lines and with application of commercially available general purpose industrial robots, the results of evaluation activities carried out in laboratory conditions and in the form of feasibility studies for concrete application in industrial manufacturing are given. The evaluation procedure is carried out within the research project INTOSA[1] [1] where the conceptual bases for one robotized system for 3d digitalization of objects with complex geometry based on CCD laser sensor with spot optical triangulation are developed and practically realized. Practical applicability of this concept is verified and demonstrated in laboratory conditions in Center for New Technologies at Faculty of Mechanical Engineering, University of Belgrade. This paper should be seen in continuity with the first part [2] where the conceptual framework is given.

2. MAPPING OF THE ROBOT ERROR

Figure 1 shows the installation for experimental verification of robotized scanning concept which is realized within Center for New Technologies (CeNT) at Faculty of Mechanical Engineering in Belgrade. System consists of 1)robot with anthropomorphic configuration with 6 DOF, payload of 10 kg and reach of 1650mm, made by Kawasaki, Japan, model JS10, 2)laser triangulation sensor made by Micro Epsilon, Germany, model optoNCDT 1700-100 (characteristics are given in Table 1), 3)PC acquisition system with corresponding interfaces and software, and 4)worktable.

Table 1: Technical performances of laser triangulation sensor ME optoNCDT 1700-100

Measuring range (MR):	100 mm
Stand-off distance:	70 mm
Linearity:	±0.08% MR
Resolution:	6 μm
Maximal mesuring rate:	2.5 kHz
Light source:	
Wave length: 100 mm	670nm, red
Max. power:	1mW
Laser class:	2(II)
Allowed ambiental light intensity:	10.000lx
Spot diameter at the middle of MR:	60μm
Temperature stability:	0.01 %FSO/K
Operating temperature:	0...+50 °C
Vibration resistance (IEC 68-2-6):	2g/20...500Hz
Shock resistance (IEC 68-2-29):	15g / 6ms
Weight:	550g

For the purpose of improvement of metrology performances of robotized measurement system the identification of positioning error of robot end point in a part of its workspace is carried out. Quantitative indexes are derived by generation of a sequence of equidistant calibration curves (vectors) which are positioned in one vertical plane perpendicular to y axis at position y=1000mm. Calibration curves are generated for straight line nominal trajectory, by scanning an etalon ruler with length of 500mm.

Figure 2 shows one of 5 calibration curves. One can observe the existence of error caused by imperfections of manipulation robot which come up from: 1) mechanics of the robot kinematic chain, 2) actuation system and 3) robot control system. In the given case this error is ± 0.142 which is for 40% greater then error specified by manufacturer (±0.1 mm in the complete workspace). Calibration curve is derived using

[1] Project MA14035: **Application of Intelligent Sensor Systems in Development of Integrated Automation of Real and Virtual Processes in Manufacturing Enterprises - INTOSA**, financed by the Government of the Republic of Serbia, Ministry of Science and Technological Development, Grant 14035, (2008-2010)

Fig 1: Instalation for experimental verification of the proposed concept within CeNT

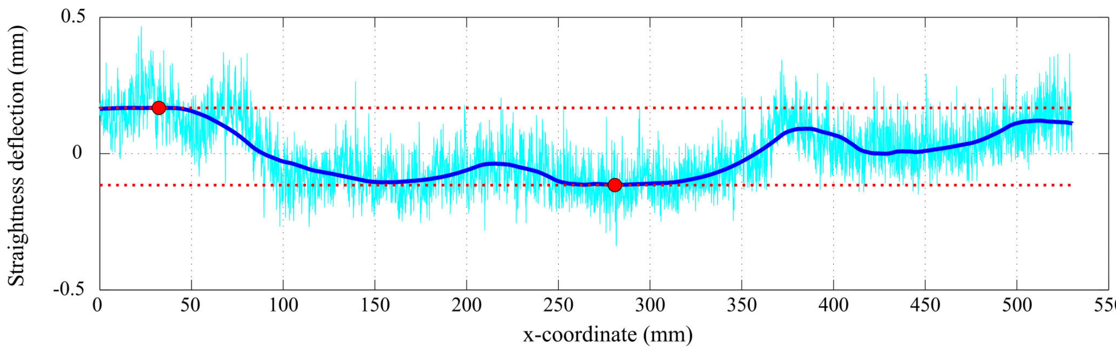

Fig. 2: Identified robot error in horizontal plane at the worktable level – straightness deflection for the nominal trajectory: y=1000; z=100; x=t.

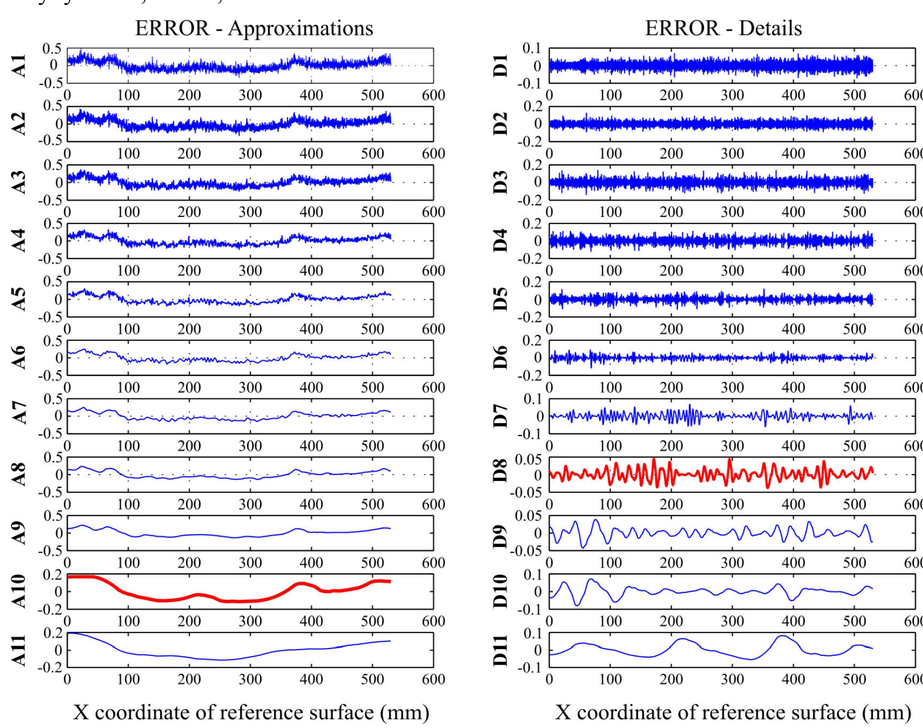

Fig. 3: Decomposed robot end point error signal given in Fig. 2 using db4 DWT at 11 levels

multuiresolution analysis of original signal transformed from time to spatial domain. Signal is decomposed at 11 levels using Discrete Wavelet Transform (DWT) with db4 wavelet [3]. Decomposed signal, that is, the sequence of its approximations and corresponding details is given in Figure 3. Elimination of high-frequency contents which come from robot and noise in sensor readings gives calibration curve. By thorough analysis of detail signals at all 11 levels, approximation level A_{10} is chosen as dominant level at which the error that comes from imperfection of mechanics and robot control is located. Error components that come from robot end-point vibrations are grouped around D_8 detail level. High frequency error components that come from sensor system are located at the level D_1 and higher levels. The error of metrological system as a whole is determined by error generated by manipulation robot.

Since the error map is derived applying DWT it is possible to reduce the amount of data to be stored in the look-up table. Instead of memorizing raw data, or approximations A_{10} it is more convenient to memorize approximation coefficients a_n^{10}. These approximation coefficients carry the complete information contents of A_{10}. A_{10} can be computed from a_n^{10} using IDWT (Inverse Discrete Wavelet Transform). Having in mind that there are 2^{10} less approximation coefficients a_n^{10} than samples in A_{10}, significant reduction of memory is feasible. Besides, since DWT is additive, it is possible to subtract the approximation coefficients of error directly from the db4 10th level approximation coefficients of signal measured during scanning.

3. SCANNING THE GEOMETRY OF FORGING

The first example of practical implementation relates to the area of forging process automation. Contemporary trends in market impose very high demands when the geometry of forgings is considered. This imposes the need for in-process inspection of key geometry parameters. For the needs of Zastava Kovacnica Company, Kragujevac, during year 2008 the feasibility study [4] for the automation of existing forging technology based on MAXI presses is carried out. In the given case the manufacturing cell consists of two presses, one for shaping with capacity of 2500 tons and the other one for flash trimming. For the purpose of forging process quality surveillance, besides two manipulation robots that serve both presses and system for inductive heating, the third robot is added. The task of the third robot is to continuously inspect key geometry parameters. The layout of given cell is shown in Figure 4. For the purpose of validation of practical applicability of suggested concept of robotized manufacturing cell, test scanning of chosen example of forging – the housing of the bearing unit of the automobile front wheel is carried out in laboratory conditions. Contour of one of the scanned cross sections of forging is shown in Figure 5.

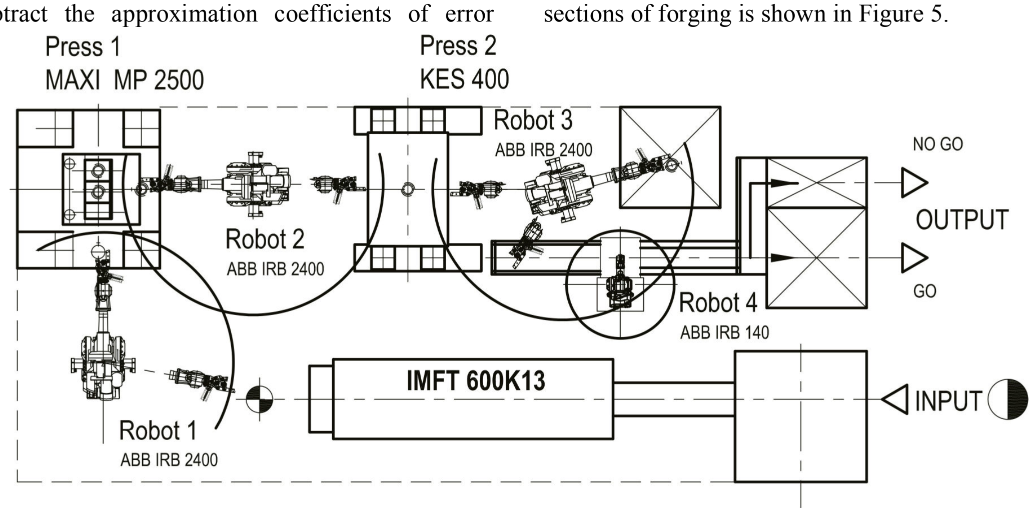

Fig. 4: Layout of robotized manufacturing cell for forging in Zastava Kovacnica Company. A variant version with integrated final forging geometry control system using universal manipulation robot IRB 1400, mfd. by ABB

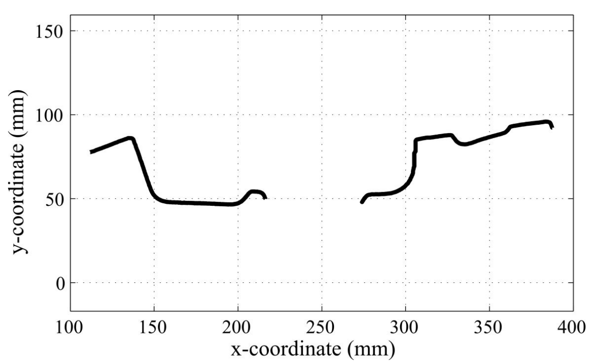

Fig. 5: An example of scanned contour of forging cross section in vertical plane transformed into spatial domain. In the left corner a photo of scanned forging in the angle showing the scanned cross section is shown

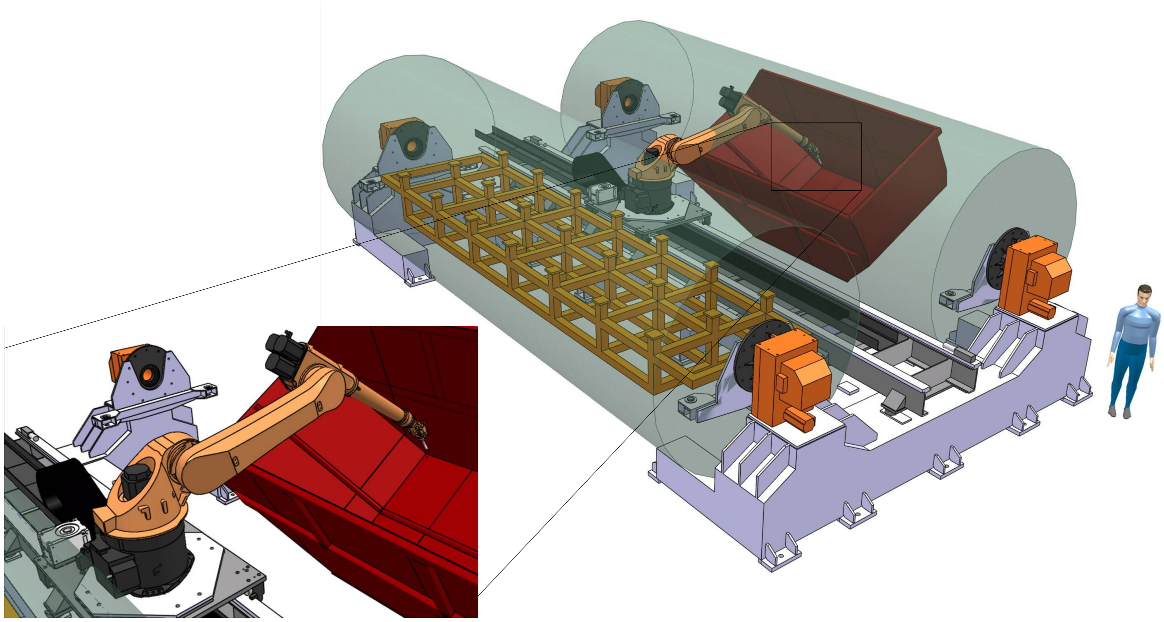

Fig. 6: Layout of robotized manufacturing cell for final assembly of family of containers. The cell is based on robot KR 30 L16, mfd. by KUKA which besides welding carries out identification of geometry and assembly location

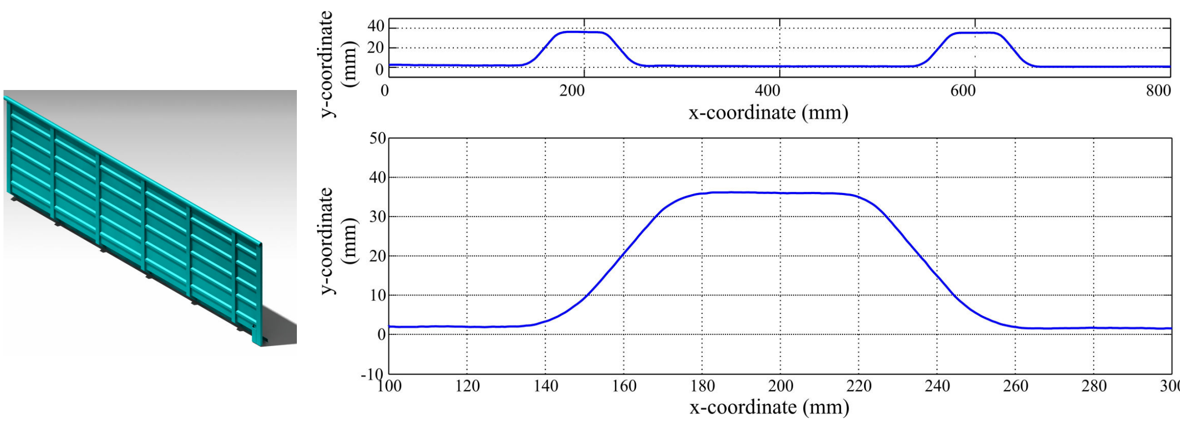

Fig 7: 3d CAD model of huge size container lateral side and an example of scanned profile geometry of ribbed sheet metal filling; Scanning is carried out in laboratory conditions in CeNT

Contour is scanned with the speed of 100mm/s which gives spatial resolution of 40µm. Only those points that are visible in the horizontal plane of orthogonal projection are shown. In this case, by applying measuring system, it is possible to realize the control of forging process directly on the manufacturing line. This approach enables fast reaction at the deflection occurrence, which guaranties the high quality and the stability of manufacturing process.

4. SCANNING THE GEOMETRY OF WELDED ASSEMBLY

The other example of practical implementation relates to the robotized system for arc welding of metal assemblies with huge size. The feasibility study [5] is carried out for the Velpan Company, Kikinda, which is specialized for manufacturing of containers for the diffuse load transport. Manufacturing system is designed in such a way that it consists of two manufacturing subsystems. The first subsystem consists of manual work places where the pre-assembly of subassemblies and final container assemblies is carried out. Pre-assembly is done on palettes which are equipped with specialized jigs and fixtures and which can be transported using bridge crane. The other subsystem consists of fully automated robotized manufacturing cell which has two rotary tables for the pickup of palettes with pre-assembled assemblies and manipulation robot KUKA KR 30 L16 with anthropomorphic configuration, reach of 3100 mm, equipped with seventh linear axis with the length of 10000mm. The layout of proposed system is given in Figure 6. The key demand for practical applicability of proposed concept is the complete information about

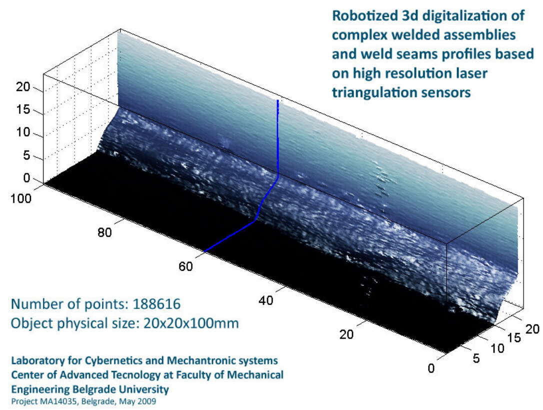

Fig. 8: 3d digitalized weld seam profile. Scanning is carried out in laboratory conditions in CeNT

geometry of pre-assembled assembly, that is, about precise location of welds to be welded. Generally, the error which occurs in this case consists of the errors of the assembly (the errors in position of assembly elements, the errors from elastic deformations and errors from thermal dilatations), the errors of geometry of assembly elements brought in during previous phases of manufacturing process and the errors of assembly positioning in jigs and fixtures, the errors of rotary table and robot positioning.

The reduction of given errors to the level acceptable for the MIG welding technology is not possible in rational way. Instead of the concept of geometric perfection, the concept of the adaptability of the system to the error is adopted. This concept is based on application of in-process robotized scanning of the assembly to be welded, starting from the initial scanning of the prepared material after the putting the pallet on the rotary table, all to the final scanning of the realized geometry after welding is finished.

Due to the complexity of subassemblies a number of successive welding and scanning operation is foreseen which enables not only the feasibility of the welding process, but also the surveillance of this process together with corrective actions on the nominal welding plan. An example of the scanned detail of lateral container side is shown in Figure 7. Based on identified profile geometry with the accuracy of ±0.15mm it is possible to continuously weld the ribbed sheet metal of the lateral container side even in the conditions when there is significant deflection in the rib profile geometry and the spatial position of the weld. Figure 8 shows the 3d visualization of the finished weld seam profile. The weld seam is scanned in laboratory conditions in CeNT.

5. CONCLUSION

Practical functionality of proposed concept of the robotized scanning is experimentally verified in laboratory conditions using anthropomorphic manipulation robot with 6 DOF and laser triangulation sensor with measuring range of 100mm and sampling rate of 2.5kHz. System has shown satisfactory behavior, and metrology performances are dominantly impressed by manipulation robot accuracy. In the given case achieved accuracy is better than ±200 μm in the comlpete work space. Developed system has general applicability at lines for assembly of products with huge or medium size, as well as on lines for manufacturing of parts made by forging and casting.

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6. REFERENCES

[1] Petrovic, P., B., Spasic, Z., Pilipovic, M., Jakovljevic, Z., *Application of Intelligent Sensor Systems in Development of Integrated Automation of Real and Virtual Processes in Manufacturing Enterprises - INTOSA*, *Annual Report,* project financed by the Government of the Republic of Serbia, Ministry of Science and Technological Development, Grant 14035, (2008-2010), Center for New Technologies, Faculty of Mechanical Engineering, University of Belgrade, 2009
[2] Petrovic, P., B., Jakovljevic, Z., Pilipovic, M., Mikovic, Dj, V., *In Process Identification of Workpiece/System Geometrical Deviations Based On General Purpose Robots and Laser Triangulation Sensors – Part 1: Conceptual Framework*, MMA, Novi Sad, 2009
[3] Daubechies,. I., *Ten lectures on wavelets*, CBMS-NSF regional conference series in applied mathematics, Philadelphia: SIAM (61), 1992
[4] Petrovic, P., B., *Flexible Manufacturing Cell For Forging Process On Maxi 2500 Press, Feasibility Study*, Center for New Technologies, Faculty of Mechanical Engineering, University of Belgrade, 2008
[5] Petrovic, P., B., Jakovljevic, Z., *Robotized Flexible Manufacturing System For Final Assembly Of Huge Dimensions Metal Assemblies, Feasibility Study*, Center for New Technologies, Faculty of Mechanical Engineering, University of Belgrade, 2009

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MODELLING OF PROCESSES AND MACHINES FOR THE SUPPORT TO HYDROENGINE COMPONENTS PRODUCTION

Abstract: *Approach of integrated design represents the bridge that connects individual stages of the product designing and the technology and has a significant role in the reduction of the overall design time, as well as the production costs. That means that the technological processes design should be connected with production planning as well,, that is the choice of tools, equipment, pressing devices and machine tool.*
Key words: *Technological process, Pressing, Additional axis, Machine tools*

1. INTRODUCTION

Integrated product and processes design is basically intended to form a competitive product. In the cycle of conceptual design variant and variable product solutions and adopted technologies have a dominant influence on the choice of machine tools for the support in the realization of the adopted technology. In the activities of the centre for integrated product and processes development, Faculty of mechanical engineering Kraljevo, special attention is given to reviatalization of the existing traditional technologies in the massive part production. In other words, it is about partial re-engineering of the existing production plants of big companies which haven't been made private yet. Taking into consideration this approach, this work shows the achieved results in the modelling of the machine tool in a narrower sense (hardware) as a support to the adopted technology of part processing , back lid of the hydroengine, in the factory Hydraulics, Trstenik.

2. FUNCTIONAL-TECHNOLOGICAL PART ANALYSIS [1], [2], [3], [4]

The process of forming the competitive product is partly connected with the technological process design of part production. Taking into consideration the fact that in this case the production process is completely defined by traditional production technology, the possibilities of machine composing with significant reduction in production costs are analysed. Special attention in the analysis is paid to the choice and adoption of the technological process parametres, that is to the correct choice of tools, the way of pressing and positioning of the part, machine. Technological analysis of the parts showed that re-engineering of pressing devices represents a significant parametre in the cost reduction in the production process. That is why special attention is paid to modelling of the machine tool with a special pressing device which in this case represents an additional fourth control axis.

Re-selection of the cutting tools is defined using the base of the necessary tools specified in the traditional production approach as well as using the production process on the machine with tool store according to the matrix of following for the adopted technology. Tools made of hard metal are usually taken and it is necessary that they have stability of 480 min.

These general observations represent the basis for the initial evaluation of production methods for part production. Based on the rules of priority through dimensional, geometrical, technological and economic limitations the matrix of dependence is acquried. Using the dependences established in this way the matrix of following is formed. As the way out of the matrix of following a logical order of moves appears (theoretical moves).

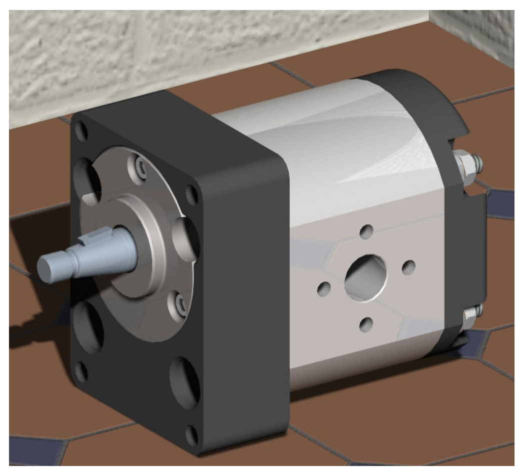


Fig. 1. Hydroengine.

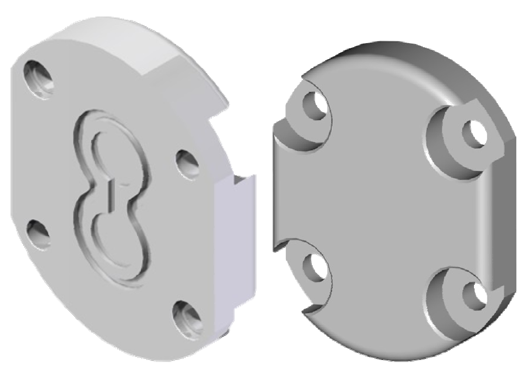


Fig. 2. Prepared and finished part.

3. SPECIFIC QUALITY OF THE PROCESS IN THE PRODUCTION OF THE BACK LID [3], [4]

The processing of a mechanically correct part requires qualitative prepared part, its correct pressing and location definition (of the position and orientation) in the space. As an addition to the definition of spesific surface positioning, it is necessary to design the way of firmly holding the part in the given position under the influence of outer forces like gravitation force, cutting force, vibrations, centrifugal forces, etc. It must not influence the previously determined function of positioning, but it has the function of providing stability of the part. The pressing devices must have the appropriate pressing force so as not to damage the part in the points of contact with its excessive pressure.

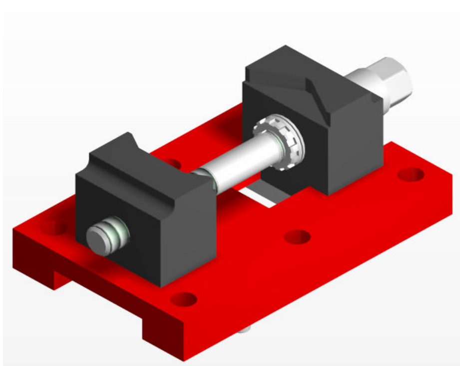
3.1. Types of pressing in cases of miling and drilling

Pressing tools design and devices for pressing the working part on the machine design are realized by the application of contemporary CAD/CAM programme packages. The position of pressing, previously described, has to follow the rules of the precision of the production and respect the relation between the segments of the part. It also has to ensure that the part doesn't move during the processing, that the parts of the pressing equipment don't interrupt the movements of the tools or cause increase in the tool operation and that it is easy to remove filing.

4. MODELLING OF THE INSTALLATION STRUCTURE OF THE MACHINE TOOL [1], [2]

The concept of the machine tool in the narrower sense is defined to support the adopted production process. In order to perform the necessary operations while processing the back lid of the hydroengine, machine variants have to have the appropriate movements which provide independent wholes – modules. For every movement, whether main or additional, there has to be the right module that provides such a movement. In order to press the processing part it is necessary to design a pressing device. Thus modular analysis is done based on which the pressing device design is done with certain modifications in relation to the already existing vices, and in particular pressing prism. From the available modules CIRPP those that meet the given demands are chosen.

4.1. Vice module



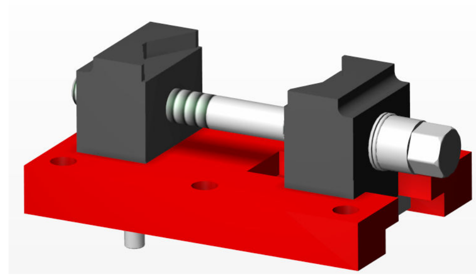


Fig. 3. Vice module

Vice module assembled with the holder, bearing and rotation desk represents an additional axis on the tool machines. For the processing of the back lid of the hydroengine, three-axis verticall drill/miling machine and three-axis horizontal drill/miling machine are chosen, so that the assembly of the vice represents the fourth additional axis. This additional axis increases the productivity, in one pressing, 16 hydroengine lids are processed. The number of simultaneously processed lids is conditioned by maximum tool stability, so that the tool can process all 16 lids, without changing the tool in the meantime. After the processing, the changing of tools and working objects is done. The vice is modelled parametrically and variantly so that it can be used for pressing of the hydroengine's back lid of different dimensions and for the appropriate number of parts that can be accepted.

4.2 Realization of the adopted technological process on variantly chosen machine tools

The prepared part for the production of the back lid of the hydroengine is an extradited aluminium pole and it's shown in fig. 2. Based on the technology that represents a way out of the matrix of following, the process of the hydroengine's back lid production is done in two pressing moves. In the first pressing move the prepared parts are put into the vice, one by one, and the look of the prepared parts is shown in fig. 4. and 5.

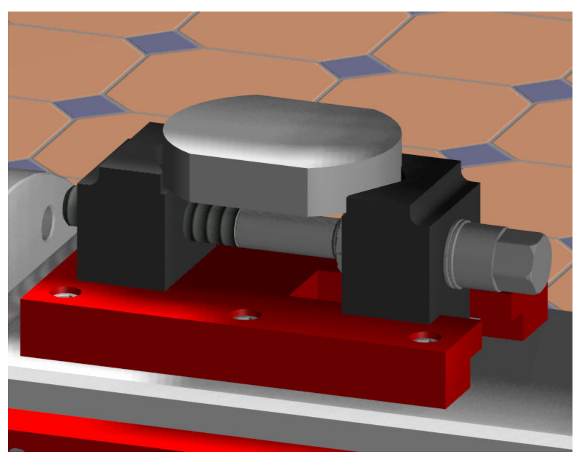
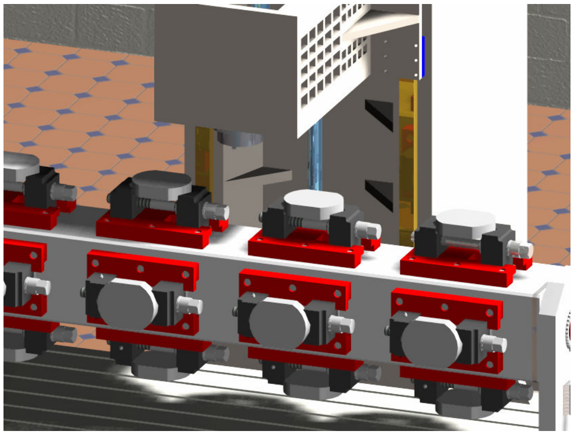
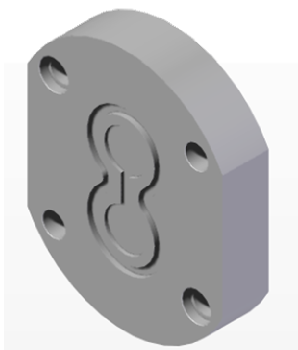


Fig. 4. The look of the prepared part in the vice.



Picture 5. The look of the prepared part in the vice.

After the finished operations in the first pressing move the working object is rotated and then the operations in the second pressing move are performed. The working object after finished operations in pressing A is shown in picture 6.



Picture 6. The back lid of the hydroengine after pressing A.

The look of the prepared part in the vice, pressing B is shown in fig. 7.

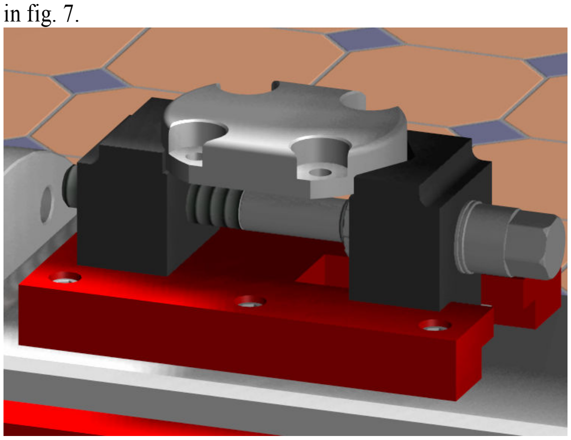


Fig. 7. The look of the prepared part in the vice. –Pressing B

The final product of the back lid of the hydroengine after the processing using technology, after pressing B, is shown in fig. 2.

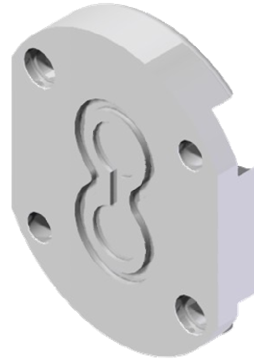


Fig. 8. The final shape of the hydroengine back lid

5. CONCLUSION

Achieved results in this work are reflections of the research of variant option in the technological production process of the hydroengine back lid using already existing tool machines. The need to introduce an additional axis on the existing three-axis processing centres appeared.
The results of the research come from a very large theoretical analysis of the individual parametres which directly influence generating of technological process. The following parametres are mentioned here:

- order of technological operations,
- the choice of tools,
- specific vice design,
- installation structures of machine tools based on the available modules.

6. LITERATURE

[1] Babić A., Pršić, D., Pljakić, M.,Ilić, N., Jedan pristup modelovanja dodatne ose mašina alatki, Savetovanje Proizvodnog Mašinstva, str. 147-150, Beograd, Mašinski fakultet Beograd, Beograd, Jun 2009.,

[2] Babić, A., Tehnologija montaže, Mašinski fakultet Kraljevo, 2005.

[3] Babić, A., Projektovanje tehnoloških procesa, Mašinski fakultet Kraljevo, 2005.

[4] Halevi, G., Weill, R., Principles of Process Planning, Alogical approach, Chapman&Hall, London, 1995.

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MODELLING OF INSTALLATION OPERATIONS IN CAM OF ROADHEADER DESIGN FOR THE PROCESSING OF INFRASTRUCTURAL OBJECTS

Abstract: *Virtual product design represents a technological key to the reduction of costs caused by mistakes generated in the processes of engineering design during the lifetime. It is important to make the connection between product design in CAD with complex limitations of installation operations in CAM, so that conditions for development and modification in the virtual surroundins are provided in the design process before the beginning of the production. This is largely seen in roadheader design for infrastructural objects processing. The advantage of this connection in design processes lies in exceeding the formation of expensive physical production systems, therefore all variant researches are done on a virtual model.*
Key words: *Product design using a computer (CAD), technology design using a computer (CAM), installation..*

1. INTRODUCTION

Installation processes in the product lifetime represent a lot higher level than binding the parts in one whole, whether they are product design or production technology design at a component level. It is the turning point in the technological cycles at which the product begins its lifetime and for the first time has the ability to function. The most obvious aspects of the product quality are reflected by the actual designed installation process.

Traditionally, the design for the easy DFA installation is based on the studying of DFDA(dismantling) disassembling process, most commonly under the assumption that 'if you can dismantle a part, you can also put it back'. In the real surroundings, things can be a lot diffrent from the inverse process of integration. It is widely known that for the given product, the number of possible installation structures exponentially increases in relation to the number of components. In the analysis of the conceptual solutions we can conclude that the designed optimal disassembling process does not have to be the best conceptual installation solution. Installation design represents an engineering process that integrates a large number of DFX approaches in the simultaneous product and process design.

The virtual product design is the technological key to the reduction of namely the costs caused by the designers' mistakes during simultaneous engineering. In the scope of product model integration the mentioned aspect is shown in the connection between product design in CAD with installation operations in CAM in which virtual surroundings are based on avoiding the usage of expensive production systems.

The complexity of installation processes and production technology processes for the designed product has a huge influence on costs, profit and recycle possibilities. Engineering product model integrates a large number of DFX approaches during which it can be estimated and adapted only after detailed consideration before it is launched into production (the turning point of product being born). According to some authors product design is 6% of the costs meant for the product development, and more than 70% of the production costs refers to the phases of conceptual design. That means that good preliminary designers' decisions are possible to make only after detailed analyses of the complexity of the production and the product's lifetime. [1]

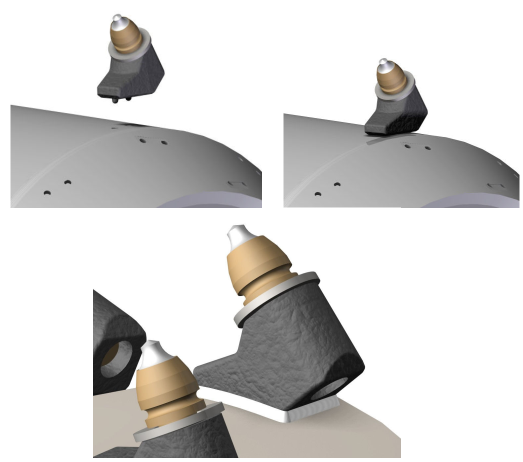


Fig. 1. Cutter holder on the roadheader's mantle attached by welding

Complex installation operations increase the actual production costs of complex products significantly. Also the products, which need complex operations for their disassembling, increase the maintenance and recycle costs. Installation and disassembling costs significantly influence the lifetime of a product, which demands the application of designer's solutions that enable an effective installation. The complexity of the installation can be defined as the complexity of the mutual movement limitation of the parts that are assembled. In order to prevent difficult installation operations in the CAM environment, it is necessary to predict the complexity of mutual assembling components during the product design in CAD environment using virtual assembling tools. [2,3]

Virtual system that connects the designers' solutions from the CAD environment with the complexity of the installation operations from the CAM environment, virtually evaluates and assesses product design and installation structure. The steps in the realization of such a system are:

- Creating the system for installation structures coding (OSACS- Open Structured Assembly Coding sistem)- which should identify and code all the assembling operations of two parts in the CAM.
- Creating the system for extracting the code that identifies compatible installation operations from the CAD model.
- Creating the installation operation order generator that generates binary tree of the installation structure for the designed product coded using compatible installation operations in the CAM for the product assembly.

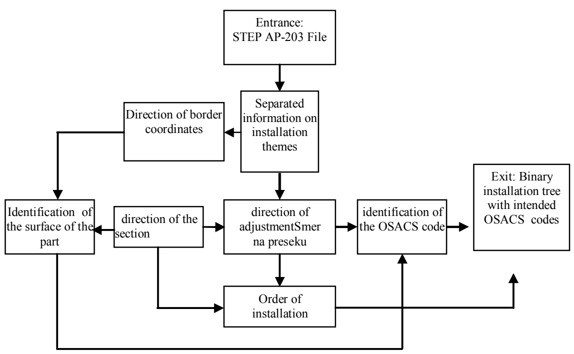


Fig. 2. Design of the installlation order generators with the coding structure system.

2. CODING STRUCTURE SYSTEM

Most of the installation operations can be divided into several elementary part assembling operations which include fitting one part into another. Each of the parts has a feature vector (F) using which the part's orientation and the part's main axis vector, with which the part's symetry is shown, are presented. By studying geometric similarities between different pairs of parts the basic system for installation structure coding is developed. The code actually contains the information equivalent to CAM operations. [1]

Further consideration of the part types and their geometry helps us identify three major features by which different installation operations are classified into two parts:

- number of translation freedom degrees between the parts,
- number of rotation freedom degrees that fits into the base part,
- relative position and orientation of two parts in the mutual coordination system.

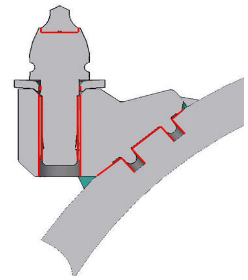


Fig. 3. The holder and cutter assembly set on the drum.

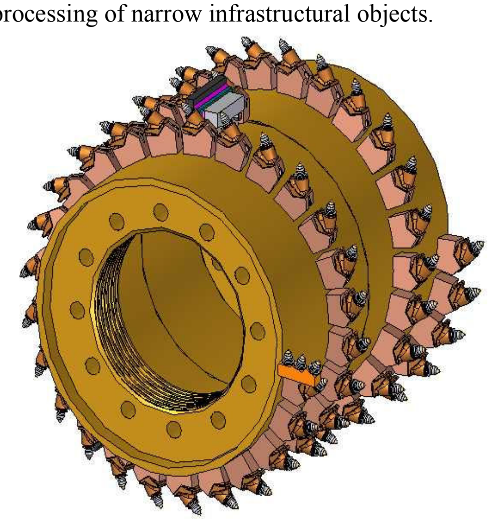
Cutter holders (Fig. 1.) are the elements that enable the rotation of the knives in them, and they provide the cutter with the needed spacial position in the cutting process. The holders have a relatively long lifetime and it isn't necessary to change them often. That's why the connection of the cutter holders with the drums is done by welding.

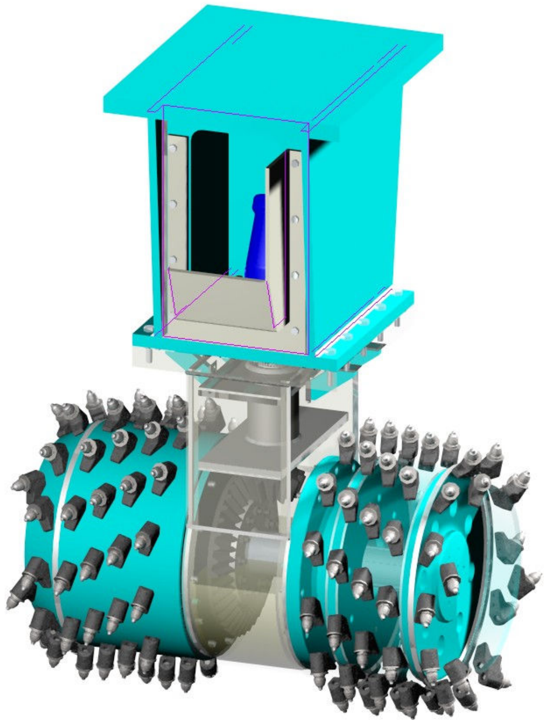
2.1 Installation operation order generator

In order to determine the order of installation operations firstly it is necessary to identify all the part pairs that can be assembled mutually. From the geometrical information provided via STEP the information on maximum and minimal borders of every part in all three directions is acquired. Using the simple algorithm we examine whether there is mutual intersection of these part borders, that is whether there is the possibility of these parts to assemble. By examining every part a list of all parts with which it has an intersection and can be assembled is acquired. [4,5]

Modelling of the roadheader drum, roadheader and roadheader disks at the installation structure level is very important because by establishing installation relations kinematic demands are met. Solid Edge has a module for product modelling at installation level, the so-called Assembly module. The installation structure is established based on the installation relations which are in this programme package defined in terms of surface leaning, co-axis of the elements, parallelism, verticalism, etc. In fig. 9. and 10. the installation structure of the roadheader sytem and the head tools is shown.

In the same way the installation structure is also done based on the example of the roadheader disks for processing of narrow infrastructural objects.





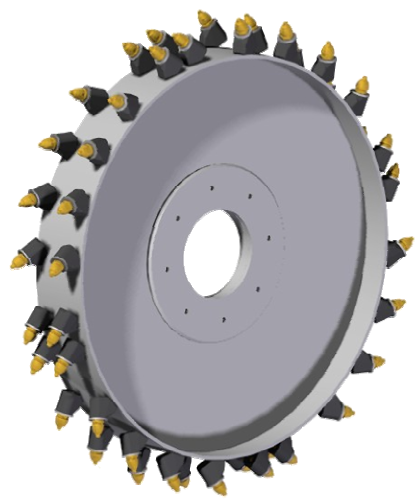


Fig. 4. Roadheader drums, roadheaders and roadheader disks

3. INSTALLATION PROCESSES

3.1 Installation axis and component mating surfaces

Base elements for installation structure modelling aremating surfaces. Mating surfaces are local elements on parts over which they mate with other parts. The examples of mating surfaces are shown in fig. 4. and 5.

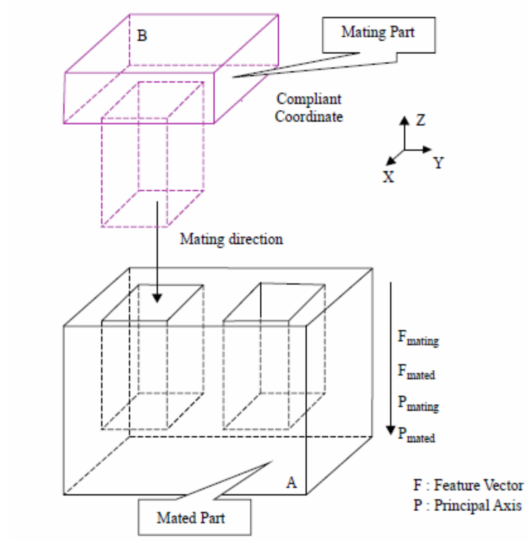


Fig. 5. Kinematics of two part installation

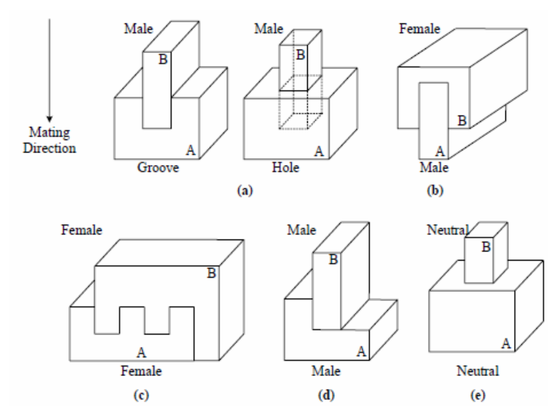


Fig. 6. Part types and surfaces

3.2 Installation at a local level

It comprises all steps or installation actions, including surface desriptions of parts, which are called mating surfaces. It also comprises all movements and directions that are included in any part of the installation process

The aspects of the installation at the local level, which can be useful in the installation-oriented data base, include:

- geometry of parts at a local level and their mating surfaces,
- the change of the shape or position of the features in relation to the nominal,
- time and costs for the installation process using different methods,
- factors that influence convenience and success of the installation, or part damage,
- needed tools and their accessibility,
- connections,
- rules or choice of the design for installation, including types of mating feature classifications and methods, rules or choice of part showing, orientation, accessibility of the parts.

3.3 Installation at a global level

The data model should at least include:

- which parts are mated with other, and with which features,
- which installations features are designed as the bearers of dimansional limitations,
- which parts are in which sub-assemblies and under which conditions,
- identification of the features suitable for usage as basic points, or that were marked as basic or measure points,
- which parts are in which product variants,
- where the parts and sub-assemblies are made and who they are made by (distributed production).

At the global level, roadheader installation structure designing is done using the 'Bottom-up' approach, in which the installation structure as the highest level of the hierarchical structure is acquired by connecting the components. The parts are mated using the mating features, by establishing the right connection between the surfaces. [6]

Roadheader tools in infrastructual object processing represent products with complex installation structure whose individual components are produced by a lot of small and medium companies using the principle of distributed production. The definition of suppliers/providers of individual installation components using the principle of distributed production is something that demands complex product structures analysis and coding with the aim of generation, and then joining the components with the installation structure. The wish is to form order coding system of CAD operations in installation structures based on the general principles, which should be the basis for the introduction of the distributed production of the roadheaders for infrastructural objects processing.

4. CONCLUSION

The development of complex products like roadheader tools is based on the installation product structure design (CAD), then the installation operations order in the CAM with an aim to generate distributed support in the component production.

5. LITERATURE

[1] Babic,A., Pljakic,M., Ilic,N., Petrovic,A., Povezivanje procesa projektovanja proizvoda u CAD-u sa mntažnim operacijama u CAM-u na primeru glodačkih glava, Savetovanje Proizvodnog Mašinstva, str. 147-150, Beograd, Mašinski fakultet Beograd, Beograd, Jun 2009.,

[2] Babić, A., Ilić, N., *Savremen koncept projektovanja glodačkih glava u rudarstvu i izradi profila tunela*, 31 Savetovanje Proizvodnog Mašinstva, str. 114-120, Kragujevac, Mašinski fakultet Kragujevac, Kragujevac, Septembar 2006.,

[3] Babić, A., Petrović A., *Sistem analiza sistema alata i mašina za obradu infrastrukturnih objekata*, Časopis Instituta IMK „14. oktobar" Kruševac, broj 22-23, str. 169-175, April 2005.

[4] Babić, A., Petrović, A., Ilić, N., Pršić, D., *Integracija CAD/CAM u projektovanju putnih glodačkih glava,* SPMS08, 501-504, Novi Sad, FTN, Novi Sad, Septembar 2008.

[5] Babić, A., *Tehnologija montaže*, udžbenik MFK,Kraljevo, 2005.

[6] H. Copur, L. Ozdemir, J. Rostami: Roadheader applications in mining and tunneling industries, Earth Mechanics Institute, Colorado school of mines, Golden, Colorado, 80401

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ADVANTAGES OF COMBINING RAPID PROTOTYPING AND RAPID TOOLING TECHNOLOGIES IN PROTOTYPE PRODUCTION

Abstract: *During the new product development, the production of several prototypes and test products is often necessary. These models can be used in design verification procedures, testing and customer feedback surveys. Various technologies collectively known as Rapid Prototyping (RP) have been developed in order to replace classical prototyping and modelling technologies. Continuous development and evolvement of RP technologies has enabled parallel development of so-called Rapid Tooling (RT) technologies. The following paper presents the advantages of combining RP and RT technologies in the production of prototypes. Recently, a common term Rapid Manufacturing (RM) has been established to include both RP and RT technologies. These technologies can considerably shorten the design-to-production cycle, and promise to revolutionize many traditional manufacturing procedures in the future.*
Key words: *Rapid manufacturing, Rapid prototyping, Rapid tooling, Silicon rubber moulding*

1. INTRODUCTION

In production of series of prototypes or test parts, the shortest possible manufacturing time is often the most important aspect to be considered. However, the manufacturing cost cannot be completely neglected. With a wide array of various rapid manufacturing technologies available [1], choosing the optimal one can be somewhat difficult. Initially, RP technologies were mostly used for design evaluation. In these cases, the material of the prototype was not very important and the whole prototype series usually consisted of just few parts. For functional testing, usually somewhat larger series is required and mechanical properties of the prototypes should be as close to the final production parts as possible. Often the implementation of a single RM technology in a small prototype series production does not yield satisfactory results and the optimal time/cost relation can only be achieved by combining several different technologies [2]. The following paper presents the advantages of combining PolyJet™ Rapid Prototyping (RP) technology and Silicone Rubber Moulding (SRM) Rapid Tooling (RT) technology in a production of a series of forty antenna housing prototypes. Not only the optimal combination yielded significant reduction of production time, but also resulted in lower costs of manufacturing.

2. THE PROTOTYPE

The basis for implementing RM technologies is part's three-dimensional CAD model. The antenna housing consisted of two different parts, the top cover and the backside connector plate (Figure 1). The backside was separated from the rest of the housing, because various different layouts of the connectors were to be tested with the prototype series. The whole series consisted of forty housings and the customer insisted on a shortest manufacturing time possible. While forty parts is not a large quantity when considering conventional industrial series, it is however somewhat larger than normal prototyping series. Usually, this quantity is produced by RT technology. A single prototype is made by a RP machine and later used as a pattern for a rapid mould production. This mould is then used for manufacturing of the whole series.

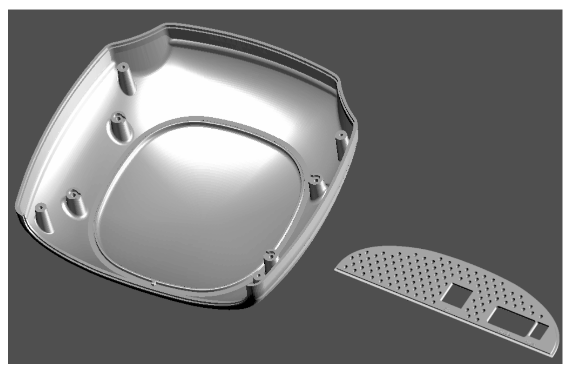


Fig.1. Two components of the prototype

Another advantage of using RT in prototype production is the possibility to "replicate" the RP pattern with the material that can more closely simulate properties of the material that will be used to manufacture the final products. This enables at least some partial functional testing that is often a necessary part of design cycle prior to serial production.

3. RAPID MANUFACTURING TECHNOLOGIES

3.1 PolyJet™ Rapid Prototyping technology

PolyJet is a three-dimensional printing technology. Building is done by layers of 16µm [3]. The printing head jets the liquid photopolymer on the work-tray. Solid object is made by polymerization under the influence of the UV light (Figure 2). Due to being one of the latest RP technologies that were available on the market, PolyJet is considered to be a good compromise between accuracy, achievable details, manufacturing speed and surface quality [4] of the finished parts. Also, mechanical properties of parts are comparable to the injection moulded parts. Therefore, PolyJet build parts can also be used for functional testing, making this technology a possible alternative to RT technologies for the project presented in this paper.

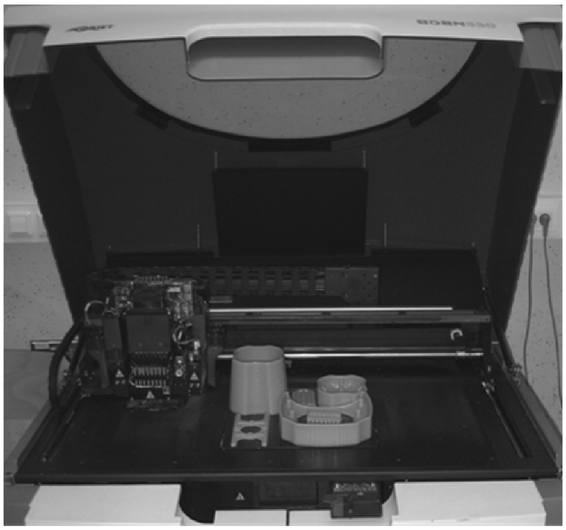


Fig.2. EDEN330™ three-dimensional printer is building objects by PolyJet™ RP technology

3.2 SRM Rapid Tooling technology

Silicone rubber moulding is a Rapid Tooling technology. All RT technologies are based on producing the mould with a pattern that is usually produced by some RP technology [5]. Alternatively, patterns can also be obtained by some other conventional technology. The pattern (in our case made by PolyJet™) is poured over by a silicone rubber. When the rubber vulcanizes the mould is cut along the parting plane. This mould is then used for vacuum casting of two component resins in order to reproduce the initial pattern. (Figure 3).

One of the main limitations of SRM technology is that the silicone mould can rather quickly become to worn out to produce quality complex parts [6]. How many good parts can be demoulded before the mould becomes unusable is hard to predict. This number depends largely on the part geometrical complexity and also on how properly is the mould treated and maintained during the manufacturing. Based on the previous experience it was predicted that in presented case, a silicone mould would last for approximately between twenty to thirty parts. This presumption was later confirmed during actual manufacturing phase.

So in order to produce the required quantity of forty prototypes by SRM two moulds had to be produced (two for each component of the prototype). This fact does not influence the predicted time of the series manufacturing because another mould can be produced in the time period when the first mould is already in use. However, costs of production are affected. Important fact is that the RP manufactured pattern that was used for producing the first mould can be reused also for the second mould. Therefore, the cost increase due to double mould production only includes material and manpower cost of manufacturing. This increase is clearly presented by spikes at the twenty part mark on all cost related diagrams presented in this paper.

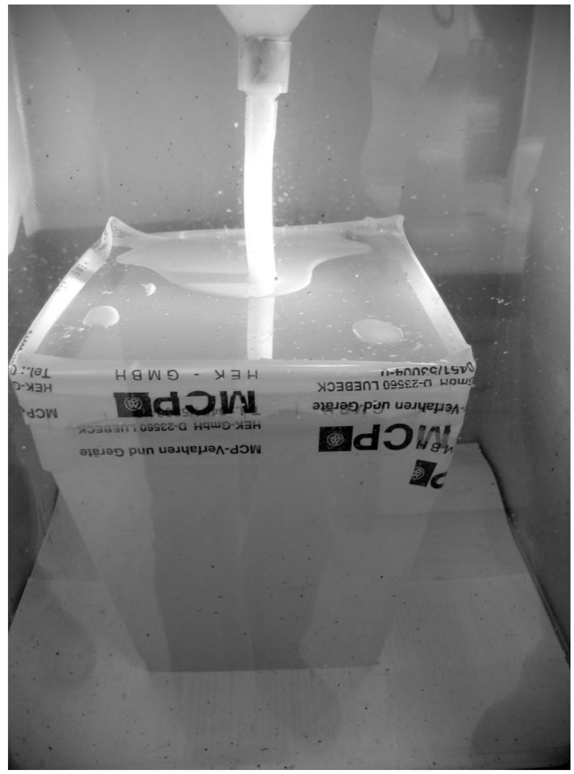


Fig. 3. Vacuum casting into SRM mould.

4. COMBINING TECHNOLOGIES

Due to both presented technologies being available and are able to produce the part with material properties that satisfied the customer's planned testing procedure, the time and costs became the only decision-making factors. Basically, because the time was much more important to the customer, at first, only the most time efficient variant was searched for. Later, additional cost analysis proved that the most time efficient is also the most cost efficient method.

Regardless which of both technologies would be chosen for the series manufacturing, at least a single prototype (of both components) had to be build by PolyJet™ RP procedure. If SRM was to be used later, the prototypes already built were to be used as silicone rubber mould patterns. The costs of producing the patters for SRM were calculated in the cost of a mould production (Figure 4 and 5).

Prior to being used as patterns for eventual SRM mould production both PolyJet prototypes were used in final design evaluation and fitting of the electric components provided by the customer. This proves how efficiently RP can be integrated during the design phase of the new product. It also signifies the importance of close cooperation between the customer and RP provider (as in presented in this case of outsourcing RP service) or between design and RP departments if this is carried out in-house.

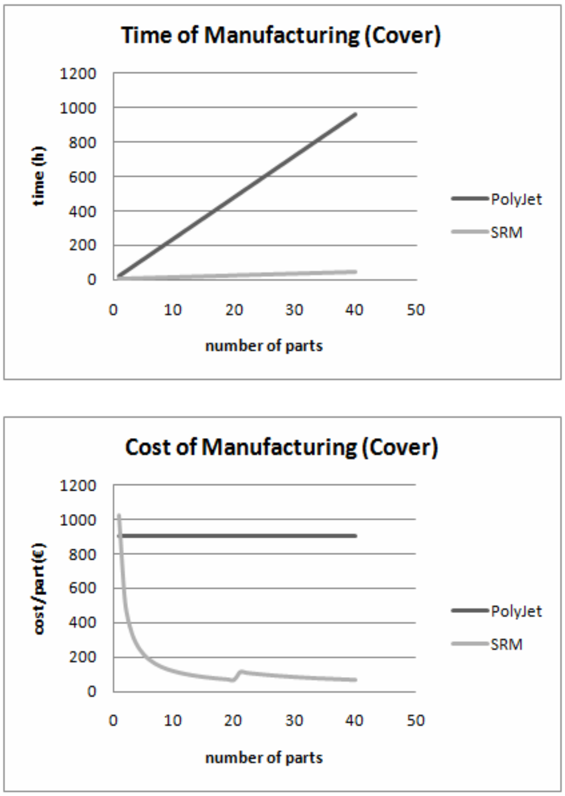


Fig.4. Time and costs of the cover prototype production (SRM and PolyJet™)

One of the main advantages of using rapid manufacturing technologies is that the geometrical complexity does not significantly influence the time and cost of manufacturing of a certain part. The most important factors regarding the cost and time are the parts volume and outer dimensions (Drstvensek 2004). As the Figure 2 shows the PolyJet™ rapid prototyping technology is totally inappropriate for manufacturing the cover prototype series in comparison to the SRM procedure. This is largely due to the parts large volume and height (Z axis dimension in the EDEN 330™ RP machine).

However, when considering the manufacturing of the back plate, the PolyJet™ technology yields better result in terms of time and costs as the SRM procedure (Figure 5). This is due to a low height of the plates. The overall size of the plate enabled the production of ten plates in individual EDEN330 machines runs. Consequently, the whole series would be produced in four machine runs. Alternatively, all forty plates could be produced in a single machine run placed in groups of tens on top of each other. However this alternative would result in significant increase of support material consumption. Due to EDEN330 machine having a relatively short warm-up time the first solution of four machine runs was accepted. This is presented by the steps of the PolyJet time of manufacturing diagram on figure 5. Nevertheless, the time of back plates manufacturing by PolyJet is still significantly shorter than the SRM alternative.

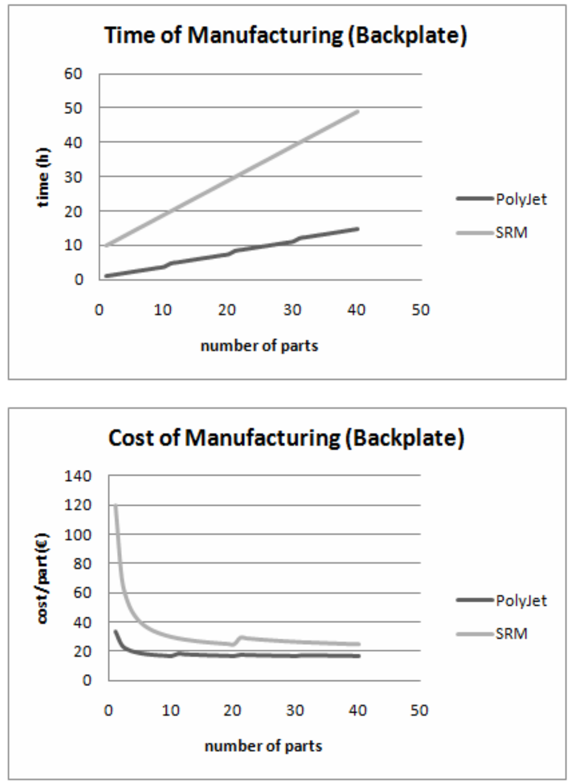


Fig.5. Time and costs of the back plate prototype production (SRM and PolyJet™)

Therefore it was decided; that the whole series of covers would be produced by SRM and the back connector plates by PolyJet™ (Figure 6). This decision had a very interesting side effect. By deciding that the whole series of back plates were to be produced by RP technology, the number of different connector layouts no longer influenced the time and cost of the production. In theory forty back plates, each with a different layout could be made in the same time (and at the same costs) as forty identical ones. This shows an enormous potential of rapid manufacturing in the future, when the individualization of products will play an ever increasing role.

On the other hand SRM is much less flexible considering the production of several variants. For example, in presented case, two variants of the housing could be made, by manufacturing one mould for each variant. But this would quickly lead to the cost increase, due to required additional pattern production. But still, when considering producing just three housings (all the same variant), RP pattern and SRM is cheaper solution then to produce all three by PolyJet alone (Figure 4).

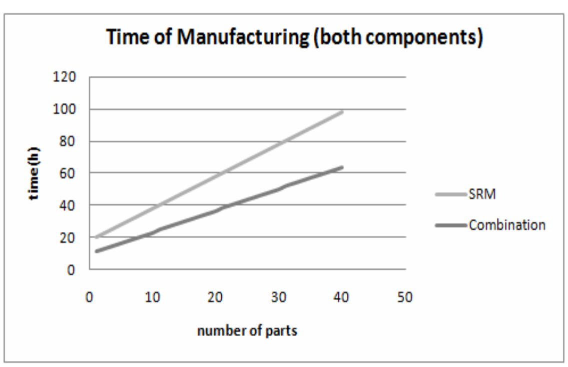
This show how in the future, the RM technologies will not only compete with conventional manufacturing technologies, but also among themselves. An optimal solution cannot be universally determined but largely depends on each individual case requirement. In the presented case the difference in both components vertical dimension resulted in different optimal solutions for their production.

Fig.6. Finished prototype made by combination of SRM (cover) and PolyJet™ (back plate) rapid manufacturing technologies

5. CONCLUSION

Different Rapid Prototyping technologies have already been in use for over twenty years. The advantages of using RP during design and product approval phase has already shown and is proved by continual increase of various machine installed each year worldwide. New technologies become available even widening the possibilities of different implementations in industrial environment.

This project has shown some of the beneficial effects of combining different rapid manufacturing technologies in production of a small prototype series. By using two different technologies the manufacturing time was shortened by 30% comparing to the time of producing everything just with SRM technology. Also, the costs were reduced by 10% (Figure 7).



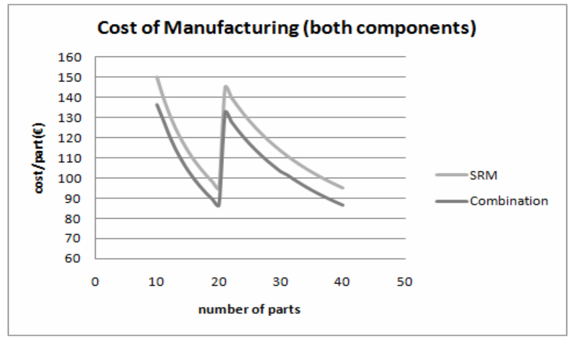


Fig.7. Time of manufacturing of the whole series

The most important aspect was the possibility of manufacturing forty different back plates in the same time/cost frame as forty identical ones. Practically, only four different connector layouts were made, but manufacturing them by PolyJet™ took 60% less time at 50% lesser cost as making them by SRM. This presents the potential of using rapid manufacturing technologies in production of individualized end-products in the future and the way this will revolutionize the traditional manufacturing procedures.

The future research should be focused on establishing a user-friendly evaluation and decision making model that would enable a potential customer not only the decision if Rapid Manufacturing is viable solution for his specific case, but also which of the many available RM, RP and RT technologies is his best alternative. These issues are a part of much wider problematic beyond the scope of research presented in this paper.

6. REFERENCES

[1] Drstvensek, I. (2004), Layered Technologies, Faculty of Mechanical Engineering, Maribor

[2] Rapiman rapid manufacturing homepage, available at: http://www.rapiman.net/ Accessed: 2009 9 9

[3] Object geometries homepage available at: http://www.2objet.com/ Accessed: 2009 9 22

[4] Brezocnik M, Kovacic M, Ficko M, Prediction of surface roughness with genetic programming, Journal of materials processing technology, Volume: 157 Special Issue: Sp. Iss. SI Pages: 28-36

[5] MTT Rapid tooling homepage available at: http://www.mtt-group.de/ Accessed: 2009 9 20

[6] T. Brajlih, I. Drstvensek, J. Balic, B. Katalinic, Casting of intake pipes by silicone rubber moulding, , Annals of DAAAM for 2005 & proceedings of the 16th International DAAAM symposium, University of Rijeka, 19-22nd October 2005, Opatija, Croatia. Vienna: DAAAM International, 2005

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Charbulova, M., Matusova, M., Caganova, D.

INTELLIGENT PRODUCTION SYSTEMS AND CLAMPING SYSTEMS FOR INTELLIGENT PRODUCION SYSTEMS

Abstract: *Within solving the project „Intelligent Assembling Cell“ in the Institute of Production Systems and Applied Mechanics this paper goes into concepts like production system, intelligent production system, clamping system. Further it addresses characteristics, division and requirements of clamping systems used in intelligent production systems.*
One of the project aims „Intelligent Assembly Cell“ is to replace the existing pneumatic clamp placed on the work board in the workplace of the Cartesian robot by a clamping device suitable for working in intelligent production systems.
Key words: *production system, flexible production system, intelligent production system, clamping system*

1. INTRODUCTION

Before mentioning clamping device for intelligent production systems it is necessary to clarify the terms: production system, flexible production system and intelligent production system. The mentioned terms are not clearly defined in any standard and this is a reason of their different interpretation in literature.

The paper also addresses the concept of clamping system what is actually one of subsystems of the production system. The clamping system itself consists of main and auxiliary structural elements, driving mechanism, control system including monitoring elements. Clamping systems determined for intelligent production systems have to satisfy special requirements.

2. TERM OF PRODUCTION SYSTEM

2.1 Production System

The term of production system is not clearly defined, in available literature there appear even several definitions of the term – production system.

For example the production system can be understood as units beginning from an individual machine and group of machines up to the whole plant including construction and assembly.

Another interpretation of the term: The production system can be defined as a group of production machines consisting of several subsystems the role of which is to execute a specified production process aimed at processing a semi-product into a required finished product.

Production system can be divided into two main subsystems:

- subsystem providing for the production process itself,
- subsystem providing for preparation and control of the production process.

Based on production process it is possible to divide the production system core into individual subsystems:

- control and information,
- technological,
- handling and transport,
- measurement and checking,
- storage.

2.2 Flexible Production System

Analogous to the term of production system also the term of flexible production system is not clearly defined and that´s why there are various interpretations in literature.

The flexible production system is represented by minimum three or more machines and is characterized by a lower degree of flexibility that means a closer assortment of components made in bigger lots (small-lot and lot production).

It also is stated that a groupment of several flexible production cells or flexible production cells and modules formed mostly by CNC machines and connected via one common transport and control system can be named a flexible production system.

Flexible production systems can be divided into three basic types:

- flexible production cells,
- flexible production systems,
- flexible production lines.

All above mentioned types of flexible production system are in principle of the same composition and consist of individual subsystems:

- control and information,
- technological,
- handling and transport,
- measurement and checking,
- storage.

2.3 Intelligent Production System

Artificial intelligence is explained as an attribute of technical systems (it can be talked about machine intelligence). Artificial intelligence is an attribute of the system artificially created by a human, characterized by an ability to distinguish things, phenomena and situations, analyze relations between them and create so an internal world model where these systems exist.

Characterization of artificial intelligence enables to determine explicitly and appoint partial theoretical tasks falling withing artificial intelligence. Artificial, the so called machine intelligence includes tasks like recognition and processing of visual information or language, automatic planning, solving of tasks by consideration, adaptation and learning, expert systems, communication with computer in natural language.

Intelligent system is a system with intelligence that enables it to know and understand reasons of changes, utilize these information for learning and adapt to changed conditions.

Intelligent systems with machine intelligence include systems able:

- to learn from data and acquire knowledge from data,
- store acquired knowledge, and
- make use of acquired knowledge.

Intelligent production system can be regarded as the highest development level of flexible production systems which must be equipped with means and methods giving a certain intelligence degree to these subsystems.

Or it is stated that the intelligent production system can be defined as a system able to respond to various situations occurring in production that means change in shape of the component being made, change in dimensions, sudden transfer to another type of product etc. The specific reaction can be reached by means and elements of machine intelligence that should be contained in individual subsystems of the intelligent production system.

Ability to process the primary information entering the system by means of sensors or intelligent sensory elements is an attribute of production monitoring systems.

Monitoring is an integral part of today´s production systems, the so called systems of new generation, intelligent production systems.

3. CLAMPING SYSTEMS FOR INTELLIGENT PRODUCTION SYSTEMS

Clamping system is one of production system subsystems. Having explained terms of production system, flexible production system and intelligent production system it can be said that clamping system for intelligent production systems must serve as a classical clamp and in addition it must be equipped by a control system including monitoring elements and drives.

Clamping system consists of:

- main elements (clamp body, moving parts, grip etc.),
- auxiliary structural elements (screws, pins, stops etc.),
- driving mechanism (e.g. pneumatic),
- control system including monitoring elements (various sensors).

Generally, clamps have to satisfy following functions:

- position the workpiece,
- fix the workpiece taking regard to action of forces and moments during production process.

Intelligent clamps must provide for following functions:

- check presence of grip in case of replaceable grip,
- check grip position to be able to insert the workpiece,
- position the workpiece,
- check presence of workpiece,
- fix the workpiece with regard to action of forces and moments during production process,
- check clamping of workpiece, value of clamping strength,
- self-diagnose driving system and in case of need to report the condition of the clamping system to the superior control system.

4. FLEXIBLE PRODUCTION CELL

In the Institute of Production Systems and Applied Mechanics – Department of Technological Equipment and Systems there is a flexible production cell (Fig. 1.) which consists of 2 main subsystems:

- 3-axial portal SMC robot,
- shelf stacking machine.

Fig. 1. Present status of flexible production cell in UVSM

4.1 3-axial portal SMC robot

The kinematic chain of the 3-axial portal SMC robot consists of translational kinematical couples with a motion possibility in axes X,Y,Z. This arrangement of kinematical couples enables maximum utilization of working place and positioning is relatively precise. Bad access to individual components is a disadvantage of this system.

The robot´s working place is shaped like a block with dimensions 1000x1000x300mm. The supporting frame and four legs are made of dural profiles. The supporting frame includes a grooved height-adjustable working board. Grooves in the working board serve for fixing the stand of tools for automatic tool replacement, tool magazine, rotary unit, pneumatic clamp, etc. The robot´s load capacity is 10 kgs.

3-axial portal SMC robot consists of (fig. 2):

- robot driving mechanism,
- robot control,
- stand of tools for automatic tool replacement,
- tool magazine,
- rotary unit,
- pneumatic clamp,
- finger magazine,
- AHC unit (AHC – system for automatic finger replacement).

Fig. 2. SMC robot

4.2 Shelf stacking machine

The shelf stacking machine is placed on the right robot side. Its frame is made of dural profiles. The pallets made of thick plexiglass are placed on legs in the shelf stacking machine. Capacity of the shelf stacking machine is 13 pallets of 250x250mm with maximum weight of 3 kgs. Components exchange between the shelf stacking machine and the robot is provided by a rotary unit – a swivelling table. Removal of pallets from the stacking machine to the swivelling table is done by means of a travelling linear pneumatic manipulator.

Shelf stacking machine consists of (fig. 3):

- shelf,
- mobile linear pneumatic manipulator.

Fig. 3. Shelf stacking machine

Pneumatic clamp

Pneumatic clamp (Fig. 4.) is placed on the work board in the workplace of the Cartesian robot and serves for clamping of components. Grip drive of the clamp is ensured by means of linear double-acting rolls. Grip movement is synchronized through the geared transmission. At present this clamp is not equipped with means and elements of machine intelligence; well it doesn´t meet the basic requirement of clamps determined for intelligent production systems.

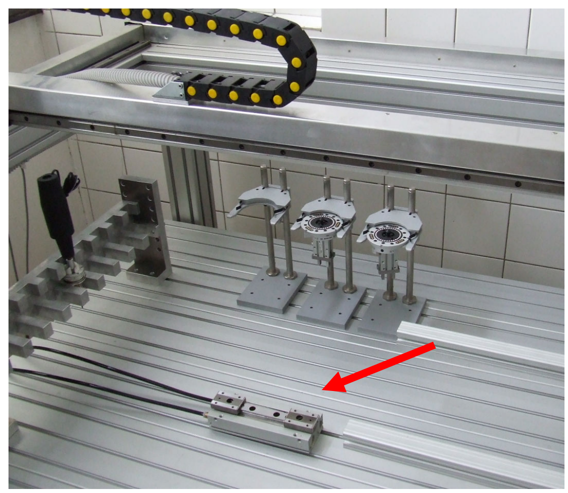

Fig. 4. Present status of pneumatic clamp in the flexible production cell

5. CONCLUSION

One of the project goals „Intelligent Assembly Cell“ is to replace the existing pneumatic clamp by a clamping device suitable for working in intelligent production systems. This objective will be achieved by sensory equipment of the mentioned clamp as well as other parts of the flexible production cell. Control of both the flexible production cell and clamp will be able to receive process information and properly respond to stimulations from all system sensors.

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6. REFERENCES

[1] Danišová, Nina: *Application of intelligent manufacturing system in the flexible assembly cell.* In: Annals of Faculty of Engineering Hunedoara - Journal of Engineering. - ISSN 1584-2673. - Tom V, Fasc 3 (2007), pp. 41-45

[2] Horváth, Štefan - Velíšek, Karol - Danišová, Nina: *Intelligent assembling systems "Machine Design".* In: Machine Design: On the occasion of 48th anniversary of the Faculty of Technical Sciences: 1960-2008. - Novi Sad: University of Novi Sad, 2008. - ISBN 978-86-7892-105-6., pp. 283-286

[3] Košťál, Peter - Velíšek, Karol - Zvolenský, Radovan: *Intelligent Clamping Fixture in General.* In: Lecture Notes in Computer Science. - ISSN 0302-9743. - Vol. 5315: Intelligent Robotics and Applications. First International Conference, ICIRA 2008, Wuhan, China, October 15-17, 2008. Part II (2008). - ISBN 978-3-540-88516-0., pp. 459-465

[4] Košťál, Peter - Velíšek, Karol: *Workpiece clamping by intelligent clamping systems.* - ISI Proceedings. In: Annals of DAAAM and Proceedings of DAAAM Symposium. - ISSN 1726-9679. - Vol. 16, No. 1 Annals of DAAAM for 2005 & Proceedings of the 16th International DAAAM Symposium "Intelligent Manufacturing & Automation: Focus on Young Researches and Scientists": 19-22nd October 2005, Opatija, Croatia (2005). - ISBN 3-901509-46-1. - ISBN 978-3-901509-46-9., pp. 197-198

[5] Kuric, Ivan a kol: *Počítačom podporované systémy v strojárstve.* Žilina: EDIS, 2003. - ISBN 80-7100-948-2.

[6] Velíšek, Karol - Javorová, Angela - Košťál, Peter: *Flexible assembly and manufacturing cell.* In: Academic Journal of Manufacturing Engineering. - ISSN 1583-7904. - Vol. 5, No. 2 (2007), pp. 141-144

[7] Velíšek, Karol - Javorová, Angela - Zvolenský, Radovan - Danišová, Nina - Košťál, Peter: *Multifunctional manufacturing and assembly system.* In: Development of Mechanical Engineering as a Tool for Enterprise Logistics Progress: Science Report Project CII-PL-0033-01-0506. - Poznaň: University of Technology, 2006. - ISBN 83-89873-28-1., pp. 135-158

[8] Velíšek, Karol – Katalinič, Branko: Výrobné systémy I. Bratislava: STU, 2004. – ISBN 80-227-2009-7.

[9] Velíšek, Karol - Košťál, Peter - Švrček, Daniel: *Flexible manufacturing cell and material flow planning.* In: Comec 2008: V.Conferencia Científica International de Ingeniería Mecánica. Del 4 al 6 de Noviembre de 2008, Cuba. - Santa Clara: Facultad de Ingeniería Mecánica Universidad Central "Marta Abreu" de Las Villas, 2008. - ISBN 978-959-250-404-2

[10] Velíšek, Karol - Košťál, Peter - Zvolenský, Radovan: *Clamping Fixtures for Intelligent Cell Manufacturing.* In: Lecture Notes in Computer Science. - ISSN 0302-9743. - Vol. 5315: Intelligent Robotics and Applications. First International Conference, ICIRA 2008, Wuhan, China, October 15-17, 2008. Part II (2008). - ISBN 978-3-540-88516-0., pp. 966-972

[11] Košťál, Peter - Hrušková, Erika - Velíšek, Karol: *Clamping fixture for flexible manufacturing cell.* - článok je uvedený: Proceedings of the Manufacturing Science. Sibiu: Editura Universitatii "Lucian Blaga", 2007. ISSN 1843-2522. MSE 2007 Proceedings of the 3rd International Conference on Manufacturing Science and Education. European Traditions and Influences in Engineering Creation. Sibiu, Romania 12th-14th July 2007, s. 81-82. In: Academic Journal of Manufacturing Engineering. - ISSN 1583-7904. - Vol. 5, No. 2 (2007), pp. 61-64

[12] Mudriková, Andrea - Košťál, Peter - Velíšek, Karol: *Material and information flow in flexible manufacturing cell.* - registrovaný v ISI Proceedings. In: Annals of DAAAM and Proceedings of DAAAM Symposium. - ISSN 1726-9679. - Vol. 18, No.1. Annals of DAAAM for 2007 & Proceedings of the 18th International DAAAM Symposium "Intelligent Manufacturing & Automation: Focus on Creativity, Responsibility, and Ethics of Engineers": Croatia, Zadar 24-27th October 2007 (2007). - Viedeň: DAAAM International Vienna. - ISBN 3-901509-58-5, pp. 485-486

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ARCHITECTURE OF INFORMATION MODEL FOR REENGINEERING OF TECHNOLOGICAL PROCESSES FOR SMALL ENTERPRISES

Abstract: *Constant enlargement of market demands from aspect of assortment and quality of products, lowering of costs and delivery time are main characteristics of modern business. Answer to the following question: "How the small enterprise to answer to these demands?" has been searched in reengineering and application of information technologies. In this manner, "soft" engineering was originally defined and software solution was applied, such as CASE tool that for designers of technological process enables development and reengineering of technological processes. Architecture of software solution for model of reengineering of technological process for small enterprises is given in this paper.*

Key words: *reengineering , tehnological processes, information model, data bases*

1. INTRODUCTION

Software solution model of technological re-engineering processes, as a CA system meets the following basic principles as follows:

The system should assist - helps the designer, not to replace him. The decision of the designer, his intuitivity and creativity are still weak side of a computer.

The system should allow for appropriate collaboration and distribution. Designing as complex process, today includes many elements that cooperate in different geographic locations and use information resources that are also located differently.

The system should be an open architecture type. Components of the system should be changed over time, through the different modification, replacement, expansion and deletion, depending on the needs and new scientific achievements.

The system must be a tool, not a solution. The system must be developed as a set of tools, not as a facilitator that could prejudice the decision on the problem.

The system must have a high degree of internal presentation. With a high degree of internal presentation of object from the real world that defines the real problem, the system forms the basis for interaction between users and systems and also a certain level of intelligence that can be implemented in its components.

The system should have implemented knowledge. Knowledge can be described as the experience derived from previous events or phenomena. Mentioned experience can be given in the form of rules, detailed analysis, standards and ordinary description of objects and systems that can serve as a prototype.

The system must have the appropriate user interface. A high degree of interaction between the designer and the various components of a CA system is of great importance.

2. ARCHITECTURE OF SOFTWARE SOLUTION’S MODEL IN REENGINEERING TECHNOLOGICAL PROCESSES

The basic architecture of software solution’s model in re-engineering technological processes, shown in Figure 1, is defined in relation to the functional requirements of the system, i.e. what the system should provide in terms of services to their customers. From the angle of system observing, software solution of re-engineering technological process should provide:

- the reduction of manual work in the technological design process that is a burden on the designers and engineers-technologists;
- improvement of existing technological processes through the use of available information on machinery, tools, accessories, workability, etc..;
- creation of technological processes of the same validity and quality; systematization and electronic documentation of technological methods, ensuring transfer of knowledge and experience of experienced designers-engineers;
- reduction of time and lower cost design.

System requirements are implemented through functional requirements, which should enable the availability of data / information: technological databases related to cutting and measuring tools, machine tools, accessories, SHP, modes of processing, materials and norms for support, and additional preliminary-final time, the target model of processing object and technological model, creating and defining the technological process and its rational variant, the parameters for the valuable analysis of development time, productivity and cost of processing variations technological process variations, as well as output documents such as operating list / map, the order of operations list, i.e. technological development list, documents that allow Pareto Analysis of time or the technological process costs through operations.

Logical data modeling is an activity that opens the "black box" which was been unknown to future users of engineers, designers-technologists. Based on the description of technological process as a real system, entities or objects of interest for the observation and their relationships are identified ,and the first next level in information modeling, semantic data model that represents a very important framework for the logical design is defined. ER (Entity Relationship) model is the one that carries the epithet of semantic model. Figure 2 shows the ER diagram of data model in re-engineering technological processes. The diagram entity attributes are omitted, due to visibility, and they are shown in logical database schema.

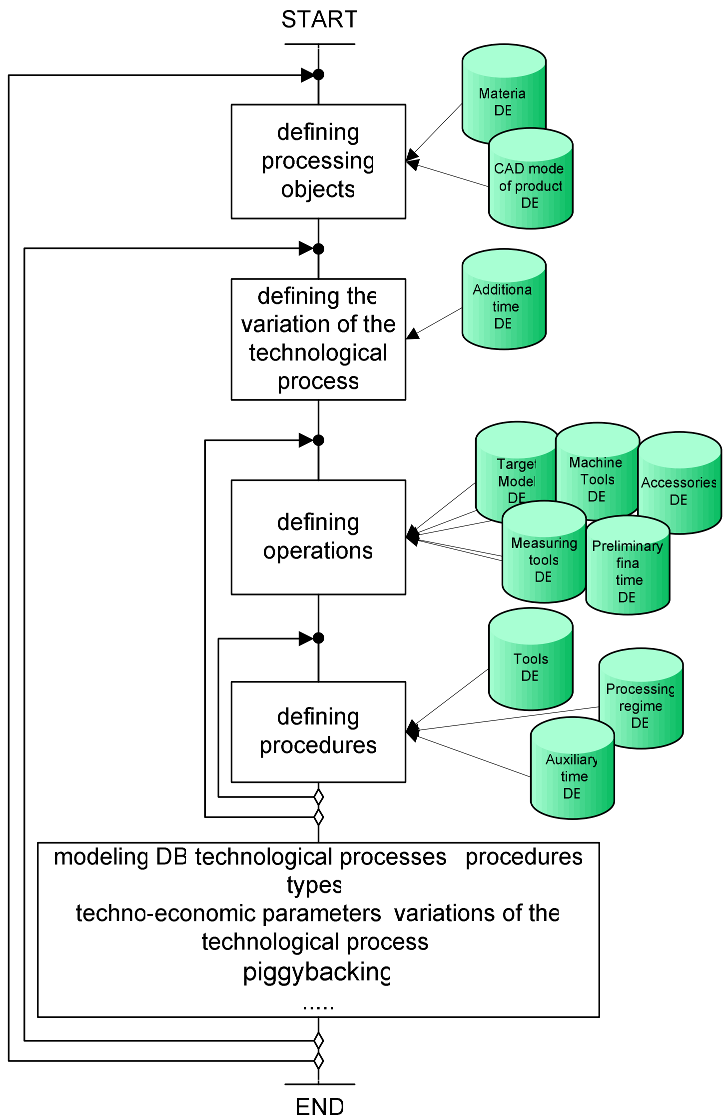

Figure 1. *Basic architecture of software solution's model in re-engineering TP*

The next level in information modeling is the translation of ER diagrams into logical data model. On the basis of ER diagrams, shown in Figure 2, a logical data model of re-engineering technological processes is defined, shown in Figure 3, which represents the conceptual database schema. This model is in the same time an analytic type because it provides information used for analysis. The fact is that using this model, the technological process can be observed from several aspects and dimensions, such as variety, time of production, productivity, costs of processing, make this model a multidimensional and database analytical.

The logical database model considers the following types of databases: **dimensional** (●) such as databases *Technological process and Operation,* and **fact databases** (●●) - remaining databases.

Fact databases, shown in ● color, were created by translating multiple to multiple relations (n: m) from ER diagram. Analytical (dimensional) databases do not meet the requirement of data consistency. They were obtained with denormalization. Also, analytical processes of data observing can be many times faster Specifically in this model, attributes that make it possible are as follows:

Specifically in this model, attributes that make it possible are: a variant of the technological process, the main processing time, support time, extra time, a preliminary final time, total processing time, the cost of tools, machinery costs, costs of SHP, a stationery costs, labor costs, productivity; all that by operation and by technological process.

Based on the conceptual scheme of the

database, physical database modeling follows and its integration into specific database menagment system (DBMS–*DataBase Management System*), which have relevant importance in the development of applications and selection of ways to access data.

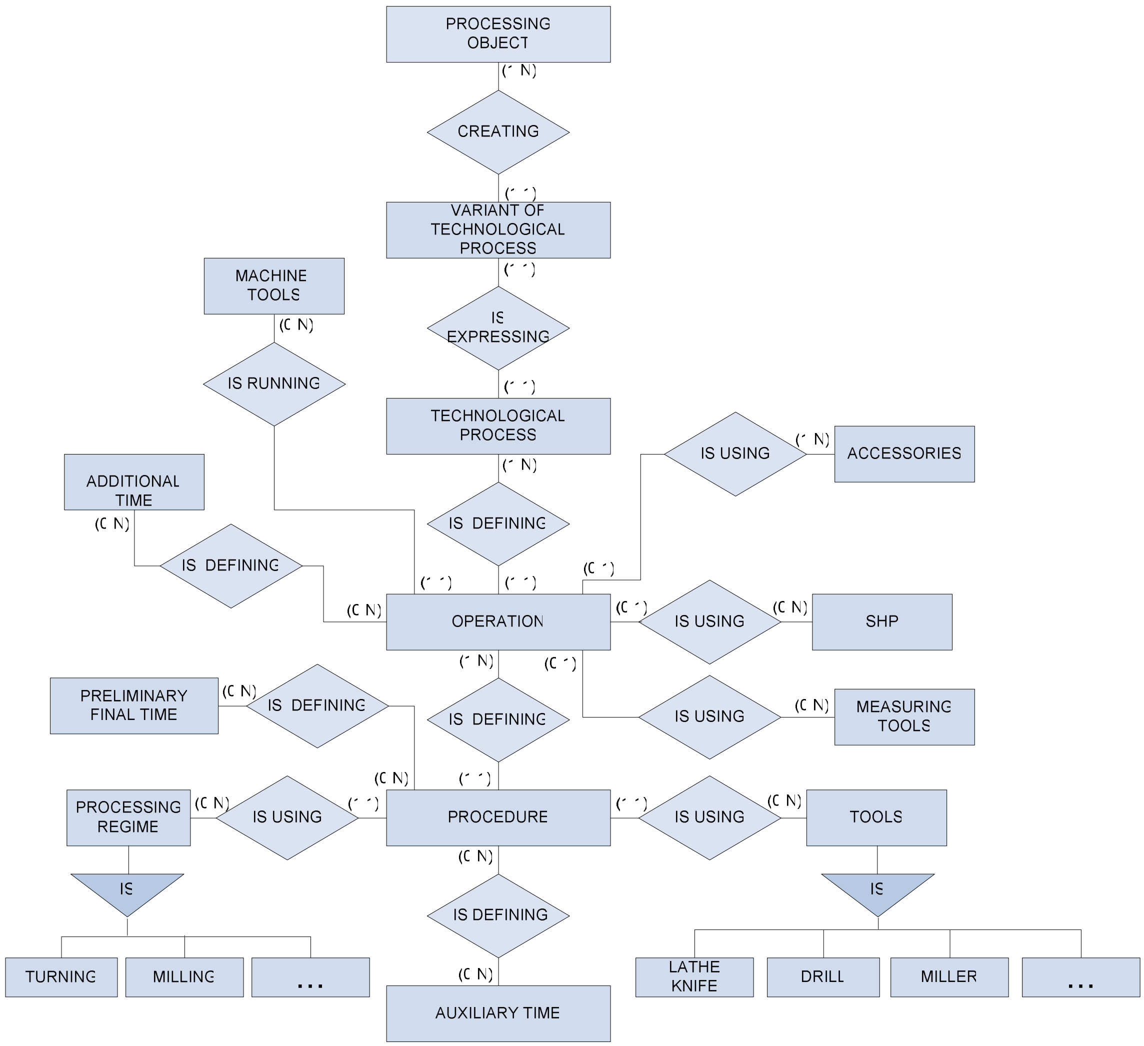

Figure 2 *ER diagram of data model in re-engeneering TP*

There are many CASE (*Computer Aided Software Engineering*) tools to enable this, such as Erwin or DeZign for Databases (Datanamic Solutions Netherlands) in which the logical database model of re-engineering technological processes is made.

Software development environment is Microsoft's Visual Basic 2005 Express Edition. Databases are generated in MS SQL Server 2005, Express Edition. Both environments are Microsoft development tools, and provide a comfortable transition to the commercial versions of the same.

In the case of analytical applications that are not included in the OLAP (On Line Analytical Processing), Microsoft Excel can be used for importing dimensional database and selecting those columns that are needed for the graphical representation and analysis.

By some estimates at least 90 percent of business analysis today is done using Microsoft Excel, although Excel is a mathematical tool, not a tool for working with data.

This environment was selected for several reasons, some more important are: openness to different types of databases (DBMS); highly developed user interface; full compatibility with MS Windows operating system; a relatively easy applicable integration of all modern techniques such as Object Linking and Embedding, Dragging and Dropping; compact object-oriented code, and extremely easy portability of the software.

The integrity of displayed databases should enable the accuracy, correctness and consistency of data, and to identify problems of database protection from wrong changes (wrong input, operator and programmer errors, system failure). Security of data relates to the mechanism of protection against unauthorized use of data that is embedded in the DBMS.

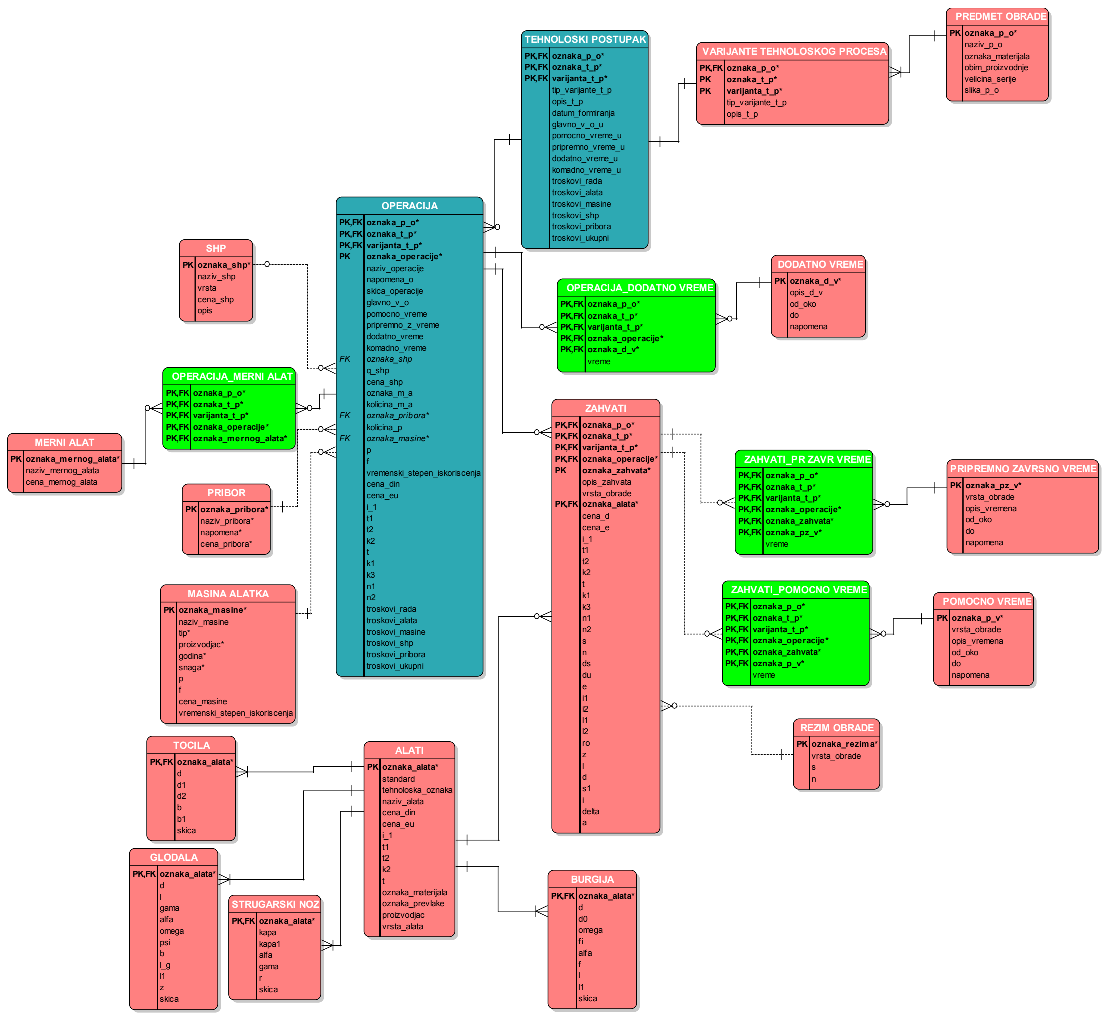

***Figure 3** Logical (conceptual) database model in reengineering TP*

Display of the architecture process focuses on the system implementation structure and takes into account requirements such as: performance, reliability, integrity, synchronization, system management. Display of user functions demonstrates and confirms the logical view, process and implementation reviews. User functions are implemented through the user interface. The user interface aims update and presentation of data from a previously defined databases and their transformation into information necessary to make timely and quality decisions.

3. CONCLUSION

Designed model provides opportunities for development and re-engineering. In order to implement re-engineering of a technological process, of course, it must be developed already. Thus developed technological process, with adding feature, is necessary to register in the database, which essentially is a physical job. However, if the thought process of designing and creating the technological process is joined to the adding function, then we can say that it is a technological process development. Reengineering allows changes to the level of improvement (defined as "soft" re-engineering) to the level of radical changes (defined as "hard" re-engineering).

4. REFERENCES

[1] Erić M., *Model reinženjeringa tehnoloških procesa malih preduzeća*, doktorska disertacija, Mašinski fakultet Kragujevac, 2007.

[2] Lazarević B., i dr., *Baze podataka*, FON, Beograd, 2003.

[3] Mitrović R., *Projektovanje tehnoloških procesa*, Naučna knjiga, Beograd, 1991.

[4] Riordan R., *Designing Effective Database Systems*, Addison-Wesley, 2005.

[5] Todić V., *Projektovanje tehnoloških procesa*, Fakultet tehničkih nauka, Novi Sad, 2004.

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IMPLEMENTATION CAD/CAE/CAM PROGRAM SYSTEM IN THE PROCESS DESIGNING AND PRODUCING REVISION HIP JOINT PROSTHESIS

Abstract *Requirements that will be placed in the modern medicine include, among other things, implementation the most sophisticated engineering methods in the process of medical treatment of patients. In orthopedics, as well as parts of medicine, that means development hip joint prosthesis, custom made with maximum time use. Having this in mind, before mechanical engineering is opening a new area which includes implementation multidisciplinary engineering knowledge with the complex CAD/CEA/CAM program system.*

Hip joint is one of the most important joint in locomotion system of humans being. Any pathological change in hip joint, disable normal functioning of hip joint. Application of implants hip joint prosthesis, enable damaged or ill part of the human body to be replaced in fully functional and esthetical form.

In this presentation is described implementation methodology of computer modeling, analysis and designing technology drafting body hip joint prosthesis, by applying modern CAD/CAE/CAM program system.

Keywords: *Revision hip joint prosthesis, CAD/CAE/CAM programming systems,*

1. INTRODUCTION

In modern medicine today, there are big requirements for establishing functions of human organs which are damaged by degenerative changes, diseases or injuries.

This is especially refers to the problems related to body extremities, how to human joint system and the need for their replacement with prosthesis, as well as for the full exchange of lost parts of human extremities implanting artificial limb.

Contemporary Research in this area is aimed at training [1]:

- Surgery technical procedure of implantation hip joint prosthesis and preventive disclosure of clinical change that preceding in breaking the stem of hip joint prosthesis.
- Biocompatible materials which are suitable for the construction implants.
- Methods designing and producing hip joint prosthesis in order to adjustments concrete patient and increase his exploitation time.

Based on clinical examination, average duration time of hip joint prosthesis is 12.5 -15 years. This is confirmed that patient with implanted hip joint prosthesis is able to make about 3000 steps per day, while healthy man for carrying out normal activities during the day make a 8000-10000 steps. In this way there is a wish to connect dynamic strength of material from which was drafted hip joint prosthesis with average daily activities of man with hip joint prosthesis.

Total numbers of implanted hip joint prosthesis are show in table T.1.1.

USA	1982.: 75.000	2005.: 240.000	2030.: 570.000
West Europe	1978.: 30.000		
Institute Banjica Belgrade	1974.: 800	2007.: 1.700	2008.: 2.000

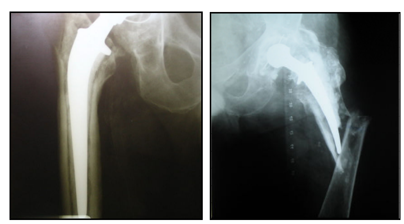
Table T.1. Total number of implanted hip joint prosthesis.

The reason for such an upward trend number of implanted hip joint prosthesis, as result of improved communication on the route from surgeon-patient, can be explain by:

- Improved clinical diagnostics
- Improved surgeon conditions
- Improved surgeon technical system
- Improved education surgeons-orthopedics
- Improved number of orthopedic surgeons
- Extended duration of human life, and serve good health care for elderly people

In Novi Sad and Ada is in the period since 1987 to 2005 are produced about 3850 endoprosthesis of hip joint (cemented endoprosthesis).

A large number of implanted hip joint prostheses include certain needs for large number of revision in the next time period.



a) b)

Fig. 1. Situation shown is hip joint prosthesis that requires review.

a) Radiolucent line wider of 2mm loosens up hip joint prosthesis.

b) Break of the femur in the prosthesis zone

In this presentation, authors want to point out the methods that are used in medical practice for determine the volume of damaged bone structure which need to be replaced, as well as volume of space in which may incorporate certain implant.

2. DIMENSIONING OF THE STEM HIP JOINT PROSTHESIS

One most important characteristic, which should have in mind in defining forms and the dimensions hip joint prosthesis, is a request to femoral component should take over and transfer full load on that part of skeletons.

In order to measure hip joint prosthesis successfully, it is taken into account elements of biomechanical load shifting, and morphology of human bone system, as biological space in which it is possible to incorporate hip joint prosthesis. Biological facilities for installing hip joint prosthesis for subsequent population can be defined in more ways:

- By RTG apparatus
- Scanner recording
- MRI.

2.1 RTG Recording

In this case to design puts based on shooting human body (skeleton) through RTG apparatus where the footage is analogue signal (figure 2 are shown RTG appliances and recording).

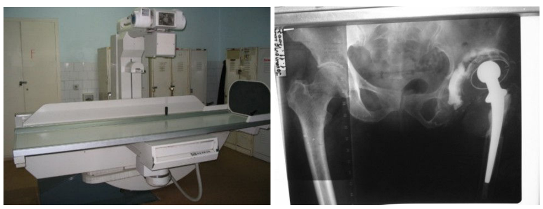
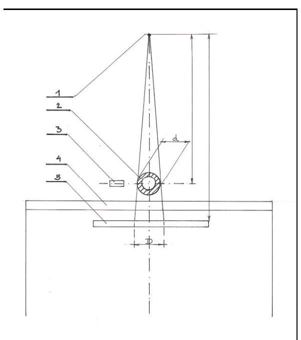


Fig. 2 RTG appliances and recording

In order to such obtained the footage could be used for the proper determination of dimensions of human bone system, it is done good preparation on determine good geometric parameters (figure 3.).



1 – Rtg head;
2 – Recording bone;
3 – Control bar with millimeter division
4 –Rtg table;
5 – Tape with Rtg movie

Fig.3. Geometric parameters Rtg recording

Based on image quality and mathematical relations $h_1 : h_2 = d : D$ could be set intervals bones that are shoots.

$$d = \frac{h_1 \cdot D}{h_2} \quad \text{where is:}$$

h_1 [mm] - height from the mid bones to RTG head
h_2 [mm] - height of RTG panel e do RTG head
d – Diameter bones that are shoots (actual size)
D - Diameter bones to RTG movie (enlarged size)

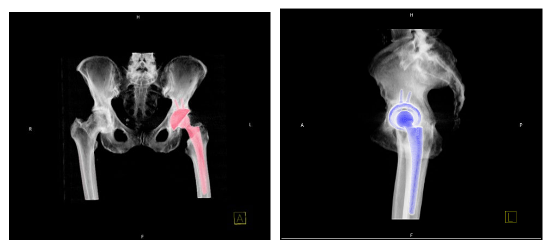
If value h2 = 1000 mm is constant, and for H1 = 800 mm, enlarged result RTG recording (D) is approximately 17-20%. The ratio can be determined by presenting the control bar with millimeter division. In this case, it is necessary take into account that the bar is placed in the middle of the bones length that being recorded

2.2. Scanner recording

Recording of the bone system using the scanner (Figure 4) will allow the formation frames in three plain:

Fig. 4. Scanner

- anterior-posterior (A-P, front view - Figure 5a),
- sagittal plane (view from the side, lateral – Figure 5b,
- and coronary (above)



a) b)

Fig.5. The footage in AP and sagittal plain (lateral)

The recording can be done and according to levels (Figure 6.), where the gap between the level can be chosen, allowing the detailed consideration of biological space in which can be incorporated implant. By scanning machines is a signal digital.

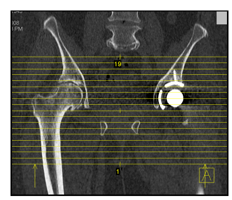


Fig.6. Recording on the levels in AP plain

2.3 MRI recording

Recording by MRI (Figure 7.), which also gives digital images, will allow the recording in three layers, according to levels, according to levels, where the gap between the level can be changed to the needs accordingly (Figure 8 a, b & c).

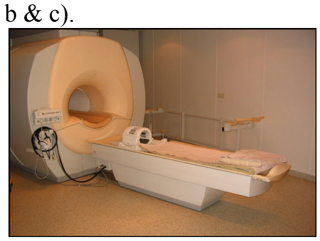
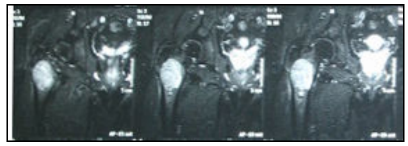
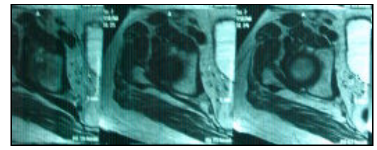


Fig. 7. MRI apparatus

a)



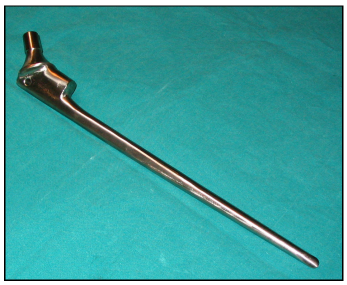
b)



c)

Fig. 8. Series frames by MRI in: a)AP plain, b)AP plain with contrast and c)coronary plain)

Digital Signal with Scanner recording or MRI will allow the better communication between the sick, and doctors. By viewing the bone system, it is possible to order exactly form and the size of majority area suitable for installing implant, hip joint prosthesis. This is especially suitable for producing special hip joint prosthesis by extent, like revision and tumor hip joint prosthesis (Figure 9.).



a) Revizion hip joint prosthesis custom made with extended kolar

b) Implanted hip joint prosthesis custom made with extended kolar

c) Revision hip joint endoprosthesis

d) Implanted hip joint prosthesis custom made

Fig. 9 Revision hip joint prosthesis

3. APPEAR COMPLICATIONS AT HIP JOINT PROSTHESIS

After implantation revision hip joint prosthesis could be some complications:

1. Early complications
   - infection
   - luksatia, mechanical complication
2. Late complications
   - loosening of prosthesis
   - brake of prosthesis, mechanical complications

Fig. 10. Luksatia hip joint prosthesis

Fig. 11. Implanted cement hip join prosthesis, loosened in proximal & distal part, and jammed in medial part with the biggest pressure and deformations, which has consequence in negative bone answer in medial part.

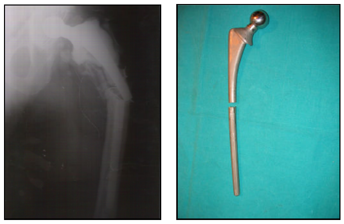


Fig. 12 Stem fracture revision hip joint prosthesis

An mechanical complications, fracture hip joint prosthesis are known in the case of very different types hip joint prosthesis which include: partial, total, revision cemented, non cemented, and hip joint prosthesis drafted by the extent. The frequency of this complication is from 0,23-0,67 with standard deviation from ±0,25. Fractures of the others implants are 11% by some other studies.

Fracture of implant is dramatic case how for patient – user of implant, as is for surgeon and implant producers.

Influential factors that affect this phenomenon are considered to be:

- Constructional solution hip join prosthesis
- Material from which is prosthesis made
- Structural mistakes in material structure
- Damaging implant trough mechanical treatment
- Damaging implant while implanting
- Operative technique
- Age of patient
- Body mass
- Body posture
- Level of activities
- Limitations in joint movement
- Health aspect of other hip joint
- Looseness of hip joint prosthesis

On the basis of clinical exam and RTG recording, it is possible to predict possible danger of fracture by fatigue, in case that is migrational, painful or loosen. These are potential reasons for review revision of hip joint prosthesis.

4. METODOLOGY DRAFTING HIP JOINT PROSTHESIS

In Orthopedics, as areas of medicine, are in the large extent encountered modern medical and engineering methods in the process designing and producing hip joint prosthesis. It comes in term of design and development of custom size hip joint prosthesis, as well as in cases when is necessary maximum degree of personification when the prosthesis expressed the need for concrete patient**.** Thus it is mechanical engineer encountered in the challenges drafting hip joint prosthesis of non-conventional in which fall under surgical steel, super alloy on the basis of cobalt, titanium est.

The design and manufacturing typically sized hip joint prosthesis is based on explorations of patients typical blueprint account. Then applying most sophisticated CAD/CAM program system and regarding the proofs administered machines starts the projecting and making of pattern for precision casting and forging prosthesis. In the second case, according to anthropology measures and the state diseases for the particular patient project special hip joint prosthesis. Prosthesis is drafted by applying the combination non-conventional methods manufacturing and numerically controlled multi axis machine tools. One of the most advantages implement contemporary software is a possibility analysis obtained hip joint prosthesis by simulating exploitation conditions and optimization their forms in order to extend their use.

On figure 13 are shown discretized model of the hip joint prosthesis for the software analysis and the simulation their making in the numeral machine tools.

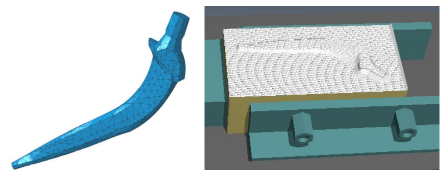


Fig. 13 Endoprosthesis CAD model and simulation of his manufacturing

6. CONCLUSIONS

As well as you can see from presentation, development of contemporary medicine is closely linked with the development engendering most sophisticated methods and means designing and producing products. It is especially steering committee level in orthopedic where the elements of human skeletons replaced with particular implants whose mechanical an physiological characteristics should as close as natural elements skeletons: bones and joints. Modern CAD/CAE/CAM software systems, the application materials new generations and integration medical diagnostic apparatuses with engineering methods present in the area reengineering can create opportunities for is a improving these hip joint prosthesis which today presented on market.

7. LITERATURA

[1] Grujić, J., Živković, A., Zeljković, M., Gatalo, R.: Računarsko modeliranje i izrada tumorske proteze zgloba kuka, Infoteh- Jahorina 2009

[2] Grujić, J.: Računarsko modeliranje i eksperimentalno ispitivanje proteze zgloba kuka, magistarski rad, Fakultet tehničkih nauka, Novi Sad, 2009.

[3] Winters, G., Nutt, M.: Stainless Steels for Medical and Surgical Applications, ASTM International, 2002

[4] Woolf, A.: Bone and Joint Futures, BMJ Books, ISBN: 0727915487, 2002

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AUTOMATED DESIGN OF ASSEMBLY SYSTEM WITH COMPUTER AIDED SYSTEM HELP

Abstract: *The paper deal about automated assembly manufacturing cell design. First part is about Methods and techniques used for assembly systems design. Next part describes specific CAD systems used for design process of our assembly cell. With help of this CAD toll we have design geometric disposition of all system elements by CATIA and also parts of control system by FluidSim. Whole design problematic was completed by process simulation model created in Witness environment.*
Key words: *Cell, design process, simulating model, computer aided design*

1. INTRODUCTION

New manufacturing culture is changing the demands to the projecting works and look to the assembly research. The development of design methods and techniques of assembly processes and system is very important and necessary. Systematic approach is needed by design of assembly processes and systems. Also others aspects are influencing to the design process. Aspects such as knowledge from other research disciplines, professional creativity, tactical and strategic decision and so on. All these aspects are coming from changing technical, technological, economical and social conditions.

2. METHODS AND TECHNIQUES USED FOR ASSEMBLY SYSTEMS DESIGN

Negative aspect of design process is, that analytic and synthetic culture is not developed on good level. In generating process of assembly processes and systems are usually creating old solutions. In these days there are many methods and techniques, which can be used for solving of problems related to the designing process. These methods allow optimalizing and innovating also the assembly problems.

From verification view was our positive experiences reached in these areas:

Area	Used instrument
Graphic design	CATIA
Design and simulation of automate control system	FluidSim
Manufacturing system simulation	Witness

Aspects as high quality, short innovation cycle and other projects attributes can be attained very hard without automation projecting what means without any application of informatics and software technologies. Introduces computer aided instruments were used by design process of automated assembly cell.

3. ANALYTICAL PRINCIPLE OF MODEL DESIGN AND SIMULATION OF ASSEMBLY CELL PRODUCT BASE

The philosophy of product base design can be realized by help of synthesis process. This way can be the philosophy developed through these ways:

- variants creation based to the:
  - building elements selection
  - building elements combination
  - selection of massive variant

- valuate accessability of solution following to the:
  - accessability range identification
  - simulating of functional activity
  - parametrical accessability decision

During the interpretation model solution process there is needed to fulfil basic conditions such as:

- to have output characteristics of element base
- to have building elements with known technical parameters
- to have technical and economical conditions of solution and realization
- to have knowledge base gull of similar solutions
- use for solution some computer aided system

By the designing process we outcome from element base of manufactured product. In assembly cell there will be assembled pneumatic linear, single acting actuators which are showed at the figure number 1.

The product consists of 5 parts. His structural piece list is showed at the figure number 2.

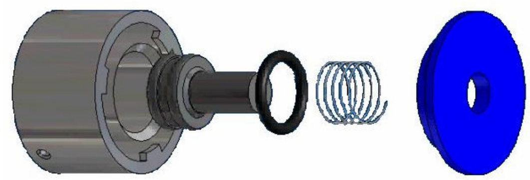


Fig. 1. The part assembled in assembly cell

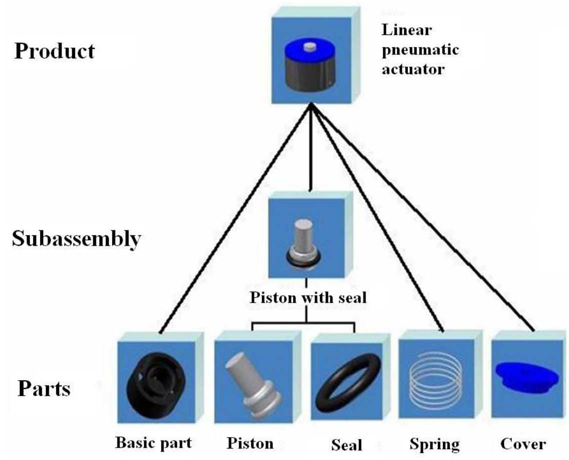


Fig. 2. Assembled product piece list

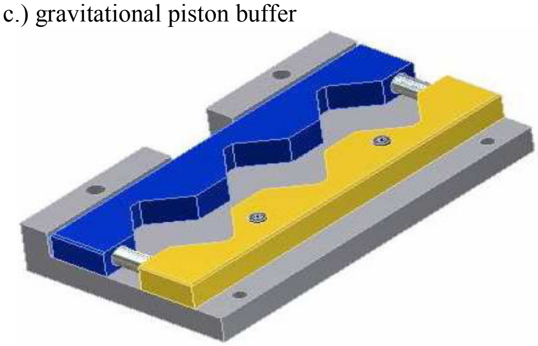
Other one request to the assembly cell was its building only from linear pneumatic driven actuators. . Single actuators were following to the specification chosen from firm FESTO offer. All chosen actuators were modelled in CATIA design environment.

Same way was also modelled all buffers, one buffer for each building part of whole assembled product. Base design criteria were to use gravitational power for part movement in to the buffer. This design will provide less actuator solution. Main advantage of this kind of solution is its simplicity. For cylinder clamping was designed pneumatic driven fixture. All CATIA 3D model are showed at the figure number 3.

a.) gravitational cylinder buffer

b.) gravitational cover buffer

c.) gravitational piston buffer



d.) clamping fixture

Fig. 3. Assembly cell devices – 3D models

Whole disposition solution of assembly cell, were modelled and was also simulated. The simulation helps to eliminate possible disadvantages and negatives in the design process. This way the design problems were not influencing, and was not taking to the verification process. The simulation model of whole device is showed at the figure number 4.

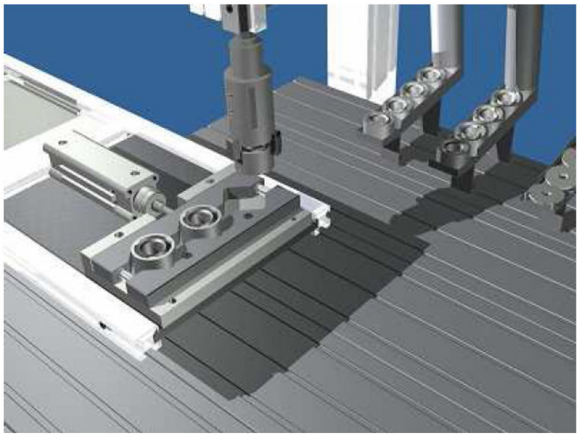


Fig. 4. Simulating model of assembly cell

4. SIMULATING MODEL CREATION OF ASSEMBLY CELL CONTROL SYSTEM

Next step of assembly cell design is to specify sensors which can be used, and which will insure back coupling in whole assembly process. Sensors and its problematic is an inseparable part of automated devices control system.

The software called FluidSim was used for creation and simulation of designed control system for assembly cell. This software allows to create some control scheme, which can be also simulated. Creation of control system scheme can be realized only after movement specification. (Fig. number 5.)

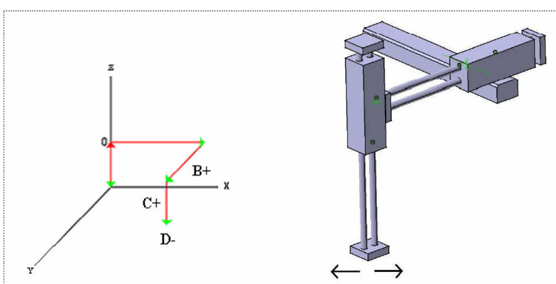


Fig. 5. Device movement analysis

Movement specification includes analyze of all device movements. Analyzed movements are then showed in diagram, which shows all movements in time steps. (Fig. number 6)

Outgoing to the device step diagram three control system alternatives were created. First alternative of control system used only pneumatic elements. Next alternative uses for creating of control system pneumatic components combined with tact blocks. Last one control system alternative combine pneumatic elements with electrical devices and creates simple pneumo-electric control system. Schemes of all three alternatives are showed at the figures number 7,8,9.

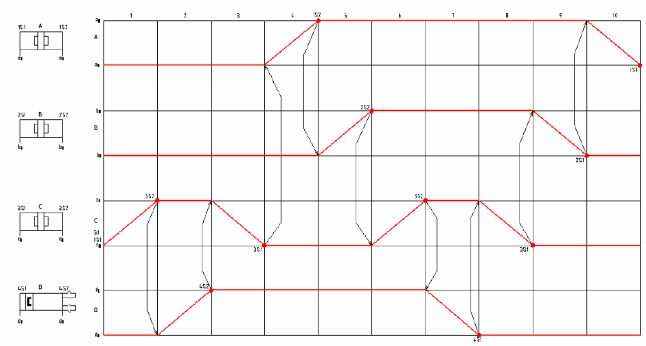


Fig. 6. Device step diagram

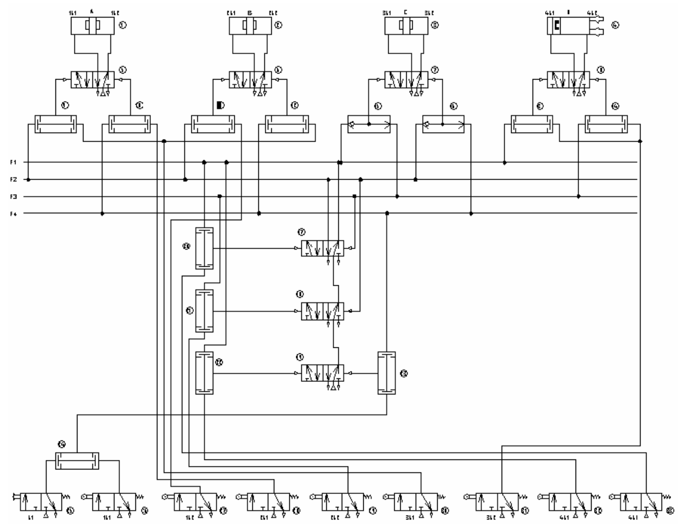


Fig. 7. Pneumatic control system – using of phases

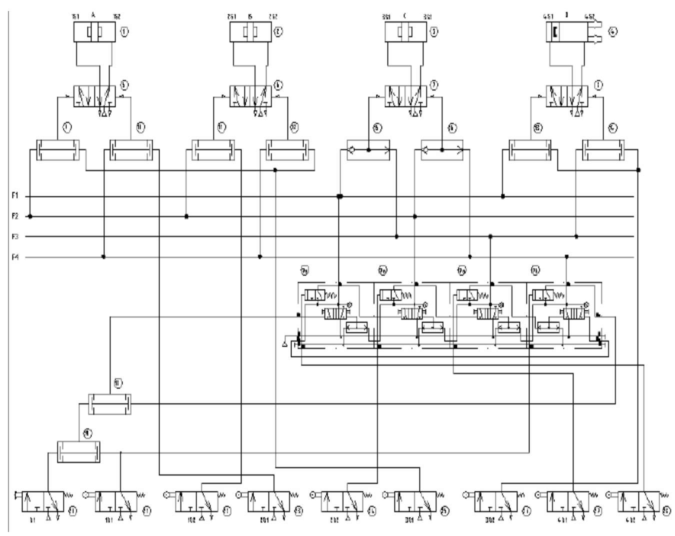


Fig. 8. Pneumatic control system – using of tact blocks

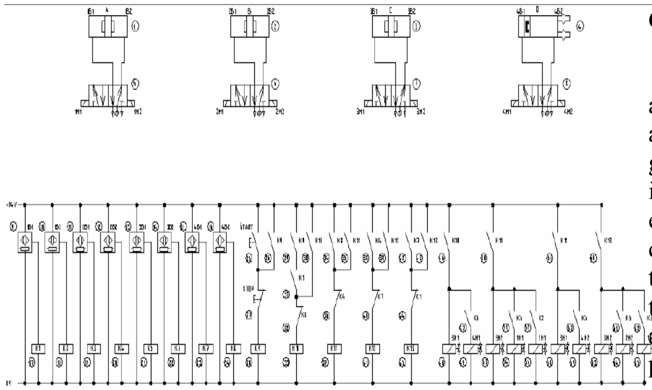


Fig. 9. Electro pneumatic control system

5. SIMULATING MODEL CREATION OF ASSEMBLY PROCESS IN TO THE ASSEMBLY CELL

Simulation can be defined as creation process of model. Model of real system which includes experiments realizations which are realized for better understanding of studied system. The system is studied for advice of various system activity variants. Simulating model is and dynamic model. In this model exists various events. This events are realized in the same order as in modelled system. Simulating methods are getting data with solving of data transformation.

This data was taken from simulating model observation. The observation activity is usually part of whole simulating model. Simulating model then gives outcomes data following to the information which are coming from time changes during the model running time. Running time is completely separated from real time in which are running the calculations.

This time separation permit to catch simulating events. Work with simulating time, design questions and model stay changes are important aspects of dynamic properties of modelled systems recording. Assembly process simulation model of our assembly cell is showed at the figure number 10.

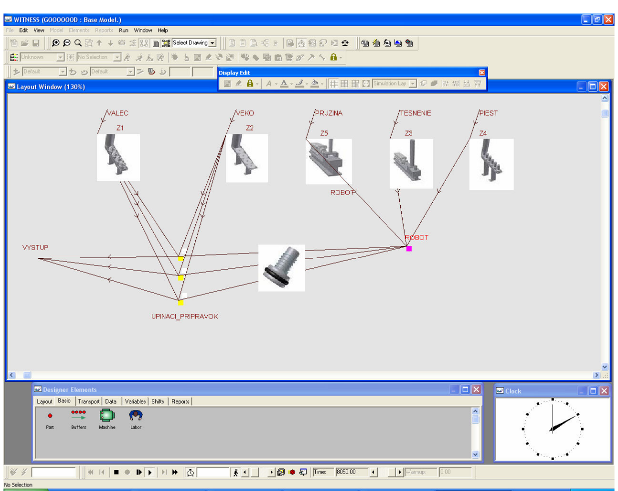


Fig. 10. Process simulating model

6. CONCLUSION

Research and realization of 3D models used for automated engineering systems, is important part of assembly systems design. Program modules of modern graphical CA system are working with high information database support, which includes elementary 3D objects used for design process of more complex models of assembly systems. Using of these types of CA systems is very important and its also short the designing time and allows possible disadvantages and mistakes and its elimination in the designing process, what save the time and also the money.

This paper was created thanks to national project VEGA 1/0206/09 **Intelligent assembly cell**.

7. REFERENCES

[1] Danišová, N.: *Application of intelligent manufacturing system in the flexible assembly cell.* In: Annals of Faculty of Engineering Hunedoara - Journal of Engineering. - ISSN 1584-2673. - Tom V, Fasc 3 (2007), s. 41-45

[2] Matúšová, M., Oravcová, J., Košťál, P.: *Gripping in robotized workplaces.* - Vega 1/0206/09. In: Machine Design. - ISSN 1821-1259. - 2009: 49th anniversary of the Faculty of technical sciences, Novi Sad. May 18th 2009. - Novi Sad : University of Novi Sad, 2009, s. 355-358

[3] Horváth, Štefan - Velíšek, Karol - Danišová, Nina: *Intelligent assembling systems "Machine Design".* In: Machine Design: On the occasion of 48th anniversary of the Faculty of Technical Sciences: 1960-2008. - Novi Sad : University of Novi Sad, 2008. - ISBN 978-86-7892-105-6. - S. 283-286.

[4] Kuric,I.; Debnár,R.; Košturiak,J.; Gregor,M.: *Integration of computer systems in production.* Engineering production, n.45, fascicle.7,-8, 1997, pp.4-12

[5] Marcinčin, J.N.: *Tendency in development of up – to - date CAD/CAM/CAE systems*. Engineering, n.3, fascicle.11, 1999, pp.36-37

[6] Matúšová, Miriam: *Method of fixture design by algorithm*. In: Proceedings of 11th International conference CO-MAT-TECH 2003 Trnava. STU Bratislava, 2003. ISBN 80-227-1949-8. - pp. 660-664

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METHODOLOGY AND DESIGN OF AUTOMATED DISASSEMBLY DEVICE

Abstract: *Disassembly is new and also rapid developed trend in the manufacturing area. In the future the disassembly will be inseparable part of manufacturing process. Especially this fact will be important for that part of industry, which is focused to the products with variable nature. The nature of such variable products is changing following to the customer requests. Especially automated disassembly is an technology, which is attempting to satisfy such needs and requirements. Many of such special requirements are supported by international institutions, research programs and foundations. Automated disassembly technique allows automated separation of various parts, from which was disassembled product created.*
Key words: *Disassembly, Robot, Flexible*

1. INTRODUCTION

Creation and design of automated disassembly device is a complex problem, which includes design problematic of automated device. Of course automated device design problematic is consequently adjusted following to the requirements of disassembly devices design problematic. Such designing process, which is designing automated disassembly device needs some guide. This guide will carry designer over the all problems which are connected with disassembly process and also its automation. After using of such guide, some automated disassembly device will be designed. Such guide, or better say such tool is and methodology of automated disassembly devices design.

2. METHODOLOGY OF AUTOMATED DISASSEMBLY DEVICE DESIGN

Each automated device consists of several building units such as suspension frame, manipulating equipment, working equipment, helping equipment, or control equipment. The same building units have to be designed and created by design of automated disassembly device. Of course choose of these building units will be limited by activities realized by disassembly processes. There is also very important to realize analysis of disassembled product before design of automated disassembly device. All information getting from this disassembled product analysis can be used for creation of proper disassembly method. In the first phase of disassembly method creation is important to focus on all movements which are realized during disassembly process. This way created disassembly method has to be supplemented by other information. With help of these information, there will be possible to create internal structure of disassembly method, or other alternatives of whole disassembly process. Ending of first analytical phase, which is used for disassembly method creation, is creation of disassembly method in form of disassembly combine processual diagram.

In the other phase is methodology for design of automated disassembly device dealing about the choice of proper automation instruments. This choice is realized regarding to the created disassembly method and also regarding to the techniques of assembly joints destruction. Following to the choice of proper automation instrument, there is needed other one choose of building components of whole automated device. These building components are for example power unit, signal unit, control unit, or carrying unit which is generating frame of whole automated device.
Last activity, which is really important for creating process of whole device is choose of proper control system. This choice is partially given by kind of chosen automated instrument. This activity is also that one, which creates single steps of control, or whole control method. Whole control method really close follows disassembly method, which was created in analytical part of design methodology.

2.1 Disassembled product analysis

Input of most manufacturing of assembly technologies is analysis of manufactured or assembled product. This analysis is analyzing product from many views. Also design of disassembly device needs product analysis, which will look to the product from many valuation views. The number of valuation views can be different; usually the number depends on complexity or largeness of whole disassembled block. Valuation views which are valuated disassembled product can be divided in the five groups.

- Disassembled element analysis according to the recycling kinds of single building products,
- Disassembled elements analysis according to its influence to the environment,
- Disassembled elements analysis according to the design materials of disassembled products,
- Disassembled elements analysis according to the using assembly joints or according to the used assembly technologies,

- Dimension and shape analysis of single products, which are used during the whole assembly process.
- Information which comes from these analyses is then used for identification of parameters which are limiting the following disassembly process.

2.2 Disassembly process design

For proper disassembly process design is necessary to know, the process which was used by its assembly. From that reason we use, as an input for disassembly process design, assembly processes and other assembly documentation. If such information and materials are not available it is necessary to create own input data. The tool which can be used for such input data creation is for example step diagram, which is added by information taken from assembly product joints analysis.

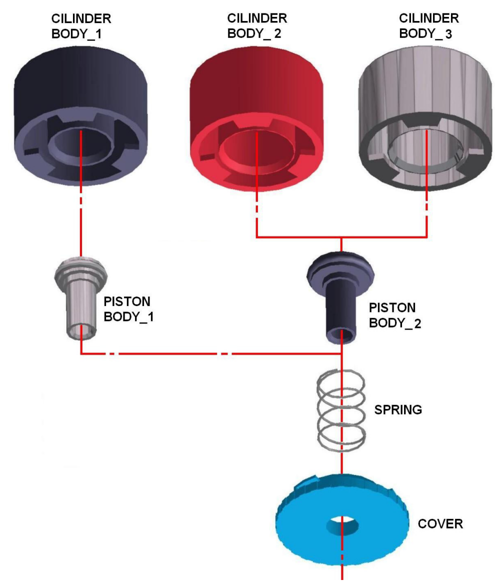

Fig. 1. Assembly process of pneumatic actuator

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This way created assembly process can be later reworked by process of creating of reverse step diagram. In case of more complicated design, not only reverse step diagram can be used. This solution needs, because of complicated and large design, the creation of internal structure, which will simple whole this kind created diagram.

Diagram doesn't include logical branching and conditions, which are needed for effective disassembly process. From this reason the reversed step diagram have to be supplemented by conditions and rules, which are presented by Petri net theory.

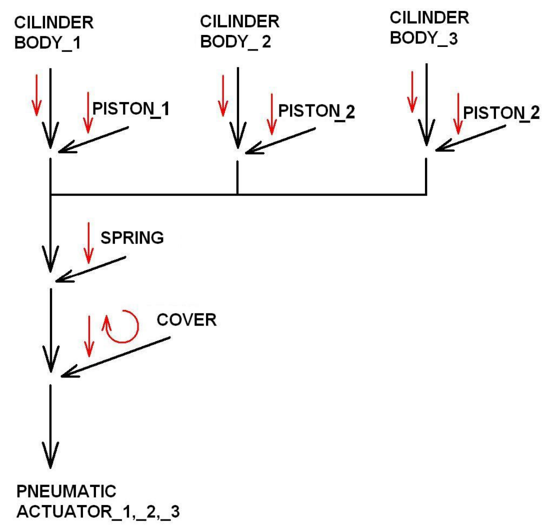

Fig. 2. Step diagram for assembly of pneumatic actuator

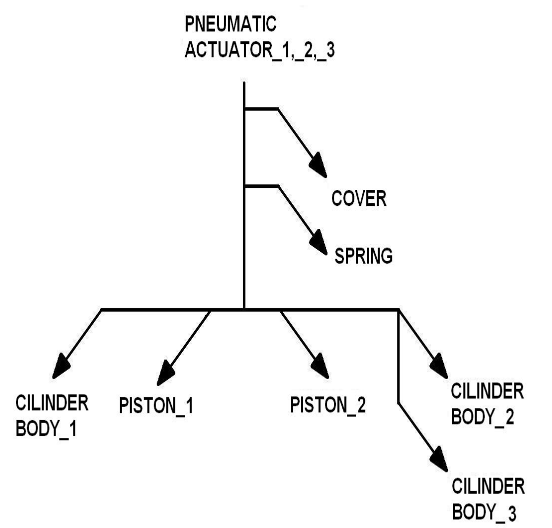

Fig. 3. Reverse step diagram

This way created diagram is an combination of two kinds of disassembly process designs. This way created scheme offers more information which can be used for design of automated disassembly device. Using of logical functions is necessary. This way created diagram also deals about need of sensors equipment, which will be used for realization of disassembly device. On the other hand this scheme also shows basic movements which are needed for whole disassembly process and it is also shows need of movement actuators which will be needed for realization of whole disassembly device. Diagram of this type was specially designed and created for needs of automated disassembly devices design methodology and is also combined by automated devices design problematic.

Diagram in this version can be used for whole disassembly process description. It is also very important guide for design of whole disassembly device. From this reason, the creation of such simple and tabular diagram is very important step in the process of automated disassembly device design methodology.

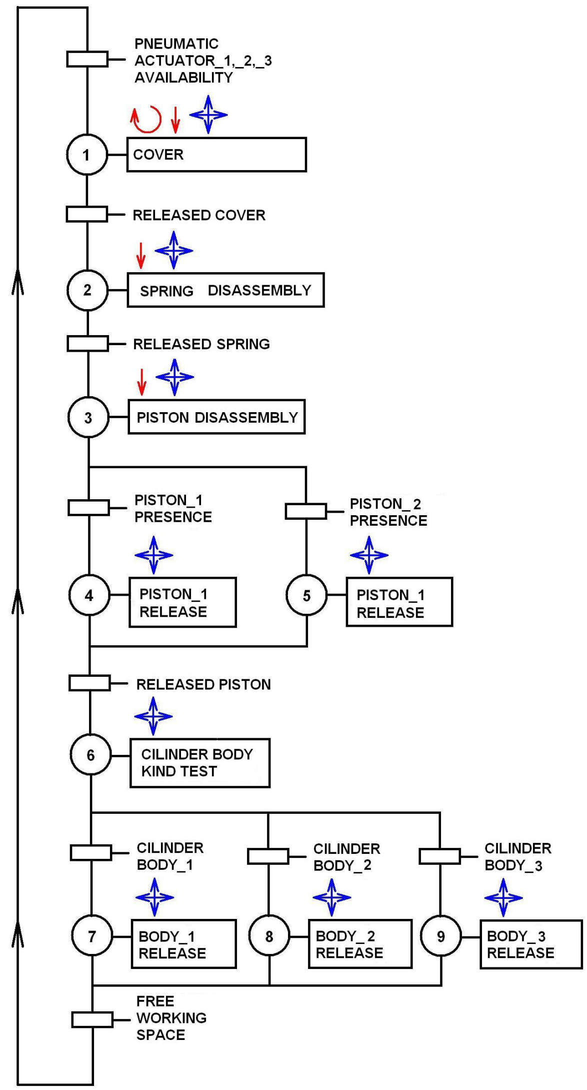

Fig. 4. Supplemented step diagram

This way created diagram is an combination of two kinds of disassembly process designs. This way created scheme offers more information which can be used for design of automated disassembly device. Using of logical functions is necessary. This way created diagram also deals about need of sensors equipment, which will be used for realization of disassembly device. On the other hand this scheme also shows basic movements which are needed for whole disassembly process and its also shows need of movement actuators which will be needed for realization of whole disassembly device. Diagram of this type was specially designed and created for needs of automated disassembly devices design methodology and is also combined by automated devices design problematic.

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3. AUTOMATED DISASSEMBLY DEVICE DESIGN

Methodology solves the automated disassembly device design in several levels, which are influencing one to another. First two solution levels are the design of elements which are creating the working space of whole device and design of disassembly device manipulation device.

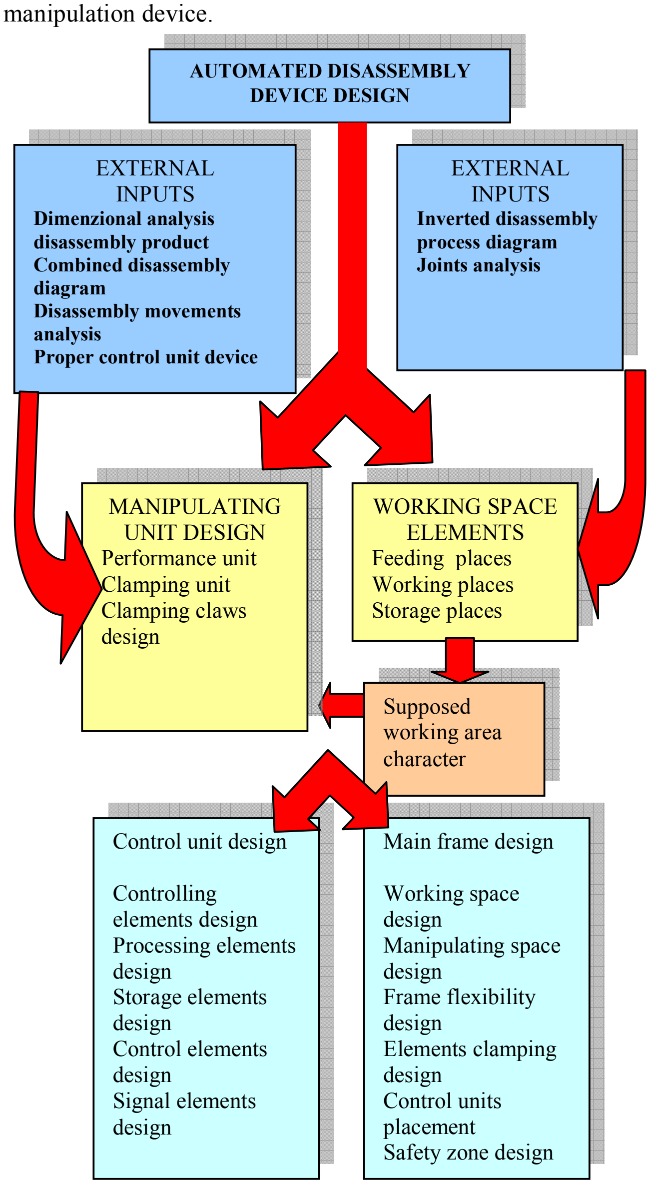

Fig. 5. Automated disassembly device design methodology

Both these problematic has also mutual relationship. As first one the problematic of working space is solved. This problematic deals about the number and also the character of manipulating and working places. Inputs, which are needed for this problematic are reversed disassembly step diagram, which was presented in the last chapters. The output of workspace elements design is and creation of first working space picture. Such working space picture or first alternative design is an elements which strongly influence to the following methodology chapter - design of manipulating part of disassembly device. Working space picture is a connection between the design of manipulating part and working part of disassembly device. Design process of manipulating device deals about design of power unit, design of clamping units, design process of clamping jaws. During the design process of manipulating unit, it is very important to focus on parameters such as load, dimensions, power, performance, manipulating repieability, clamping dimensions and so on. For definition of these parameters the methodology uses external inputs in the form of input analysis or step diagrams.

Information which is coming from these starting activities realized during the methodology using is also input data for other two activities. The realization of these two activities is important for design of the automated disassembly device.

Better say the activities such as working space character and manipulating device will have influence to the design of main frame and to the control unit design of automated disassembly device. On the opposite side, the activities such as main frame design and control unit design are not influence one to another. But it is better to solve main frame design as first one, because the design of whole device will be that realized by more simple way. The end of whole automated disassembly device design process is characterized by activity called collision analysis. This analysis defines single zones created in the working space of the device such as manipulating zone, working zone, non usable zone, and so on. This activity defines the intersections of these zones and analyses possible collision stays.

The next one activity which is realized in the design methodology is design of control unit. This activity includes the design of control elements, design of processing elements, design of storage elements, design of control elements and design of signal elements. Main area of this activity is focused on the design of control algorithm of automated disassembly device, which will be realized in three steps. These steps are creating of step diagram, creating of progress table and creating of normalized tool called Grafcet. With connection of these three parts the design of whole automated disassembly device is can be realized.

4. CONCLUSION

Designed methodology, step by step deals about single activities and works. Realization of such activities is necessary for complex design of automated disassembly device. Single steps are using known analytical project methods which are modified following to the disassembly devices problematic. But generally the methodology of automated disassembly device design stand on the methods which were specially created for needs of disassembly devices needs. Methodology includes before project as well as project phases, which are followed by design phases of whole automated disassembly device. By connecting of updated well known methods and specialized newly created methods a new methodology is created, and it is able to create working automated disassembly device.

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5. REFERENCES

[1] Zvolensky, R., Ruzarovsky, R., Kostal, P: *Design of automated disassembly devices*, MicroCAD 2008, pp 51-56, ISBN 978-963-661-812-4, ISBN 978-963-661-822-3.

[2] Zvolensky, R., Ruzarovsky, R., Velisek, K: *Design of automated manufacturing and disassembly systems*, Machine Design 2008, pp. 277-282, Novi Sad, ISBN 978-86-7892-105-6.,

[3] Ruzarovsky, R., Horvath, Š., Velisek, K.: *Designing of automated manufacturing and assembly systems.* - registrovaný v ISI Proceedings. In: Annals of DAAAM and Proceedings of DAAAM Symposium. - ISSN 1726-9679. - Vol. 19, No.1. Annals of DAAAM for 2008 & Proceedings of the 19th International DAAAM Symposium "Intelligent Manufacturing & Automation: Focus on Next Generation of Intelligent Systems and Solutions", 22-25th October 2008, Trnava, Slovakia. - Vieden: DAAAM International Vienna, 2008. - ISBN 978-3-901509-68-1, s. 1201-1202

[4] Matusova, M., Javorova, A.: *Modular clamping fixtures design for unrotary workpieces,* Annals of Faculty of Engineering Hunedoara - Journal of Engineering 2008, pp. 128-130, ISSN 1584-2673.

[5] Matúšová, M., Hrušková, E.: *Simulation of machining in CATIA V5R15.* KOD 2008. pp. 71-72ISBN 978-86-7892-104-9.

[6] Danisova, N., Charbulova, M.: Design of additional check station with intelligent camera system. In: MATAR Praha 2008. Part 1: Drives & control, design, models & simulation: Proceedings of international congress. - Prague 16th-17th September, Brno 18th September 2008. - Praha : České vysoké učení technické v Praze, 2008. - ISBN 978-80-903421-9-4. - S. 187-189

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GESTURE RECOGNITION USING DATA GLOVE AND ANN-BASED PROCESSOR

Abstract: *Discussed in this paper is the problem of gesture recognition using a commercial data glove 5DT 5 Ultra, with the aim to improve its ergonomic features and usability for Mechanical CAD (MCAD). The authors improved the standard gesture dictionary by eliminating 11 original simple static gestures and substituting them with new complex static gestures. Since the restructuring of the original gesture dictionary imposed a problem of lower gesture recognition rate, this issue was approached using artificial neural networks. Obtained results indicate that the proposed restructuring of data dictionary can be efficiently supported by application of ANN-based processing.*

Key words: *virtual reality, data glove, static gesture, artificial neural network.*

1. INTRODUCTION

Virtual reality-based technologies are common in modern production manufacturing. As the result, a number of simulations exist which, besides the classical human-computer interface (HIC), also use multi-modal HIC. Multi-modal interaction puts a human in the center of the interface, focusing on extraction and interpretation of information gathered from hand gestures, speech, tactile feedback and other modalities of communication.

Since the second half of the 1970s when their use was pioneered by M. Krueger, hand gestures have been recognized as a natural and intuitive way of communicating not only with virtual environments, but with computers in general. However, despite of some three decades of development, the application of gestures in virtual environments is far from desired. As Poupyrev et al. noted, there exists no unified framework for virtual environment interaction, no desktop-style metaphor familiar to the majority of users, and no optimal interaction technique for all possible task and input devices in virtual environments [1].

Amongst various definitions of the gesture found in general dictionaries and scientific papers, a definition by Turk seems to be most comprehensive stating that a gesture is a meaningful body motion - i.e. physical movement of the fingers, hands, arms, head, face or body with the intent to convey information or interact with the environment [3]. A number of authors have contributed to the development of classification and taxonomy of gestures [2-8].

Discussion in this paper is confined to hand gestures. In addition, the distinction is made between hand gestures based on two fundamental properties: complexity and dynamics, which are required for proper gesture recognition. According to these criteria, hand gestures can be classified into:

- simple static gestures (postures) – in which finger configurations consist of either fully closed or fully open fingers,
- complex static gestures (postures) – in which fingers can be flexed at an arbitrary angle,
- simple dynamic gestures – in which either just a hand is moved or the fingers are moving with the hand in a fixed position,
- complex dynamic gestures – which involve the movement of fingers, as well as changes in location and orientation of a hand.

With this classification in view, the scope of this paper is limited to simple and complex static gestures.

2. PROBLEM DEFINITION

Owing to its all-round characteristics and low price, 5DT 5 Ultra data glove (Fifth Dimension Technologies) is very popular among industry professionals and researchers. The glove is equipped with five proprietary optical sensors, which allow it to measure finger flexure using one sensor per finger. Thus, signals from the sensors represent mean value of finger flexions at metacarpophanlangeal and proximal joints [10]. It also comes with a ready software support for the detection of the predefined set of 16 gestures. The authors have used this glove with an experimental VR desktop system, which is described in more detail in [11]. However, the glove is not suitable for use with MCAD without some important modifications:

- only a third of the predefined gesture set are ergonomically suitable for prolonged use, since they cause muscle fatigue,
- although thumb flexure is measured, none of the standard-dictionary gestures include the use of thumb, which not only prevents the simulation of grasping but also makes it impossible to simulate useful gestures which require the use of thumb,

- owing to the ergonomic issues and the principles of operation of the optical sensors, the gestures are sometimes misinterpreted or undefined,
- most of the gestures lack symbolical meaningfulness which is necessary for efficient use with MCAD applications.

Gestures supported by 5DT 5 Ultra are coded as the combination of binary states (open = 1 / closed = 0) of the four fingers, excluding the thumb. Thus, it is possible to create 24=16 gestures as combinations of open/closed fingers. The gestures are assigned numbers from 0 to 15, 0 representing the fist (all fingers closed) and 15 representing the open hand (all fingers open). Gesture recognition is based on boundary values. If the sensor reading for a particular finger is above the predefined boundary value, the finger is considered closed (flexed).

Conversely, if the reading falls below the boundary value, the finger is open (no flexion). All readings which fall between the boundary values are considered as errors, and the gesture is undefined.

This simple method of gesture recognition works well in some situations but is not always reliable. This can be attributed to anatomical variations in various users, as well as to the disposition of optical sensors and their cross-coupling, which can often result in incorrect recognition of a gesture [12].

3. MODIFICATION OF STANDARD GESTURE DICTIONARY

Ergonomic and cognitive issues of the existing gesture dictionary were addressed by restructuring the predefined gesture dictionary, eliminating some simple gestures and substituting them with the complex ones.

Considering the ergonomic features and iconic and metaphoric meaningfulness, the existing gesture dictionary was restructured in order to allow the elimination of:

- finger configurations which involve full extension of the middle finger with the index and ring finger fully flexed,
- finger configurations which involve full extension of the ring finger with the middle finger or middle and index finger fully flexed,
- finger configurations which involve full flexion of the index, middle and ring finger with the small finger and thumb fully extended.

Following the above stated guidelines, a total of eleven gestures were eliminated from the standard 5DT gesture. Of the remaining five gestures, three were left in their original form while the two remaining gestures were modified. Thus, gesture designated 1, was modified into gesture G03, while gesture 3 became gesture G05. Also added were five novel gestures, G04, G06, G08, G09 and G10 (Fig. 1).

The modified gesture dictionary comprises twelve static gestures and, according to conditional classification proposed by LaViola [7], belongs to small gesture dictionaries. This is an advantage regarding the efficiency of gesture recognition. Should the dictionary require an extension at any point, this can be solved with a context-dependent gesture recognition where a single gesture can be attributed with several meanings, depending on the suggested context of the application.

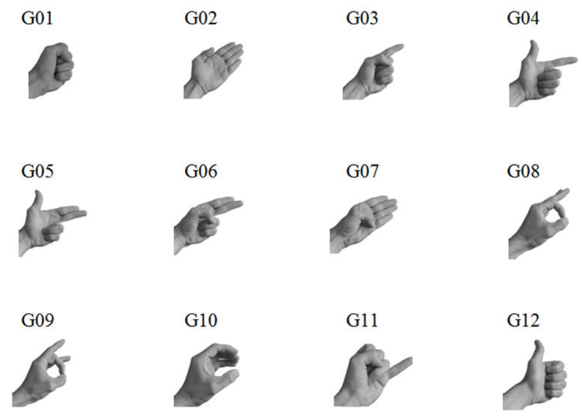

Fig. 1 Modified dictionary comprising 12 gestures

4. DEVELOPMENT OF ANN-BASED GESTURE RECOGNITION PROCESSOR

4.1 Architecture of experimental desktop VR platform

The experimental platform for which the processor was designed and built is based on a PC graphics workstation, with a stereo graphics card (Fig. *2*) which operates at double refresh rate. Having in mind that the user which wears LCD shutter glasses has a field of view which is limited to the size of the monitor screen, this platform is equipped with a 22" CRT monitor. Stereoscopic LCD shutter glasses function in a wireless mode, while the synchronization between the stereo graphics adapter and the glasses is performed by an infrared emitter.

As can be seen in Fig.2, the platform has two 6 DoF input devices - a data glove 5DT 5 Ultra and a trackball - Spaceball 5000. Software platform consists of OS *Windows XP,* CAD/CAE/CAM system *NX* and a VR CASE tool *Vizard (WorldViz)*. Integration of the data glove into the VR system is performed by a custom-developed recognition system for static gestures which is based on a probabilistic neural network (PNN) [10]. The PNN-based gesture recognition system allows two basic advantages over conventional approach: (i) better gesture recognition rate and (ii) enhancement of standard gesture library with new static gestures. Acquisition of a magnetic tracking system is in progress, which will allow the data glove to be used for dynamic gestures within the simulation space.

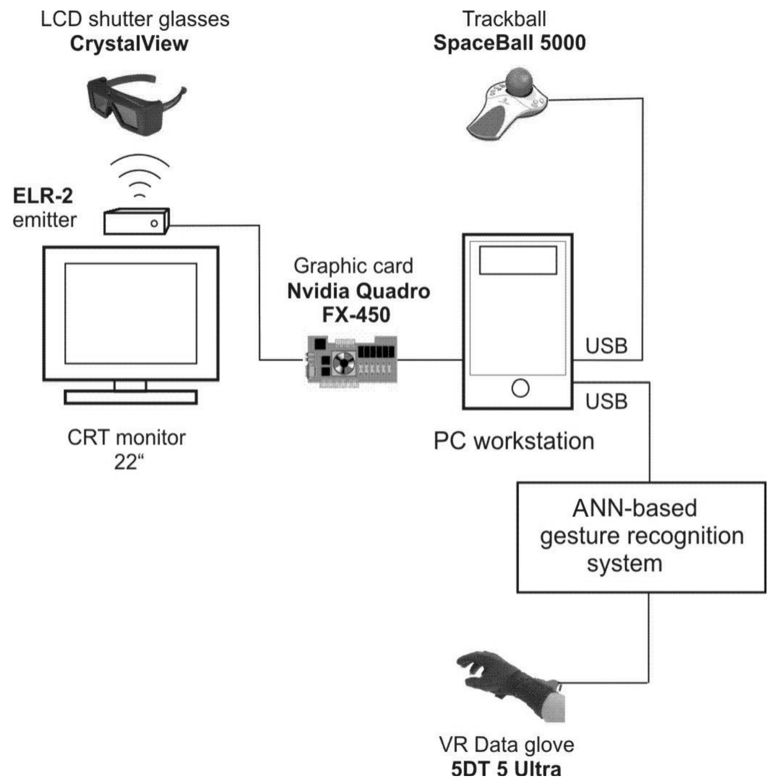

Fig. 2 Architecture of experimental desktop VR platform at the Laboratory for plastic forming technologies, DPM, Novi Sad

4.2 Realization and testing of ANN processor

The gesture recognition task was fulfilled using an ensemble of neural networks, i.e. multilayer perceptrons (MLPs) with one hidden layer and back propagation learning. Simulations were performed in the neural networks module of Statistica 7. Instead of using just one neural network for the task, a set of ten

MLPs was formed, trained, validated and tested in order to select the best five MLPs which formed an ensemble. Ensembles improve performance since averaging across different MLPs lowers the expected variance, i.e. the sensitivity of MLPs to the choice of the data set which would otherwise cause variations in classification error. Logistic and linear transfer functions were used for the neurons in the hidden and output layer, respectively.

The summary statistics for classification results obtained by the ensemble are given in Table 1. The data represent average values scored by the five member networks (MLPs).

	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11	G12
Total	200	200	200	200	200	200	200	200	200	200	200	200
Correct	193	199	196	199	196	191	200	190	175	200	200	185
Wrong	7	1	4	1	4	9	0	10	25	0	0	15
Unknown	0	0	0	0	0	0	0	0	0	0	0	1
Correct (%)	96.5	99.5	98.0	99.5	98.0	95.5	100	95.0	87.5	100	100	92.5
Wrong (%)	3.5	0.5	2.0	0.5	2.0	4.5	0.0	5.0	12.5	0.0	0.0	7.0
Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5

Table 1 The results of gesture classification by ANN-based processor

5. DISCUSSION OF RESULTS

The five member networks used in final experiment differed in the number of neurons in the hidden layer. The number of neurons ranged from 18 to 30. The mean value of test errors for the five member networks equaled 0.35443.

The classification results for individual gestures (Table 1) reveal that gestures G7, G10 and G11 were classified with 100% accuracy. As expected, the ensemble performed worst in the case of two very similar gestures, G8 and G9, and gesture G12, which is very similar to G01. In addition, a single case of gesture G12 was unclassified and thus labeled as unknown gesture. Its class could not be decided by voting due to a disagreement between the five member networks.

In all, gesture recognition using the five-membered ensemble yielded satisfactory results showing that the modified gesture dictionary can be successfully used without significant deterioration of recognition accuracy.

6. CONCLUSION

The restructuring of the standard static gesture dictionary of 5DT 5 Ultra data glove successfully tackled the issue of ergonomy and symbolic meaning. Improvements were made by introducing complex static gestures which not only improved the ergonomic features of the gesture dictionary, but also imposed a distinct symbolic framework which helps users to pinpoint the function of particular gestures without extensive training. The problem of gesture recognition was efficiently solved using an ensemble of five MLPs.

The authors are currently designing and testing a novel system for static gestures recognition which would be flexible enough to allow efficient introduction of novel static gestures, as well as new users of data glove. Multilayer perceptrons with backpropagation are not suitable for this task primarily due to the fact that they require lengthy retraining with old and new data sets in case of any modifications. For that reason, the system shall be based on a probabilistic neural network (PNN) which shall be trained on a clustered data set to allow the necessary reduction of network complexity and higher processing speed.

7. REFERENCES

[1] Poupyrev, I., Billinghurst, M., Weghorst, S., Ichikawa T. (1997) A Framework for testbed for studying manipulation techniques for immersive virtual reality. Proc. of the ACM Symposium on Virtual Reality Software and Tech., p.21-28.

[2] Cerney, M., Vance, J. (2005) Gesture Recognition in Virtual Environments: A Review and Framework for Future Development. Iowa State University Human Computer Interaction Technical Report, ISU-HCI-2005-01

[3] Turk, M. (2002) Gesture recognition, Handbook of Virtual Environments, Design, Implementation and Applications, K.Stanney (Ed.), Lawrence Erlbaum Associates, 2002, ISBN: 080583270X, p.223-239.

[4] Bowman, D., Kruijff, E., LaViola, J., Poupyrev, I. (2005) 3D User Interfaces–Theory and Practice, , ISBN: 0-201-75867-9.

[5] Förster, J., Lang, H., Rinker, B., Santos, F. (2005) Gestenerkennung/Gesture-Recognition, Referat im Rahmen der Vorlesung Benutzerschnitstellen

[6] Funck, S., Fuchs, S. (2005) Entwicklung eines gestisch-intuitiven Mensch-Maschine-Interface auf basis der videogestütztest Erkennung von Handzeichen, Technischer Berricht, TUD-FI02-05, Technische Universität Dresden, ISSN 1430-211x,

[7] LaViola, J. (1999) A Survey of Hand Posture Recognition Techniques and Technology, Technical Report CS-99-11, Department of Computer Science, Brown University, Providence

[8] Nielsen, M., Störring, M., Moeslund, T., Nielsen, E.,G. (2003) A Procedure For Developing Intuitive and Ergonomic Gesture Interfaces for Man-Machine Interaction, Technical Report CVMT 03-01, ISSN 1601-3646, CVMT, Aalborg University

[10] Fifth Dimension Technologies (2004), 5DT Data Glove Ultra Series, User's Manual

[11] Lužanin, O., Plančak, M. (2008) Virtual Reality Technologies in Virtual manufacturing - Current Trends and Applications, Journal of Technology of Plasticity, Vol.33, Number 1-2, ISSN:0354-3870, p.103-111

[12] Kahlesz, F., Zachmann, G., Klein, R. (2004) Visual-fidelity dataglove calibration. Computer Graphics International (CGI), June 16-19, Crete, Greece, IEEE Computer Society Press Workshop on Human Motion (HUMO'00), p.121-126.

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INTEGRATED CAD/CAM AND SIMULATION TOOLS FOR DESIGN AND MANUFACTURE OF FORGING TOOLS

Abstract: *This paper deals with the advanced CAD/CAM and simulation tools which are used by the Laboratory for Technology of Plasticity, the Department for Production Engineering, Novi Sad, for design of forging processes and tools. Starting from the general discussion of benefits from using CAD/CAM tools, the authors review NX system, i.e. its sub-system, NX CAM, which offers integrated simulation and verification software modules necessary to create forming tools. Beside NX CAM's workflow and principal modes of operation, also discussed are the levels of simulation which depend on user requirements and complexity of particular task.*
Key words: *CAD/CAM, forging, technology, simulation.*

1. INTRODUCTION

In its various forms, metal forming is the oldest metal processing technology. It started with the prehistoric people who learned to smith virgin gold peaces and later to beat a heated sponge iron with a stone in order to form useful tools [1]. Moreover, forging, as one of the most common forming technologies, has from its earliest days strongly depended upon skills of the blacksmith, and, in that respect, resembled an artform rather then a technological method. With the advent of computer technologies and the development of powerful graphics and processing hardware, software tools for simulation of numerous manufacturing technologies have also evolved. Present-day CAD/CAM tools have reached maturity, enabling scientists and engineers to simulate manufacturing processes of various complexity. According to data from 2005, *Forging* reports that 80% of the large companies (more than 250 employees), 75% of the mid-sized companies (100-249), and even 50% of smaller firms (50-99) in the US are using CAM and process simulation tools [2]. These numbers have more than doubled over the last decade, similar to the expanded use of CAD systems in the early 1980s [3].

This paper focuses on advanced CAD/CAM and simulation tools which are used by the Laboratory for Technology of Plasticity, the Department for Production Engineering, Novi Sad, effects of their use, and their capabilities.

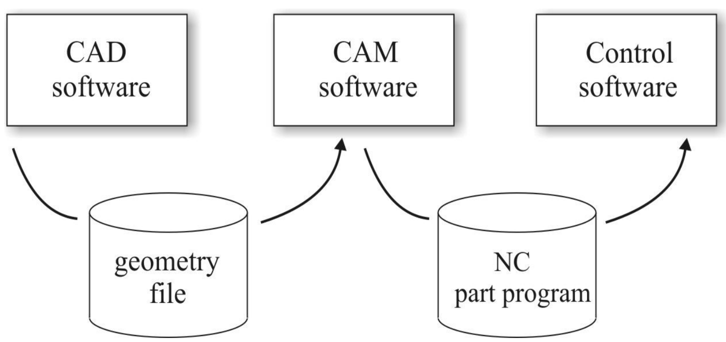

Fig.1 Typical position of CAM software in the design/manufacture process

2. BENEFITS FROM USING CAD/CAM TOOLS

In order to manufacture a part using modern methodology, an engineering department typically needs three different software programs (Fig.1):

- the CAD software to make the design of the part
- the CAM software to calculate the toolpaths based on the design, compensating for the cutter's geometry, adding feedrate and spindle commands, etc.
- the control software to read the toolpaths and allow the machine tool to perform required motions and operations

As regards the CAM software, since the 1980s there have been developed a number of software tools dedicated to forging technologies. By providing detailed insight into the forging process prior to tool selection and important process decisions, forging simulation offers substantial cost and time savings. It allows simulation of a number of essential factors such as material flow, stresses and strains, temperatures, etc. It can also allow early detection of defects such as laps and under-fill of die cavities, thus enabling user to correct the mistakes before the production process is initiated.

Generally speaking, application of CAD/CAM solutions in forging helps reduce [4],[5]:

- number of die physical prototypes
- number of defects
- scrap and material waste
- number of shop floor trials
- product development time

By the same token, those software tools contribute to increase of:

- product quality
- die life
- reliability
- flexibility
- process know-how.

Also important to note is that on today's CAM market, high-end software solutions have advanced features which include following [6]:

- support for a fourth axis, or for full 5 axis machining
- optimization for high speed machining (constant tool load)
- special sequences for approaching and leaving the geometry (lead-ins)
- automatic stepover calculation
- a wide choice of machining strategies, like parallel, spiral, radial, pencil tracing, flat surface recognition, offset machining, plunge milling and automatic smoothing of almost vertical surfaces.
- automatic detection and removal of rest material
- management of undercuts
- rendered machining simulations.

One such solution, NX CAM, is licensed to the Laboratory for Technology of Plastiticy of the Department for Production Engineering in Novi Sad, and it is being used to generate process plans and NC part programs for manufacture of forging and other forming tools.

3. NX CAM TOOLS FOR INTEGRATED SIMULATION AND VERIFICATION

In general, NX is a complex Computer-Aided Design, Computer-Aided Manufacturing, and Computer-Aided Engineering (CAD/CAM/CAE) system. The CAD functions automate the normal engineering, design, and drafting capabilities found in today's manufacturing companies, the CAM functions provide NC programming for modern machine tools using the NX design model to describe the finished part. The CAE functions provide a number of product, assembly, and part performance simulation abilities, across a broad range of engineering disciplines [6].

NX CAM – Integrated Simulation and Verification (ISV) is a part of NX system that allows the NC programmer to perform toolpath and machine motion validation through digital simulation without leaving the programming session. The software si structured in a modular fashion and enables users to simulate toolpath and material removal through complete machine tool motion simulation. Using advanced simulation technology, full 3D in-process representations of the part, coupled with gouge and collision checking methods, ISV eliminates the need to utilize expensive production equipment to verify manufacturability. This system is completely integrated with NX CAM, which allows simulation process to be simultaneous with programming and provides immediate, real-time feedback and validation.

Among numerous advantages offered to scientists and engineers, this systems allows following:

- Verification of material removal and simulation of entire machine tool motion
- Operates in NX CAM, within the NC programming session
- Simultaneous collision detection and gouge checking
- Accurate representation of machine tool kinematics and configuration
- Modular software from metal removal verification to full machine tool simulation and the addition of new machines.

The features listed above allow a number of advantages over conventional approach:

- Checks proposed toolpath validity during CAM session for fast and easy problem identification and change opportunity
- Faster and more efficient than conventional try-out methods
- Automatic collision and gouge checking elements provide warning capability; avoids costly and dangerous errors
- Allows the entire machine operation to be validated – not just the toolpath
- Tooling, fixture and machine geometry needs to be created only once, reducing time and costs

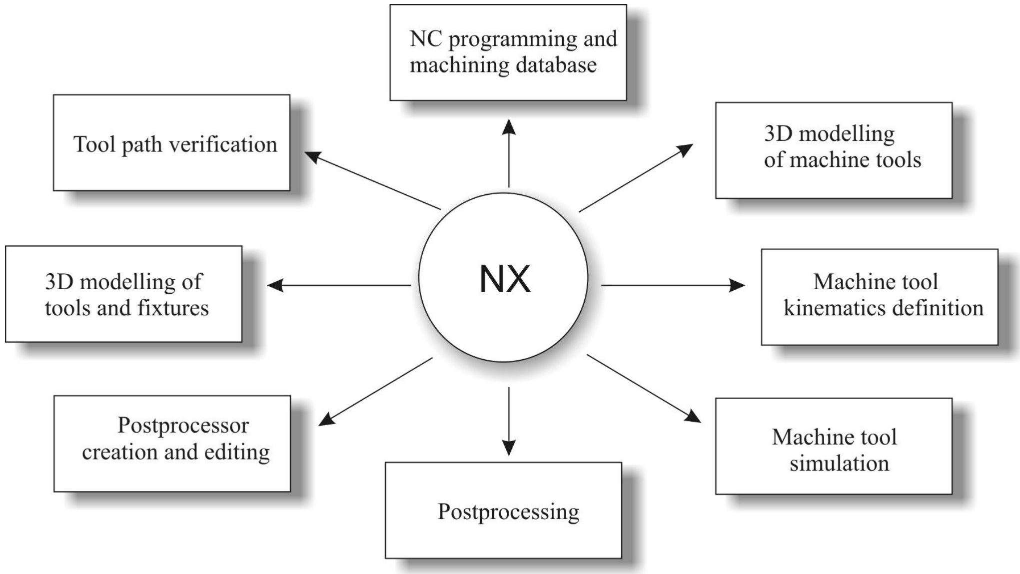

Fig.2 NX CAM integrated simulation and verification tools [6]

The system uses common Parasolid platform to transfer geometry and other data across. Starting with the prepared CAD data of the part that has to be machined, the link with NX CAM is associative, which means that the link to original data is maintained through all stages of the process.

3.1 Workflow and principal modes of operation

The NX CAM workflow allows user to work in two different operating modes. For less exeprienced users there is a template mode, while the more experienced users are allowed to make all the required settings and adjustments manually.

When it comes to the template mode, all the processes are driven via predefined templates which are designed to automate the set-up process of any job – whether that's production part (prismatic parts), Mold and Die or Advanced Machining. The user is prompted to step through the various steps to set-up the required job (machine tool and material selection, work piece and billet size). Next, the user selects a geometric entity as the stock model and adds additional elements to define jogs and fixtures. In the next step, datums and retract heights are selected. In order to create first operation, cutting tool should be defined either manually or from a library, selecting the carousel position, the geometry to be cut and the sequence of machining operations (roughing, semi-roughing, finishing etc).

The alternative way of defining all the necessary parameters is meant for more experienced CAM users, allowing them to define everything manually. In NX CAM, users can define their own templates and then save them for later use, which greatly enhances flexibility (Fig. 3).

3.2 Levels of simulation

NX CAM system allows CAM simulation to be performed on three different levels, depending on user requirements and the complexity of particular task.

Bearing this in mind, CAM simulations can be performed as:

- generic simulations
- post-processor-driven simulations
- controller-driven simulations

Generic simulation

Like other commercial systems that utilize an internal tool path, a CL (Cutter Location) file or another prepost output to drive the simulation, NX also enables user to drive its machining simulation based on the prepost processor data. This level of simulation provides sufficient accuracy for many machines.

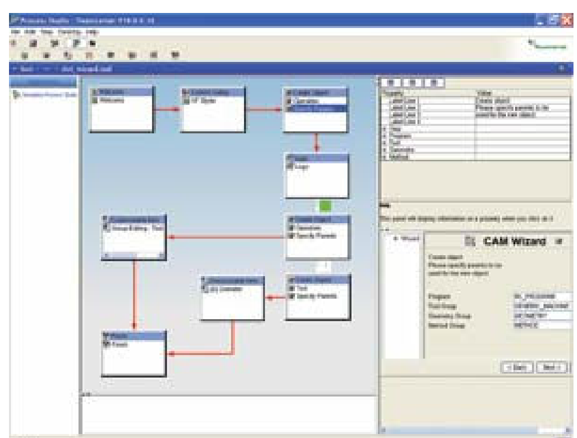

Fig. 3 Definition of user templates in NX CAM as a way to increase system flexibility

Postprocessor-driven simulation

Postprocessor-driven simulation is a more advanced level of simulation which offers higher levels of accuracy for advanced machines. In this case, NX Machining utilises the output of the production postprocessor in the form of G and M codes. In this way a more complete representation of the machine tool motion is provided while, at the same time, errors are reduced to minimum. This level of simulation is in most cases required with advanced machines, such as merging lathes, mill-turns, etc.

Controller-driven simulation

The most advanced level of simulation is enabled by software modules which emulate functions of real machine controllers, which are integrated within the basic solution. This offers most accurate representation of all machine tool motions, including accelerations, speeds and timings as well as controller-specific machining [6].

4. OTHER TOOLS FOR FORMING SIMULATION

Another licensed software tool which is used by the Laboratory for Technology of Plasticity in development of forming processes is the *Simufact forming*. *Simufact forming* is a simulation tool that has been developed especially for the forming industry.

The system stems from the well-known solutions MSC.SuperForm and MSC.SuperForge (MSC.Software), which are now integrated in a single system dedicated to forming technologies.

Simufact is a modular system that allows customization according to particular requirements. The system comprizes different application modules for a wide variety of different production areas: solid forming, sheet metal forming, mechanical joining as well as welding. Their functionality can be additionaly enhanced by additional modules to suit specific tasks.

Simufact can completely represent the simulated forging process, including [7]:

- import of CAD geometry via standard formats: STL, DXF, Nastran, and VRML,
- selection of press from the press database, as well as selection of workpiece and tool material from the materials database,
- definition of friction conditions, definition of temperatures and heat transfer coefficients,
  positioning of workpiece.

5. CONCLUDING REMARKS

In order to reduce lead-time and investment cost for the development of metal forming processes, integrated CAD/CAM/CAE solution is needed. Integrated technologies offered by NX system, or NX CAM in particular, offer a number of advantages, such as: advanced capability in key machining areas including High Speed Machining, 5-Axis machining and the support of multi-function machine tools, complete programming package with everything from a wide range of NC programming functions in the same system: turning, basic milling and drilling, fixed axis milling, variable axis milling, feature based automated programming, and support for multi-function machining. As part of a complex NX solution, NX CAM provides benefits either as an element of a standalone CAD/CAM solution or in a heterogenous CAx environment where data may come from a variety of sources.

6. REFERENCES

[1] Tomov, B.: Hot closed die forging – State-of-Art and future development, Journal of Achievement in Materials and Manufacturing Engineering, Vol. 24, Issue 1 September, 2007, pp.443-449

[2] Walter, J.: The Present and Future of Forging Simulation, Forging, Jan/Feb, 2006 http://www.forgingmagazine.com/zone/1188/news/71425/the_present_and_future_of_forging_simulation

[3] Fu, M. W., Yong, M. S., Tong, K. K., Muramatsu, T.: Simulation aided solution generation in metal forming product development, SIMTech technical reports Volume 6, No. 2, Jul-Sep 2005, pp. 5-10

[4] Vujović, V.: Technology of plasticity in mechanical engineering (in Serbian), Faculty of technical science, Novi Sad, 1990.

[5] Plančak, M., Vilotić, D., Trbojević, I., Milutinović, M., Movrin, D., Lužanin, O., Skakun, P. Some Contemporary Trends in Forging Design, XXXII Savetovanja proizvodnog mašinstva Srbije., Novi Sad, 2008, pp. 187-190

[6] NX 6 Help Library, Siemens Product Lifecycle Management Software Inc., 2008

[7] Simufact Forming – User manual, *Simufact* Engineering GmbH, 2008

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Matin, I., Hadzistevic, M., Hodolic, J., Vukelic, Dj., Tadic, B.

DEVELOPMENT CAD/CAE SYSTEM FOR MOLD DESIGN

Abstract: *Development of CAx for numerical simulation of injection molding and mold design has opened new possibilities for product analysis during the design process of plastic products. This development contributed to higher quality performance as well as to lower cost of product. The paper presents developed integrated CAD/CAE software for mold design. This program solution presents integrated system with unique applications for mold parameters computations, verifies injection molding parameters and for final mold CAD modeling.*
Key words: *plastic injection molding, mold design, CAD, CAE*

1. INTRODUCTION

Injection molding is one of the most important commercial processes for the production of plastic articles. It is the most important process used to manufacture plastic products. More than one third of all thermoplastic materials are processed by injection molding. The injection process has in fact one major disadvantage, namely the high cost of molds, which is why manufacturing products by this process is ideally suited to manufacture mass-produced parts of complex shapes that require precise dimensions. This disadvantage led to the development of the numerical simulation techniques that have great implications for the design of molds. During the last decade, there has been tremendous development in CAE, which offers flexibility to determine the effect of different geometric futures and different molding and processing conditions on the mold ability and quality of the final part [1].

During the last decade, many authors developed systems of mold design for injection molding. Todic et al. [2] have been developed system for automated process planning for plastic injection molds manufacturing. System is based on integration of CAD/CAPP/CAM activities without CAE calculations of parameters for injection molding. Godec et al. [3] have been developed CAE system for mold and injection molding parameters calculations. System used MS Access, MS Excel for thermal, rheology and mechanical calculation and material base management. Kovljenić et al. [4] developed model of CAD/CAM/CAE system for mold design using Pro/E for injection molding. Ren Jong et al. [5] have been developed a collaborative integrated design system for mold design within the CAD browser, using Pro/E module Pro/Web Link as the core tool. Providing both concurrent engineering and collaborative design functions, the navigation system is capable of assisting designers in accomplishing 3D mold development efficiently and accurately with the help of the standard component library and design decision-making system. Low et al [6] have been developed application of standardization for initial design of plastic injection molds. Proposed a methodology of standardizing the cavity layout design system for plastic injection mold such that only standard cavity layouts are used. When only standard layouts are used, their layout configurations can be easily stored in a database. Bor-Tsuen Lin at al. [7] describes a structural design system for 3D drawing dies based on functional features using a minimum set of initial information. In addition, it is also applicable to assign the functional features flexibly before accomplishing the design of a solid model for the main parts of a drawing mold. This design system is integrated with a Pro/E. CAD system including feature selector, calculator, model generator, design coordinator, and user interface. Kong et al. [8] developed a Windows-native 3D plastic injection mold design system based on Solid Works using Visual C++. Other knowledge-based systems, such as IMOLD, ESMOLD, IKMOULD, and IKBMOULD, were developed for injection mold design. IMOLD divides mold design into four major steps; parting surface design, core and cavity design, runner system design, and moldbase design. Software uses a knowledge-based CAD system to provide an interactive environment, assist designers in the rapid completion of mold design, and promotes the standardization of the mold design process.

2. MODEL OF INTEGRATED CAD/CAE SYSTEM

Generally, plastic injection molding design includes plastic part design, mold design, and injection molding process design, all of which contribute to the quality of the molded product as well as production efficiency [9].

The developed program system makes possible to perform: 3D modeling of the parts, analysis and of part design, numerical simulation of injection molding, and mold design with calculation [10].

By realization of proposed informational system, this problem could be solved. Architecture of integrated CAD/CAE system for automation mold design presents in Fig. 1.

System consists of four foundation modules. There are:

- CAD/I module for solid modeling of the part,
- CAE/I module for numerical simulation of injection

molding process,

- CAE/II module for calculation of parameters of injection molding and optimization of mold design and,
- CAD/II module for final mold modeling (Core and Cavity design and design all residual mold components)

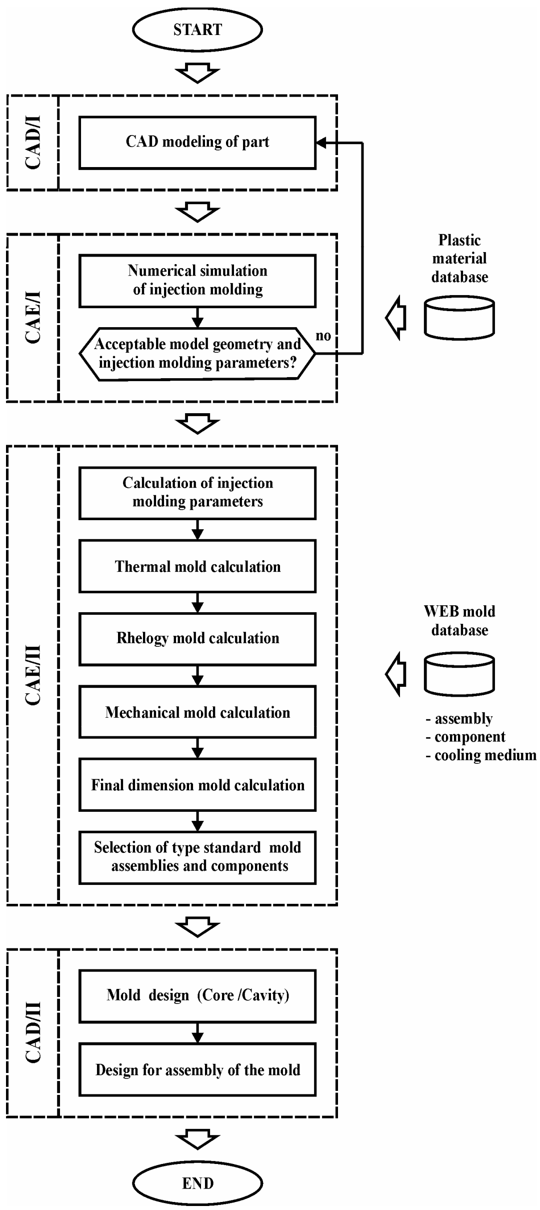

Fig.1 Model of integrated CAD/CAE system

2.1 CAD modeling (CAD/I module)

CAD/I module is the first module in to the integrated CAD/CAE system for optimal mold design. This module used for generating CAD model of the plastic products. The result of this module is solid model of plastic part with all necessary geometrical specification.

2.2 Numerical simulation of injection molding process (CAE/I module)

CAE/I module utilized for numerical simulation of the injection molding. After creation of 3D CAD model of plastic product, numerical simulation of injection molding process can be performed in the module Pro/E, Pro/Plastic Advisor. This application supports also other different CAD formats such as IGES, STEP, DXF, STL etc. It means that this module makes possible to carry out a simulation that is not designed in Pro/E. After importing the CAD model, material choice from the database (which can be permanently completed), and definition of injection molding parameters, system automatically applies the suggested parameters for chosen material, but there is a possibility to make subsequent changes and alterations. Date-Base of plastic materials included 6000 plastic materials. CAE/I module offers four different types of mold flow analysis. Each analysis is aimed at solving specific problems:

- Part Analysis - This analysis is used to test a known gate location, material, and part geometry to verify that a part will have acceptable processing conditions.
- Gate Optimization - This analysis test multiple gate locations and compares the analysis outputs to determine the ideal gate location.
- Part Optimization - This analysis test multiple thicknesses of the same part in order to reduce part thickness thereby minimizing cycle time and part weight.
- Sink Mark Analysis - This analysis detects sink mark locations and depths to resolve cosmetic problems before the mould is built eliminating quality disputes that could arise between the molder and the customer.

The part molding process is heavily affected by factors of the part design. If the critical parameters of a part are not set correctly, the part will have quality issues during the molding process. The most critical of these parameters is as follows:

- Part thickness,
- Part flow length,
- Thickness transitions,
- Part material,
- Location of gates,
- Number of gates,
- Mold temperature, and
- Melt temperature.

2.3 Special calculation (CAE/II module)

CAE/II module has been developed to solve problem of mold thermal, rheology and mechanical calculations for injection molding and optimizing mold design.

Outcome CAE/I parameters like as (injection pressure, mass properties, maximal melt temperature, mold temperature, injection time...) must be inserted in to inlet form of the CAE/II module as presented in Fig. 2.

After that software, lead engineer in to thermal, rheology and mechanical calculation. One of the several forms for thermal calculus is presented in Fig. 3.

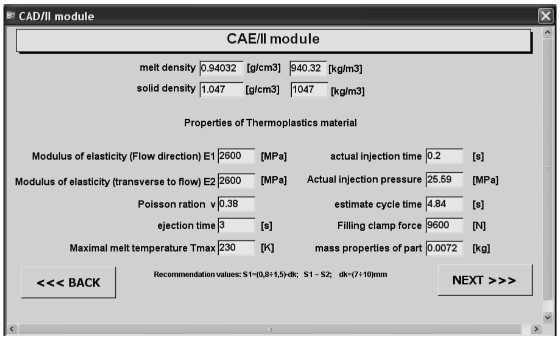

Fig.2 Inlet form of CAE/II module

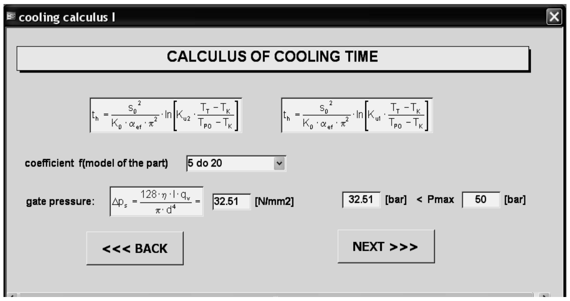

Fig.3 Form for thermal mold calculation

One of the several forms for wall thickness calculus is presented in Fig. 4.

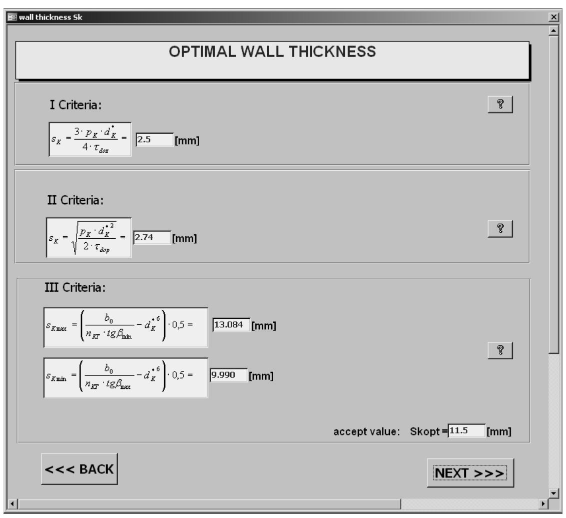

Fig. 4 Form for wall thickness calculation

After all thermal, rheology and mechanical calculations user, prefer choice of mold plates from mold base. Form for selection D-M-E standard mold plates is presented in Fig. 5.

Application load dimensions from date base and generating solid model of the plate. Dimensions of mold component (for example clamping plate) are presented in Fig. 6.

Outcomes results of CAE/II module are optimal parameters of injection molding, geometrical and technology specification of the mold.

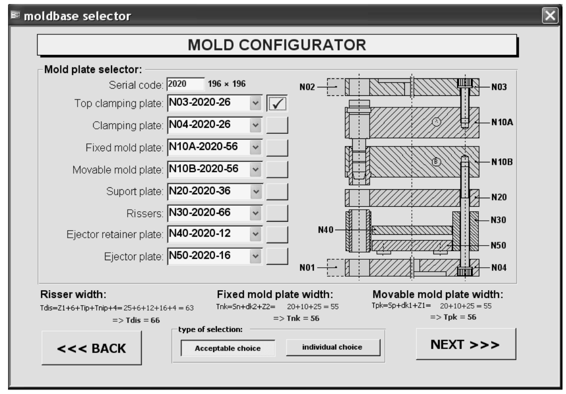

Fig.5 Form for selection standard mold plates

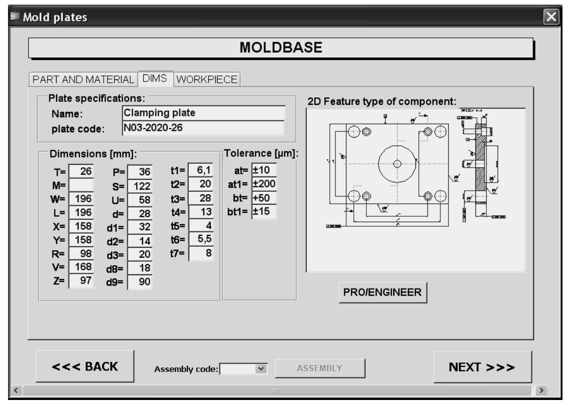

Fig.6 Form for generating solid model of clamping mold plate

2.4 Mold design (CAD/II module)

CAD/II module used for final CAD modeling of the mold (core and cavity design). This module used additional software tools for automation creating core and cavity from CAD model including shrinkage factor of plastics material and automation splitting mold volumes of the stationary and movable plates. Additional capability of CAD/II module is software tools for:

- Apply a shrinkage that corresponds to design plastic part, geometry, and molding conditions, which are, compute in CAE/I and CAE/II module for automation core and cavity design,
- Make conceptual CAD model for non-standard plates and mold components.
- Design core and cavity inserts, sand cores, sliders, lifters, and other components that define a shape of molded part,
- Populate a mold assembly with standard components such as mold base (D-M-E, HASCO , Futaba, Strack, DMS, EOC, MISUMI, Meusburger, Strack, Pedrotti), and CAD modeling ejector pins, screws, and other components creating corresponding clearance holes,
- Create runners and waterlines, which dimensions was calculated in CAE/II module,
- Check interference of components during mold opening, and check the draft surfaces.

After applied dimensions and selection mold components, CAD/II module generating 3D model of the fixed and movable plate. Geometry mold specifications, which are calculating in CAE/II module, automatically integrated in to CAD/II module, as results CAD/II outcomes are assembly of mold plates.

3. CONCLUSION

In this paper process design of plastic parts production, by means of Pro/E and special application for mold design are presented. As the production, results show the analyses, which have been performed during the process design, prove to be correct, e.g., integrated CAD/CAE system proves to be a confident software tool. All described modules of CAD/CAE system are 3D solid-based, feature oriented, associative and modular. Plastics flow simulation product in CAE/I that allows engineers to determine optimal critical parameters. CAD/II module also enables engineers to capture their own unique design standards and best practices directly within the mold assemblies and components. Module for calculation of mold specification and parameters of injection molding (CAE/II) improves design efficiency, reduce mold design errors, and make need fully information of geometry and technology for complete mold design. Of course, that standard components library (CAD/II) ensures the consistency of mold development and reduces the time and manufacturing cost of standard components. A design decision-making system assists the project leader in making key decisions quickly to guide designers via module.

The future work of this research can focus on two issues. The first one is an intelligent core and mold base with knowledge-based management for automatic parting surface creation, and components assembling through feature-oriented approach and development new high-tech formulas for mold calculation in CAE/II module.

4. REFERENCES

[1] Hodolic, J., Matin, I., Stevic, M., Kovačevic, I., Kuric, I.: *Mold design and simulation of plastic injection molding process in the CAD/CAE software*, 12th International Scientific Conference MECHANICAL ENGINEERING 2008, pp. CD-ROM, The Faculty of Mechanical Engineering, Bratislava, 13.-14. November 2008.

[2] Todic, V., Lukic, D., Stevic, M., Milosevic, M.: *Integrated CAPP System for Plastic Injection Molds Manufacturing.*, Materiale Plastice, Vol. 44, No. 4, pp.381-389, 2008.

[3] Godec, D.: *Development of systemic theory of mould for injection molding of thermoplastics*, Faculty of Mechanical Engineering and Naval Architecture, MSc Thesis, pp. 217, Zagreb, Croatia, 2000.

[4] Kovljenic, B., Ivanovic, R., Puzovic, R., Popovic, M.: T*he state and perspectives of CAD/CAM/CAE application in plastic products and corresponding tools design*, 29th Jupiter Conference, pp. 2.47-2.50., Faculty of Mechanical Engineering, Belgrade, February, 2003.

[5] Ren Jong , W., Wu, Ch., Liu, H. H.,. Li, M.Y.: *A Collaboration Navigation System for Concurente Mold Design*, The International Journal of Advanced Manufacturing Technology, Vol. 40, No. 3-4, pp. 215-225, 2009.

[6] Low, M. L. H., Lee, K. S.: *Application of standardization for initial design of plastic injection moulds,* International Journal of Production Research, Vol. 41, No. 10, pp. 2301–2324, 2003.

[7] Bor-Tsuen Lin, Ming-Ren Chang, Hau-Luen Huang and Chun-Yu Liu.: *Computer-aided structural design of drawing dies for stamping processes based on functional features*, The International Journal of Advanced Manufacturing Technology, Vol. 42, No. 11-12, pp. 468-479, 2008.

[8] Kong, L., Fuh, J. Y. H., Lee, K. S., Liu, X. L., Ling, L. S., Zhang, Y. F., Nee, A. Y. C. *A Windows-native 3D plastic injection mold design system,* Journal of Materials Processing Technology, Vol. 139, No. 1-3, pp. 81-89, 2003.

[9] Matin, I., Hodolic, J., Budak, I.: *Injection moulding simulation in the automated product designing systems,* International Journal of Simulation Modeling, Vol. 3, No. 2-3, pp 69-79, 2004.

[10] Hodolic, J., Matin, I., Vukelic, Dj., Antic, A.: *Using compex surfaces for Core and Cavity design of mold*, 8th International Scientific Conference - New ways in Manufacturing Technologies, pp. 299-302, Technical University of Košice - Faculty of Manufacturing Technologies with a seat in Prešov, Prešov, 22-23 June, 2006.

[11] Lou, Z., Jiang, H., Ruan, X.: *Development of Integrated knowlledge-based system for mold-base Design*, Journal of Materials Processing Technology, Vol. 150, No. 1-2, pp.194-199, 2004.

[12] Lam, Y. C., Britton, G. A., Deng, Y. M.: A computer-aided system for an optimal moulding conditions design using a simulation-based approach, The International Journal of Advanced Manufacturing Technology, Vol. 22, No. 7-8, pp. 574–586, 2003.

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DESIGN OF FORGING TOOLS FOR YOKE-LIKE ELEMENTS BASED ON NUMERICAL SIMULATION

Abstract: *Forming-sequence design of multi-stage hot forging is an open-ended process with numerous possible solutions that has great influence on the cost and quality of forged part. It is time consuming procedure and requires many kinds of technical and empirical knowledge of design engineers. However, recent development of CAD and CAE techniques, including process visualization, made it possible to utilize computerized forming process and tools design. It enables analysis of great number of process variables and many solutions to be simultaneously considered. Result of this is significant saving in time of forming-sequence procedure and overall improvement of forging process and product quality.*

In this paper design of tools for hot closed die forging are given for yoke-like part was analyzed. Also, influence of contact pressure between specimen and dies is considered. For finite element and finite volume simulation software SimufactForming was used.

Key words: *Hot forging, Tool design, FE and FV simulation.*

1. INTRODUCTION

In hot forging process, an initial block of heated metal with a simple cross section is compressed between two ore more dies to produce a complex-shaped part. During forging not only the shape of input material is changed but also its structure and mechanical properties as a result of refinement of starting grain size and favorable fiber orientation. Good mechanical properties and high reliability bring forgings reputation of irreplaceable components in applications where tension, dynamic loads, demanding environments, human safety etc. are critical considerations [1].

In recent years, hot forging has shown continuous technological changes, mainly in the geometry of the dies and in the dimensional accuracy of forgings [2]. Since today hot forging have to be competitive even for small lot sizes, forgings weight and machining allowances are being minimized and therefore subsequent machining is being reduced with low final costs and investments [2, 3].

Hot forging is usually performed as multi-stage process since simply billet geometry could rarely be transformed into its final shape in only one operation. Therefore, the forming sequence design plays a key role in this process. It influences both: the quality of hot forged components and manufacturing cost. With proper number of preform steps and preform shapes, die filling without defects, high quality of the surfaces and high accuracy of the forged part can be achieved and metal losses into flash minimized in the final forging operation [4].

In the past tool design was relied on activities strongly dependent on human expertise, intuition and creativity [2] and performed by iterative trial-and-error approach which requires extensive experimental work. However in many cases, this trial-and-error procedure is neither optimal nor cost effective in terms of achieving the desired properties of the finished product. Recent development of computer-aided simulation techniques made it possible to upgrade efficiency of the process of forming-sequence design. Numerical simulations based on Finite Element Method reduce time and man power in process design and enable simultaneously analysis of large number of process variables and pre-form solutions before actual try out [5, 6, 7]

In this paper design of tools for hot closed die forging yoke-like element is given. Two methods are considered:

- Preforming with open dies
- Preforming with closed dies.

2. PROCESS DESCRIPTION

The process of hot closed-die forging of yoke-like element consist of operations of forging to mass and geometry distribution (pre-forming), final forging, flash trimming and plate punching. Starting bulk (billet) of proper size is firstly cropped from rectangular bars and then heated to forging temperature. Its volume is about 20% larger from the volume of final part after machining because of loses into the flash, draft, radii, scrap and machining allowances that should be included in volume calculation. For small series open die forging is commonly applied in preforming of billet, while for large series closed die preforming is used. The goal is to obtain proper material distribution along longitudinal axis of workpiece.

Dimension of the yoke-like element is shown in Fig. 1. Radii and draft dimensions are adopted form recommendation given by experts [8, 9].

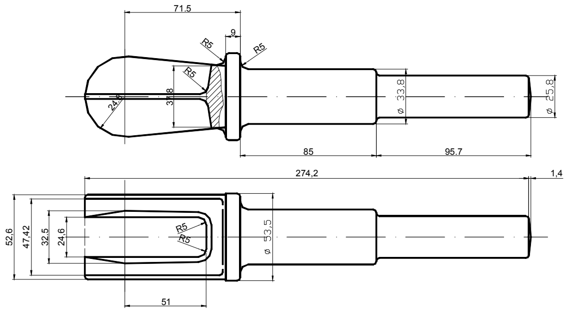

Fig 1. Dimension of forged yoke- like element

3. PROCESS MODELING

Process of manufacturing yoke-like element has been analyzed by using Finite Elements and Finite Volume methods and commercial software Simufact Forming v.8.1.

Determination of number of preforming stages is the most critical part in process modeling. In case of yoke like element operation of hot forging can be done by one or two preform operation; according to [9]. It depends on the quantity of production. For small series one preforming operation is suggested and for large series two operations is more favorable.

For preformin operation open and close dies can be used. Which die will be used, depends on the quantity of production, because closed dies are expensive and more complicated for manufacturing then open

Material of the yoke-like element was steel C25. The material data necessary for simulation were imported from the list of materials incorporated in Simufact.Forming8.1. In simulations, the following assumptions of the process variables are implied: the dies are considered as rigid bodies, fixed bottom die and movable upper die, strain rate $\dot{\varphi}$=6.5 [s^{-1}]. As for boundary conditions the initial forging temperature is 1150°C, preheated dies temperature 400°C, heat transfer all the surface and internal body of the dies and workpiece, constant friction model is applied and friction factor is assumed to be m=0.3 [8,10]. The capacity of pneumatic hammer which is used in simulations is limited to 80kJ in respect of the actual hammer capacity in industry.

One of the more influential parts of die on accuracy of forged part is a flash, especially in case yoke-like element forging. Details of flash geometry in the finishing dies are depicted in Fig. 2. Thickness (s) and width (b) of the flash land are calculated according following empirical expressions [9]:

$$s = 0.017 \cdot d_1 + \frac{1}{\sqrt{d_1 + 5}} \qquad (1)$$

$$\frac{b}{s} = \frac{30}{\sqrt{d_1\left(1 + \frac{2d_1^2}{h\left(2r_h + d_1\right)}\right)}} \qquad (2)$$

where are:
d_1 – diameter of the forge at parting-line surface
h – maximal height of the forge in direction of forging
r_h – distance between the highest elements of the forge and parting line

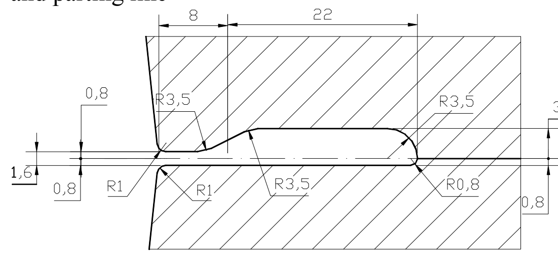

Fig. 2. Geometry of the flash in the finishing dies

4. TOOL DESIGN

4.1 Preforming with open dies

Intermediate steps in pre-forming with open dies are schematically illustrated in Fig.3. Dimensions of the billet were 50x50x136mm [10]. It requires 6 blows while rotating the workpiece between upper and bottom die to model pre-form shown in Fig.3 which is then forged into the final shape.

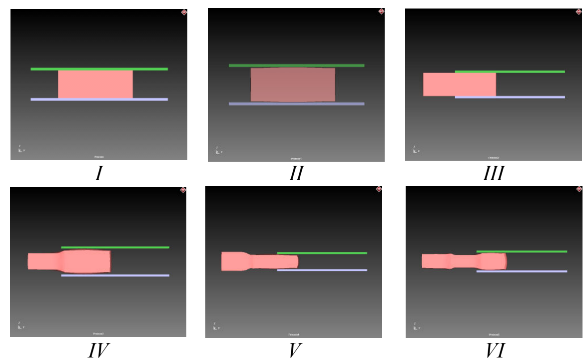

Fig. 3. Pre-forming stages realized with open dies

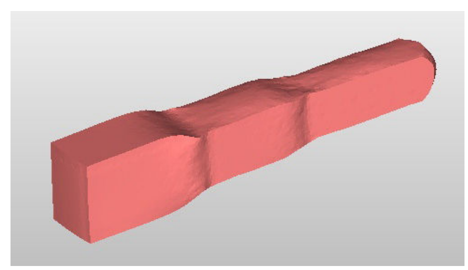

Fig. 4. Pre-form after flat upsetting

In this case the number of pre-forming stages necessary to attain an intermediate shape depends mostly on operator’s skills. It needs several blows of hammer to reach desired shape. Such large number of the preforming stages increases manufacturing time and energy consumption. Also there is limitation in the form of cross section of the pre-form (only rectangular) when used flat upsetting in pre-forming stages. Result of this could be cavity underfilling in the final forging and an overload of the finishing dies. It is illustrated by Fig. 5 where preform is set 15 mm away from it nominal position. It can be seen from figure that a relatively large cavity remains at the upper surface of head section.

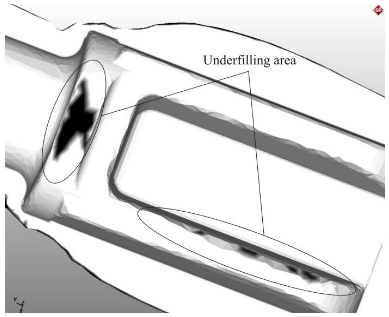

Fig. 5. Under filling in case of non-proper positioning of the pre-form in the finishing dies

For complete die cavity of the finishing dies, 3 blows are required when use 80kJ hammer. Fig.6 displays distribution of contact stresses at the end of forging. Predicted values of the contact stresses are pretty high 1800MPa in average and with maximum values of 3000 MPa. It means that finishing dies are partly overloaded which may reduce their service life significantly.

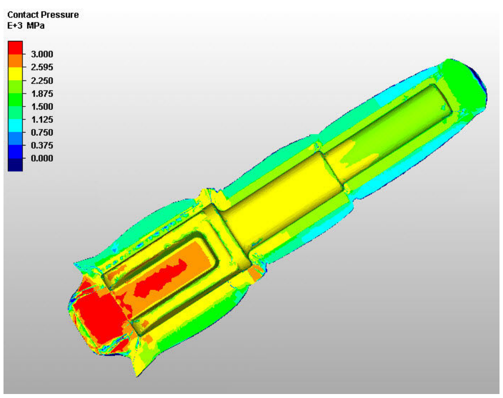

Fig. 6. Contact stresses in the operation of final forging (open die preform)

This way of manufacturing of yoke-like element is applicable for small series. In Fig. 6 die for hot forging yoke-like element with one preforming operation are shown.

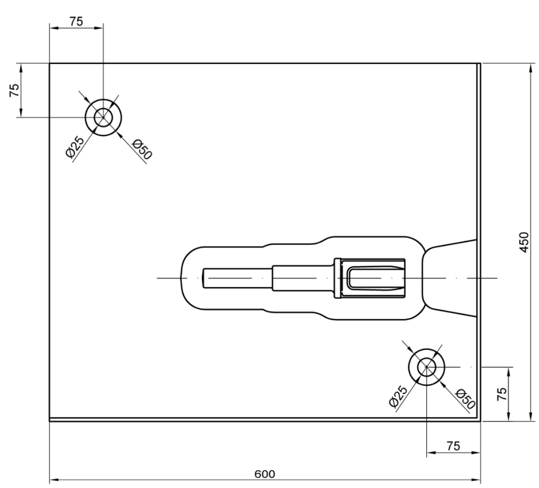

Fig. 7. Overall dimension of die for hot forging yoke-like element with one preforming operation

4.2 Preforming with closed dies

Complex form of the pneumatic clamp requires an optimization process of the geometry of the finishing dies. In that sense special attention should be paid to the design of various sections in the final die cavity which have to be balanced in order to avoid extreme differences in metal flow as the flash dimensions should provide correct die cavity filing with reasonable forging pressures. Also, two preforming operation are used; one for mass distribution and other for geometry distribution.

Fig.8 shows scheme of closed-die forging process for mass distribution in which an impression with elliptical cross-section is used. Simulations shown that elliptical cross-section of the pre-form leads to an increase of the horizontal forces which are crucial for mass redistribution along longitudinal axis when forge the pneumatic clamp. In this case intermediate shape for final forging is obtained in 3 steps by pivoting workpiece for 90° for each hammer blow. Billet 40x50x170mm has the same volume as one in flat upsetting, but starting height was chosen smaller to avoid an operation of flat upsetting. The final shape of workpiece after pre-forming operations of mass distribution is depicted in Fig.9.

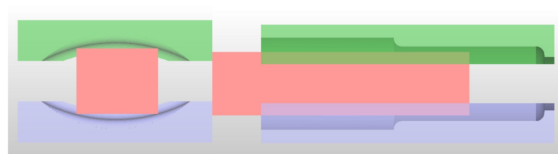

Fig. 8. Elliptical impression for operations of mass distribution

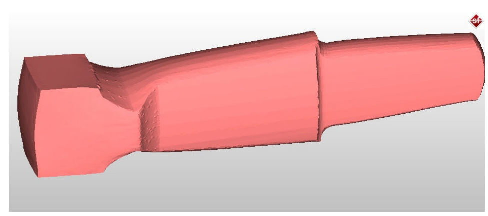

Fig. 9. Pre-form after operation of preforming (mass distribution)

In Fig.10 the contact stresses after operation of preforming for geometry distribution is shown. As it can bee seen, maximal contact stresses are about 800 MPa, which gives good starting base for operation of final forging.

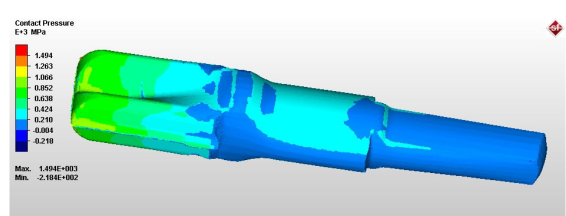

Fig. 10. Contact stresses after operation of preforming (geometry distribution)

The material flow and the process of cavity filling of finishing dies is better then one depicted in Fig.5, and in this case contact pressures predict by FV analysis (Fig.11) are lower in average for about 60%, as the maximal contact pressure was about 1000MPa. Also in this case only 2 blows of 80MJ hammer are needed for complete die cavity filling.

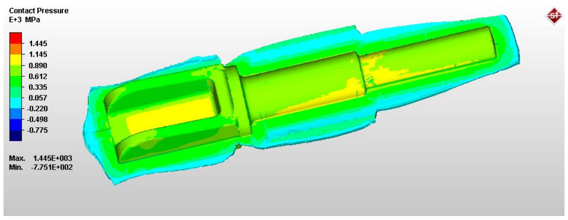

Fig. 11 Contact stresses in the operation of final forging (closed die preform)

3D model of tool with three cavities (two for operation preforming and one for finished forging) is depicted in Fig.12.

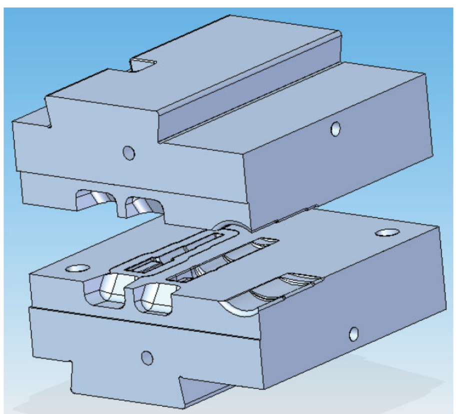

Fig. 12. 3D model of dies for hot forging yoke-like element with two preforming operation

5. CONCLUSION

In this paper two approaches for forging tool design are presented and analyzed by numerical simulation. From the simulation results following can be concluded:

- In the case of open-die preforming several blows of hammer are necessary to reach desired shape which results in increasing of production time and energy consumption. Numerical simulation showed potential places of cavity underfilling. Values of contact stresses, predicted by simulation indicated that finishing die would be partly overloaded.
- Results obtained by numerical simulation showed that material flows and cavity filling are better when preform is produced by closed-die preforming. Also in that case contact pressures are lower.
- Although numerical simulation showed that better process parameters can be achieved by closed-die preforming, but that solution is acceptable for large series production only, because of the pre-form tool cost.

Acknowledgement

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11. REFERENCES

[1] Milutinović M., Vilotić D., Movrin D.: *Precision forging – tool concepts and process design,* Journal for technology of plasticity, Vol. 33, pp.73-89, 2008.
[2] Caporalli A., Gileno L. A., Button S. T. Expert system for hot forging design, Journal of Mat. Proces. Technology 80–81, pp 131–135, 1998
[3] Behrens B.A., et al.: *Precision forging processes for high-duty automotive components,* Journal of Mat. Proces. Technology 185, pp. 139–146, 2007.
[4] Dies and Die Materials for Hot Forging in Forming and forging, 9th ed, Metals Handbook, American society for metals, 1993.
[5] Fujikawa, S.: Application of CAE for Hot Forging of Automotive Components. Journal of Mat. Proces. Technology, Vol. 98, pp 176–181, 2000.
[6] Tomov B.I., Gagov V.I., Radev R.H.: Numerical simulations of hot die forging processes using finite element method, Journal of Materials Processing Technology 153–154, pp 352–358, 2004.
[7] Šraml M., et al.: Computer-aided analysis of the forging process, Int J Adv Manuf Technol 23, pp 161–168, 2004.
[8] Altan T.: Cold and Hot Fortings-Fundamentals and applications. ASM International, 2005.
[9] Vujović V.: Technology of plasticity in mechanical engineering (In Serbian), Faculty of technical science, Novi Sad, 1990.
[10] Movrin D. et al.: Optimization of pneumatic clamp forging process by numerical simulation, Proceedings of 33rd conference on production engineering of Serbia with foreign participants, Belgrade, pp 229-232, 2009.

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STRESS ANALYSIS OF A BRAKE DISC CONSIDERING CENTRIFUGAL LOAD

Abstract: *Disc brakes appear in all transportation systems. They are also used in railway transport. Because of the influence of different loads on a brake disc, an analysis is carried out with a finite elements method (FEM). The goal is to find out the influence of the centrifugal force on a brake disc. The analysis is carried out for a brand new disc and a worn out disc because of its operation. After the analysis the results are interpreted and suggestions for improvements are made.*
Key words: *railway transport, brake disc, centrifugal load, FEM.*

1. INTRODUCTION

Brake discs are exposed to a variety of loads during their use. While driving without braking the disc is affected only with the centrifugal force. When the brake cycle starts, two additional forces affect the disc. These forces represent the force from the brake calliper and the force from the heat impute (as a result of friction). In this analysis only the influence of the centrifugal force is being determined.

The first goal of this research is to find out the maximum stress in the disc and the second goal is to find out the maximum extension of the disc, caused by the high centrifugal force. During the analysis two models of the brake disc are considered:

- a brand new disc,
- a worn out disc because of its daily operation (this disc has a permitted wearing of 7 mm on both sides).

Fig. 1. The brake mounted on the hub

2. NUMERICAL ANALYSIS OF A BRAKE DISC

In the beginning of the analysis the brake disc is simplified. Only one section of the whole disc is used. Considering the systems boundary conditions and the symmetry of the disc, only 1/12 of the disc is chosen. The analysis is carried out with help of FEM in the program Abaqus 6.7.1, which gives the results in numerical and picture form. With this program it is also possible to determine the spot where the stresses and extensions reach their maximum.

The material of the disc brake is spherical graphite, defined according to SIST EN 1563:1988 and with the characteristics according to EN-GJS-500-7 (EN-JS 1050) with surface roughness of Ra = 3.2 mm. Disc brakes were machined on CNC machine tool with cutting conditions which were previously optimized by an intelligent optimization software [5]. Surface roughness and cutting forces acting on the disc during machining were kept constant by continuous adaptation of cutting parameters [6] to current machining conditions.

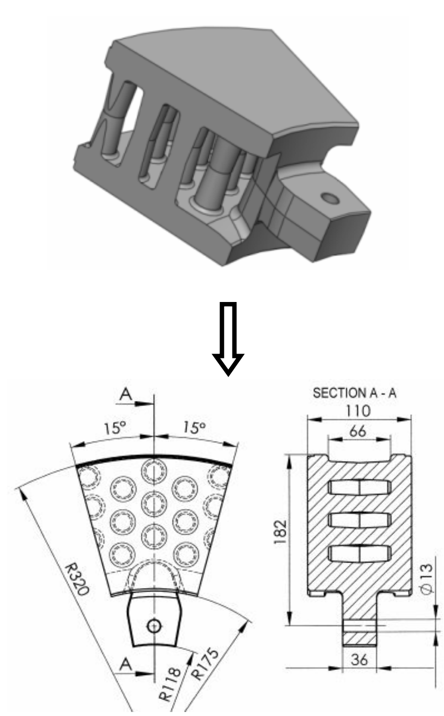


Fig. 2. The chosen section of the brake disc

2.1 The analysis

In this analysis the stresses, that are a direct result of the centrifugal load, are determined. This load comes as a result from high travelling speeds of the train. Beside that the weight distribution of the vehicle is also considered. The vehicle has one front and one back bogie. Each bogie consists of two axles with 3 brake discs. The weight arrangement is 50:50 – all discs are treated equal. In our case only 8.33 % of the whole brake force is applied to one disc of the carriage. All the data, used in the calculation and needed to run the analysis, are shown in Table 1.

Number of axles	4
Number of discs per axle	3
Diameter of the wheel d_{wheel}	0,92 m
Effective radius of the wheel r_{disc}	0,247 m
Deceleration at braking	1,4 m/s^2
Maximum velocity	250 km/h=69 m/s
Density of the material	7100 kg/m^3
Elastic module	169000 N/mm^2
Poisson number	0,275
Heat conductivity	35,2 W/m^2K
Specifically heat of the material	515 J/ kgK
$R_{p0,2}$	320 MPa
R_m	500 MPa
Minimal extension	7%
Total mass of the vehicle	70000 kg
Time to standstill	50 s
Initial temperature of the disc	150°C
Temperature of the environment	50°C

Table 1. The data used for calculation

The consequences of centrifugal loads (caused by the high travelling speed of the vehicle) applied to the disc were determined and calculated in the analysis. The results were stresses. To begin the calculation, the angular velocity was needed:

$$\omega = \frac{v}{r} = 151\left[s^{-1}\right] \quad (1)$$

where the v [km/h] represents the maximum velocity of the vehicle and r [m] the radius of the wheel. It is also necessary to determine the holding force of the brake clamps on the disc. The surface pressure between the disc brake and the brake pads was determined on the basis of the calculated braking force and because the brakes work on the brake disc by means of pneumatic system, the pressure was:

$$p = \frac{F_{disc}}{A_c \cdot \mu}\left[MPa\right] \quad (2)$$

The surface pressure was 1.14 MPa. This boundary condition was also considered in the calculation although because of its low value, it could be disregarded.

The braking force on the disc is equal:

$$F_{disc} = \frac{0.0833 \cdot \frac{1}{2} \cdot M \cdot v_0^2}{2 \cdot \frac{r_{disc}}{r_{wheel}} \cdot \left(v_0 \cdot t_s - \frac{1}{2} \cdot a \cdot t_s^2\right)}\left[N\right] \quad (3)$$

The force permitted on one side of the disc is 17500 N; the calculated value is lower. This means that the calculated force does not exceed the maximum value. Other parameters and material properties are from international standards for materials and from the internal standards defined by the maker of the disc. The section of the disc and its geometry is transferred from the program SolidWorks 2008 to the program Abaqus 6.7.1. Immediately after the transfer the geometry is scaled. Because of that, the results are in N/mm2. After that, the models boundary conditions are determined and the material properties are put into the program.

Additional boundary conditions were determined on the surfaces where the brake disc was cut up. The symmetrical boundary condition on the edge of the selected section was modelled with slide supports in radial direction. After that, the main load is determined. The main load is the centrifugal load caused by the maximum travel velocity of the vehicle.

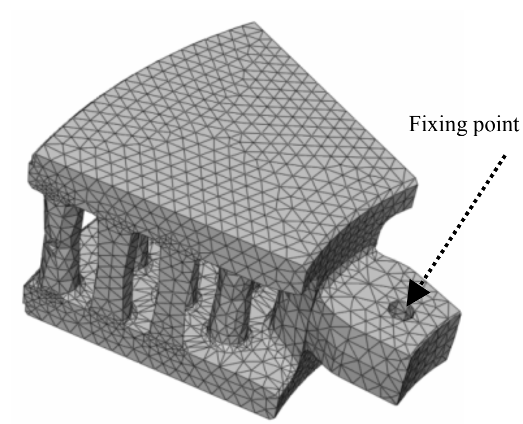


Fig. 3. Meshed section of the disc

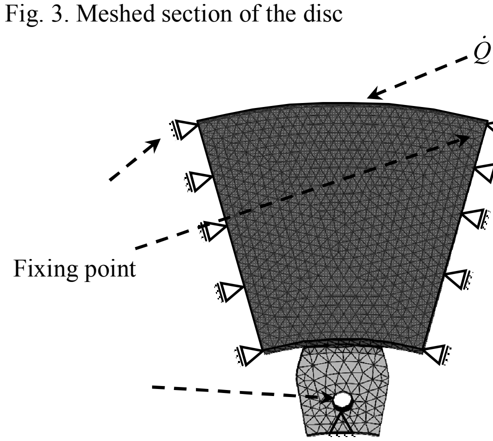


Fig. 4. Load, fixing and mesh of the selected section

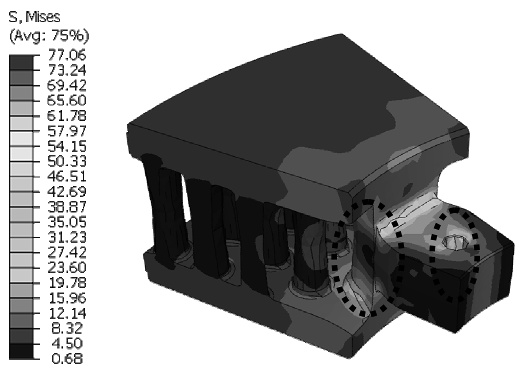
In the next step the model is meshed. Because of the complex geometry of the model it is not possible to use hexagonal mesh element. Instead tetrahedral mesh elements were used. The creation of a mesh volume was conducted automatically by the software package Abaqus CAE 6.7.1. The mesh consists of 86713 tetrahedral elements (element code C3D4AT – allows linear thermo – deformational analysis). The average size of the elements is 6mm and the number of nodes is 18135. Figure 3 shows the meshed model.

3. THE RESULTS

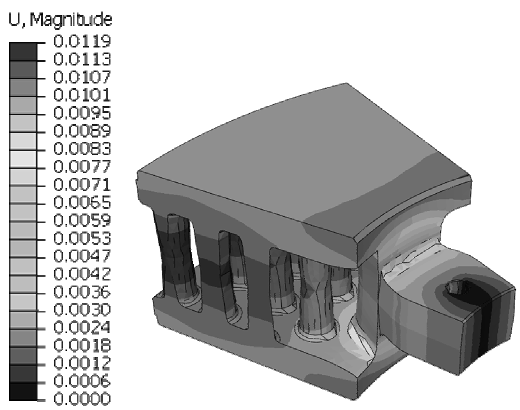
3.1. The calculation of centrifugal load for the new disk 195H6

In the first phase of the analysis, the new disc was analysed. This disc is without wear. The figure 4a and 4b show the calculated results. On behave of the analysis a comparison of stresses on von Mises and maximum extension was made.

The analysis was carried out at the maximum velocity of the vehicle - 250 km/h. The maximum value for stress is in the hole where the disc is attached to the hub, which is later on press fitted onto the axle, and on the passage from the fixing point to the disc rim, on the figure 5a marked with the line. The maximum value for stress amounted to 77.06 MPa.



a)



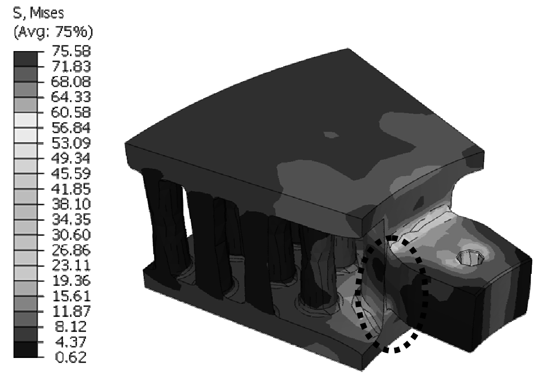
b)

Fig. 5. Stress on von Mises and extension

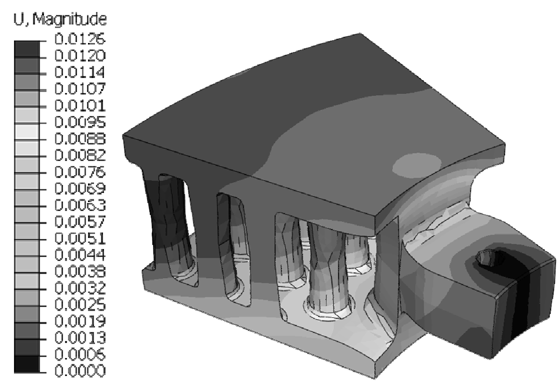
The figure 5b shows the movement respectively the extension because of the influence of the centrifugal load. From the figure 5b we can see that the maximum extension lies in the boundary of 0.012 mm.

3.2 The calculation of centrifugal load for the worn out disk 195H6

The figure 6a shows values for the amounted stress for the chosen section of the disc. The maximum value for stress is in the hole, where the disc is attached to the axle and on the passage, on the figure 6a marked with the line. The maximum value for stress amounted to 75.58 MPa.



a)



b)

Fig. 6. Stress on von Mises and extension

Figure 6b shows the maximum extension of the disc–the value amounted to 0.0126 mm.

4. DISCUSION OF THE RESULTS

Table 2 shows the results, which are a consequence of the influence of the centrifugal load on the material of the brake disc. This analysis is made for the worst case scenario. In our case, this occurs at the maximum velocity of 250 km/h. The stresses are high but in comparison with the allowed stress for this material, which includes a safety factor of 1.5, the brake disc is adequately dimensioned. The difference in stress between the brand new disc and the worn out disc is a consequence of the material properties. All materials have the tendency to elongate or shrink under certain circumstances. In this case the more material we have, the harder it is to deform it. Consequently the less material we have, the easier the high centrifugal forces can deform it. The material deforms and the stresses are lower. Although too little of the material on one spot can cause a catastrophic failure of the brake disc. That is why the brake discs should regularly undergo an inspection.

Brake disc	σ_{max} [MPa]	extension [mm]
Brand new	77.06	0.012
Warn	75.58	0.0126

Table 2. The results

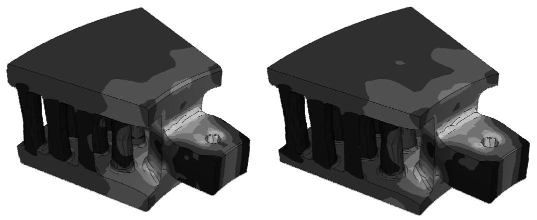


Fig. 7. Direct comparison of stress fields, left the new disc and right the worn out

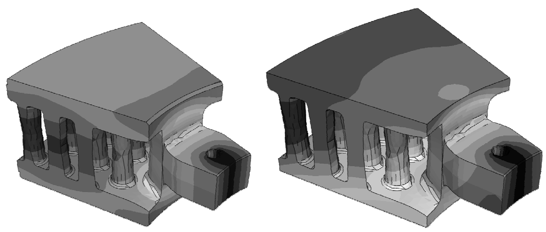


Fig. 8. Direct comparison of extension, left the new disc and right the worn out

On figure 7 and 8 we can directly see how the stress fields are distibuted in both sections and also how the extenson is affecting the disc.

5. CONCLUSION

The results of the analysis show what a centrifugal load can do to a solid object, in our case a brake disc. In conclusion the brake disc needs to be primarily analyzed for centrifugal load. Also a whole array of other forces is affecting the brake disc. For further analyses we would recommend to add additional boundary conditions to the centrifugal force and run through more test. Also a field test would be recommended to compare the results. An analysis could also be run through, to determine the affect of milling process on the structural integrity of the disc.

To lower the stress and extension we recommend two constructional improvements:

- choosing another material with better mechanical properties,
- changing the passages respectively the radiuses where the stresses are the highest.

6. REFERENCES

[1] Mackin, T. J.: *Thermal cracking in disc brakes*. *Engineering Failure Analysis* (2002), no. 9

[2] Ren, Z.; Ulbin M.: *FEM practical course for Abaqus:* Faculty of mechanical engineering Maribor, 2002. Acquired 13.04.2009 at http://lace.uni-mb.si/Num _meth _konst / *ABAQUS 6.7.1*

[3] Reibenschuh, M.: *Napetostna analiza zavornega diska s sredobezno in termicno obremenitvijo*: diplomsko delo. Maribor: Fakulteta za strojnistvo, 2008

[4] Oder, G.: *Dolocitev nestacionarnih termicnih in napetostnih polj zavornih diskov*: diplomsko delo. Maribor: Fakulteta za strojnistvo, 2008

[5] Zuperl, U.; Cus, F.: (2008) *Machining process optimization by colony based cooperative search technique*. Strojniski vestnik - Journal of Mechanical Engeneering, vol. 54, no. 11, p. 751-758.

[6] Cus, F.; Zuperl, U.; Kiker, E.: (2007) *A model - based system for the dynamic adjustment of cutting parameters during a milling process*, Strojniski vestnik - Journal of Mechanical Engeneering, vol. 53, no. 9, p. 524-540.

[7] Potrc, I.; Lerher, T.; Sraml, M.; Samec, B.; Oder, G.: *Expert advice on the levels of tensions in A, B, C, D and M versions of brake discs*, Maribor 2008.

[8] Reibenschuh, M.; Oder, G.; Cus, F.; Potrc, I.: *Modelling and Analysis of Thermal and Stress Loads in Train Disc Brakes – Braking from 250 km/h to Standstill*. Strojniski vestnik - Journal of Mechanical Engeneering, vol. 55, no. 7-8, p. 494-502.

[9] Weitz&Luxenberg P.C.: *Recent Train Accidents*. Acquired 14.05.2009, at http:// www.weitzlux.com/ trainaccident_4533.html

[10] Yevtushenko, A.A.; Kuciej, M.: *Frictional heating during braking in a three - element tribosystem*, International Journal of Heat and Mass Transfer, vol. 52, no. 13-14, p. 2942-2948, *2009.*

[11] *ECONOMIC expert, List of rail accidents. Acquired 14.05.2009 at http://www.economi cexpert.com/2a/ List:of:railway: disasters.htm*

[12] Panier, S.; Dufrénoy P.; Weichert D.: *An experimental investigation of hot spots in railway disc brakes,* Wear, vol. 256, no. 7-8, p. 764-773, 2004.

[13] Zhen-cai Z.; Yu-xing P.; Zhi-yuan S.; Guo-an C.: (2009) *Three-dimensional transient temperature field of brake shoe during hoist's emergency braking*, Applied Thermal Engineering, vol. 29, no. 5-6, p. 932-937.

[14] Bagnoli, F.; Dolce, F.; Bernabei, M.: (2009) *Thermal fatigue cracks of fire fighting vehicles gray iron brake discs*, Engineering Failure Analysis, vol. 16, Iss. 1, p. 152-163.

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THE APPLICATION OF COMPUTER-AIDED METHODS IN DEVELOPMENT PROCESSES OF PLASTIC PRODUCT

Abstract: *In order to shorten manufacturing time for new products and their moulds, the use and the development of modern techniques are critical. One of such technologies is the rapid prototyping method, which enables to designers and customers to see the physical presentation of a new product. Application of the CAE methods is accentuated in the development phase of the product, which redounds to cost reducing on tools and moulds development. The paper deals with several steps in prototype development, the application of computer simulation by means of CAE system Moldflow MPI in mould development for mold plastic part and utilization of CAM system for NC programming of the mould manufacturing.*

Key words: *Rapid Prototyping, CAE technology, injection molding simulation, NC programming*

1. INTRODUCTION

A present–day rapid growth in diverse industries put the demanding requirements on rapid innovations of products. In order to reduction of manufacturing time for new products and their moulds, the use and the development of modern techniques are critical. One of such technologies is the Rapid Prototyping method, which enables to both, designer and customer to see the physical presentation of a new product.

The design of molded plastic parts as well as design of moulds for plastic injection processes is comparatively complicated process. It is needs takes into the account costs, production time, part design, ergonomic and aesthetic requirements. The part development process includes conceptual design – CAD model, engineering analysis, process simulation, manufacturing of prototype and testing [1,2]. The utilization of CAE methods allows through simulation to speed up the mould design process and the injection molding process optimization. Research in plastic injection molding area has brought a many scientific papers with the aim to improving optimalization algorithms of mold design [3-5]. Many other authors utilize CAE tools for optimization of variable parameters in plastic injection processes, as are minimal pressure [6], elimination of distortion and uniform of hot-melt flow in mold cavity [7], determination and evaluation of weld/melt lines [8] and shrinkage prediction [9].
The integration of product development processes like Rapid Prototyping, CAE and CAM methods has been presented in the paper. The procedure in prototype manufacturing by FDM method and subsequent plastic injection simulation by means of Moldflow MPI software was presented. In this analysis was analyzed injection molding parameters as are the fill time, injection pressure, distortion, shape precision as well as the influence of gate location.

2. EXPERIMENTAL PROCEDURE

2.1 Rapid prototyping

The Dimension 3D printers utilize for build model the FDM technology also known as Fused Deposition Modeling is layered manufacturing process. Dimension SST machine offers functional prototypes with ABS. The required geometry is produced in thin layers by a small CNC-controlled extruder A thin bead of molten plastic is extruded through the computer controlled nozzle, which is deposited on a layer-by-layer basis to construct a prototype directly from 3D CAD data. The technology is commonly applied to form, fit and the function analysis and the concept visualization. In addition, parts can be used for form fit and light testing purpose.

In order to reduction of manufacturing time and increasing of design reliability is needs to utilize the Rapid Prototyping methods in product development phase. After this it is possible to check if the product is adequately aesthetic, or if the part meets to specifications for requirement function. The Rapid Prototyping contributes to early mold development for given part.

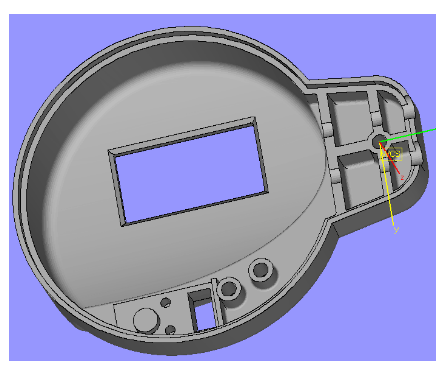


Fig.1 3D model of the product

A 3D computer model of the product presents the basis for the prototype manufacturing is shown in Fig.1. The prototype was oriented in machine's working area in consideration of functional, stiffness, and other product requirements. For the quality of manufacturing of the prototype, so-called supports that are attached to the model have to be determined, these supports being presented in Fig.2.

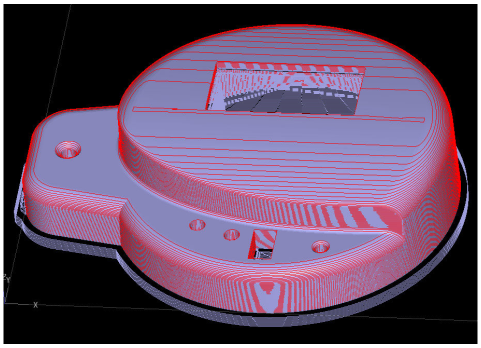


Fig.2 Model with supports

After that the manufactured parameters must be prepared. When the printing of prototype is finished Fig.3, the supports must be removed, and the prototype must be cleaned, hardened and completed. For rapid removing the supports from the prototype, it is suitable to apply device making use of sinuous flow of special solution.

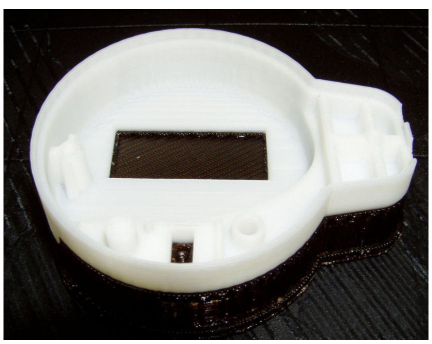


Fig.3 Prototype after printing with support structure

Depending on next exploitation of prototype, the prototype can be used directly for testing and presentation (Fig.4) or after surface finishing used as master model for manufacturing of a silicon mould for the first production (up to 100 parts), for easier design of the real moulding, as an aid in visualization and as an aid in sales activities.

Fig.4 Prototype with removed support ready for testing

2.2 Injection molding simulation

The simulation was performed in three variants of gate location. The gate selection was performed on the basis of part geometry, surface quality of part and analysis performed for optimal gate location (MPI) (see Fig. 5). The simulation was done with equal terms in all three cases, listed in Table 1.

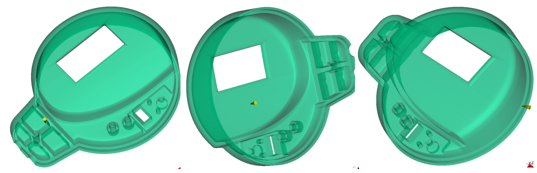
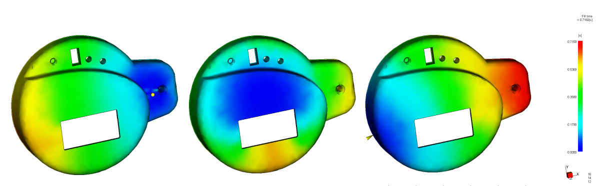


Fig.5 Gate location for variant A, B and C (from left to right)

Material	Enduran 7065 PBT
Melt temperature	280^o C
Mold temperature	60^o C
Cooling time	20 s
Fill control	automatic
No. of nodes	17579
No. of tetraeder elements	97916

Table 1. Settings of simulation process

Manufacturability was checked from severe different point of view, among which the optimal one had to found: the lowest fill time, the lowest injection pressure and minimal shrinkage and warpage of part. The results of simulation for concrete examined parameters and all variants are mentioned below.



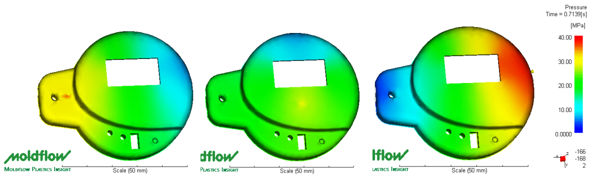
variant A – 0,6141 s variant B – 0,6135 s variant C – 0,7170 s

Fig.6 Results of analysis – fill time

From results (Fig. 6) it is possible to see, the fill time is shortest for variant A, however, the difference among all variants is within the range 0,1 s. Considering this small difference, the fill time will have low importance in selection of final variant.

Injection pressure was analyzed for selection of injection molding machine, especially, at which tendency is to minimize it. Fig. 7 shows minimal injection pressure for variant B and maximum injection pressure for variant C.

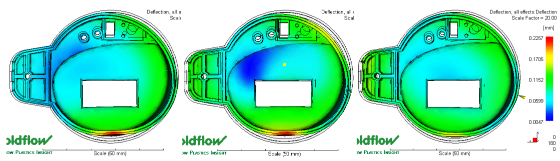
From Fig. 8, it is possible to see shrinkage and warpage of part as well as geometrical precision of molded parts. For better illustration, the results were enlarged 20 times.



variant A variant B variant C

Fig.7 Injection pressure at end of fill

The precision of molded pieces is very important due to fact, that part is component of thermometer who measures the fluid flow exactly. An emphasis will be focused just on this criterion.



variant A variant B variant C

Fig.8 Shrinkage and warpage of part

2.3 Computer Aided Manufacturing of the mould

In the mould making industry there are even higher demands for the reduction of manufacturing time. In order to achieve the most optimal manufacturing as regards reduction of manufacturing time and surface quality, some different milling strategies were carried out. A detailed description of milling operations will be done only for the core side of the mould – Fig.9 and Fig. 10. Manufacturing for the core side of the mould was simulated in system Catia V5.

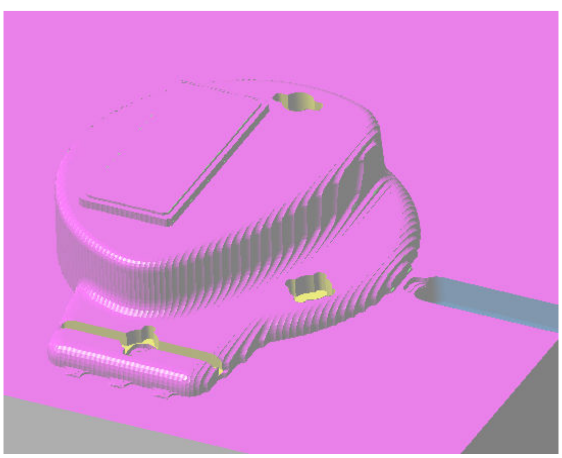


Fig. 9 Visualization of the surface quality after rough milling

The machining was suggested and realized as follows:

- rough milling of the mould by sweeping strategy (also runner system) – Fig.9,
- finish milling by pocketing strategy,
- drilling of tempering system and
- finish milling by sweep roughing strategy - Fig. 10 (applied on runner system too).

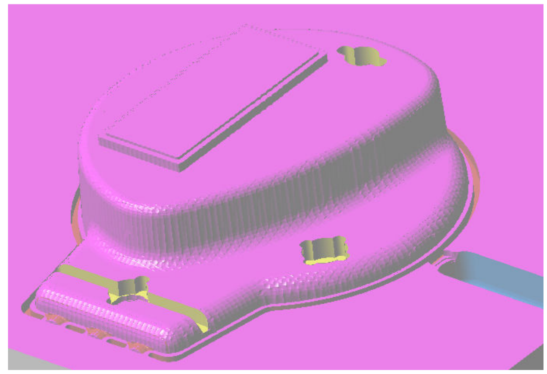


Fig. 10 Visualization of the surface quality after finish milling

When all required operations for machining of the mould was suggested, the simulation of whole CNC machining process was performed. The verification of the CNC program was performing to detect errors, potential collisions, or areas of inefficiency. CAM system enables to correct errors before the program is ever loaded on the machine, thereby eliminating manual prove-outs.

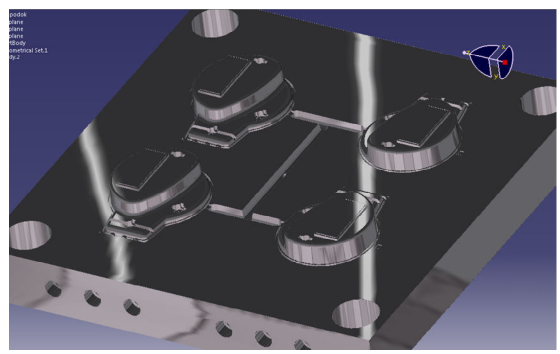


Fig. 11 The detail of core side of the mould (bottom part)

For the mould forming system was applied material Alumec 89 with hardness 199 HV30. All milling operations were made on the Emco Mill 155 machine with the Heidenhain 426/430 TNC control system.

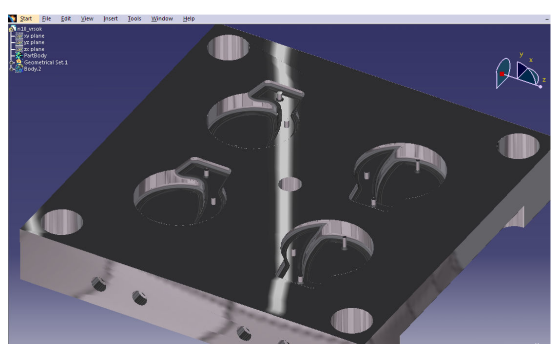


Fig. 12 The detail of core side of the mould (top part)

The forming system of the mould was assembled by standard parts from catalogue HASCO - Fig. 13.

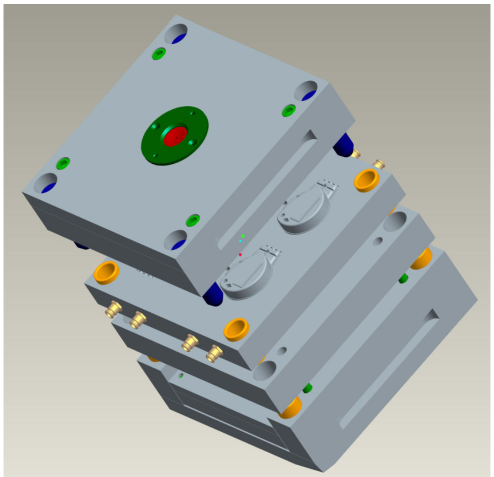


Fig. 13 Complete forming system of the mould

3. CONCLUSIONS

In this paper, all key points in modem product like Rapid Prototyping, CAD/CAM/CAE tools and mould development are presented. This kind of knowledge enables the possibility to develop a completely new product in a period of 6 months, from the idea to the start of the production. This paper does not deal with the preparation of production in the plant.

CAE tools enables, except the design of moulds and optimization process conditions, respectively, determination some injection molding process limits like minimal thickness of thinnest area of the product to achieve required quality of molded part. In simulation of injection molding process, it is possible to assess some critical parameters some variables.

At the moment the ability to manufacture the prototype of the product in the period of 3-4 days, injection molding simulation in 4-5 days and the manufacturing of the mould in 2-2,5 months is given. If these processes are conducted simultaneously, the decrease of the development time of the mould down to less than 3 months is possible.

4. MISCELLANEOUS

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5. REFERENCES

[1] BUDZIK, G., MARKOWSKA, O. MARKOWSKI, T.: *STL files parameters of the selective objects for rapid prototyping*, Proceedings of The 2nd International Conference on Additive Technologies; DAAAM Specialized Conference, 2008, Ptuj, Slovenia

[2] BUDZIK G., SOBOLAK M.: Generating stereolitographic (STL) files from CAD systems. Acta Mechanica Slovaca, 2B/2006, Košice, 2006, s. 73-78.

[3] LEE, B.H., KIM, B.H.: Polym-Plast Technol. Eng. 34(1995), 793-811.

[4] PANDELIDIS, I., ZOU, Q.: Polym. Eng. Sci. 30 (1990), 873-882.

[5] PANDELIDIS, I., ZOU, Q.: Polym. Eng. Sci. 30 (1990), 883-892.

[6] TUMG, L.S., CHIANG, H.H., STEVENSON, J.F.: SPE Tech. Pap., 1 (1995), 668-672.

[7] SEOW, L.W., LAM, Y.C.: J. Mat. Proc. Tech., 72 (1997), 333-341

[8] LAUTENBACH, S., WANG, K.X., CHIANG, H.H., JONH, W.R.: In: Proceedings of the SPE Annual Technical Conference, ANTEC ´91, 1991, pp. 372-376

[9] JANSEN, K.M.B., VAN DIJK, D.L., BURGERS, E.V.: Int. Polym. Process 13 (1) (1998), pp. 99-104.

[10] KUZMAN, K., NARDIN, B., KOVAČ, M., JURKOŠEK, B.: *The integration of rapid prototyping and CAE in mould manufacturing.* Journal of Material Processing Technology 111 (2001) 279-285.

[11] http://www.moldflow.com (15.9.2009)

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MODELING OF FORWARD EXTRUSION PROCESS BY VIRTUAL MANUFACTURING

Abstract: *The paper presents modeling of forward extrusion process by virtual manufacturing. For defined process model by virtual manufacturing has done: problem identification, discretization domain elements, the establishment boundary condition, linking elements, formation of equations and numerical simulation. For the validation of the numerical simulations results, into account are taken the data for the stress and deformation force determined experimentally. Comparing the experimental obtained results with results obtained using the visualization of simulation results came to the characteristics forward extrusion process that truly reflect the real situation.*
Key words: *Modeling, forward extrusion, virtual manufacturing, simulation*

1. INTRODUCTION

The Virtual manufacturing is the use of computer numerical simulations for production process evaluation and for product design optimization. By Virtual Manufacturing it is possible to predict potential problems and inefficiencies in product functionality and manufacturability before real manufacturing occurs, fig. 1.

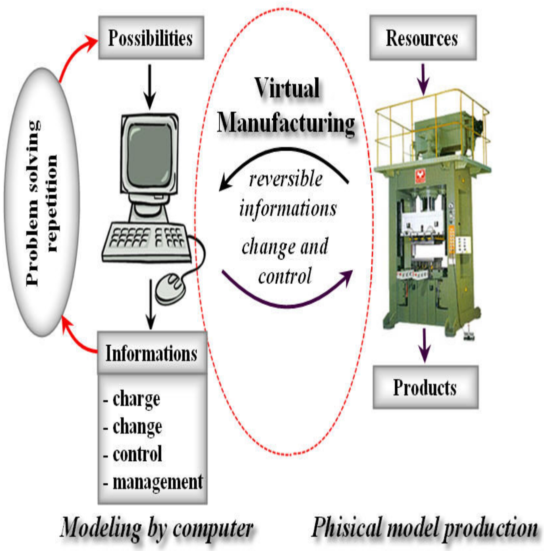

Fig. 1. Virtual Manufacturing possibilities

Modeling is an activity for defining of all necessary parameters based on existing technical knowledge, ideas and innovation for creating of a product or process virtual model.
Simulation is the illustration, imitation, or a dedicated created presentation for demonstration or analysis of previously pre-processed problem that performs computer - numerical simulation.

For numerical simulation of forming processes firstly it is necessary to prepare and define all geometrical data about tools and specimen and their material data. After that, it is possible sequentially simulate process and find optimal resolution.
The process of solving tasks by finite element method (FEM) consists of the basic following steps:

- The problem identification,
- Discretization - element definition,
- Determination of boundary condition,
- Setting up the element equation
- Assembling the element equations,
- Numerical solving of formed equations
- Analysis of achieved results.

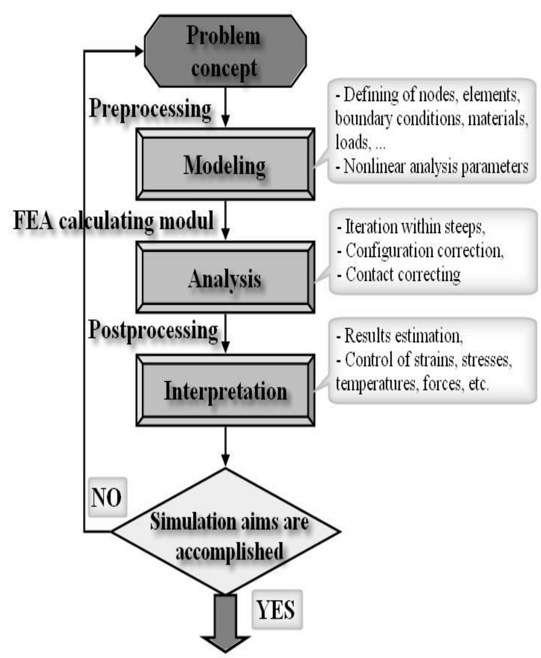

Fig. 2. Procedure for problem solving by FEM

2. FORWARD EXTRUSION PROCESS AT COLD STAGE

Forward extrusion process is used to produce a large variety of continuous sections. Cold extrusion process is a special type of forging process in which cold metal is forced to flow plastically under compressive force into a variety of shapes.

These shapes are usually axisymmetric with relatively small nonsymmetrical features. Parts which are produced by extrusion have very good dimension accuracy, surface quality and better mechanical properties.

Numerical simulation of forward extrusion process has been done, because of real stress determination in dependency with strain degree. Finite element analysis has done with software package DEFORM 3D. Derived data were compared with the experimental results (process model is shown at fig. 3.).

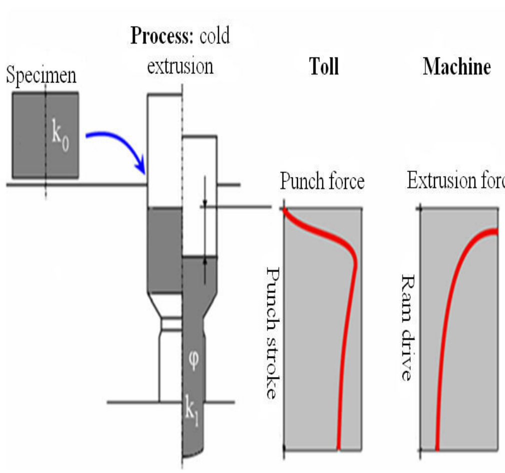

Fig. 3. Model of forward extrusion process

In the experimental determination of the actual stress and deformation force specimens are prepared from material 16CrMn5, and were treated with soft annealing process in order to obtain a suitable structural condition (globular ferrite in the perlite weight) and chemical (lubrication of the contact specimen surfaces; carrying layer for lubricant is done with Zn phosphate plus lubricant layer infliction with the molybdenum disulfide suspension).

Workpieces had the cylindrical form with the diameter d=28mm and height h=31mm, and experiment is done with three different degrees of deformation: φ_1=0,308, φ_2=0,678 и φ_3=0,8836 [4].

Strain degree presents a natural logarithm between unformed and formed surface as follows:

$$\varphi = \ln \frac{A_0}{A_1} \qquad (1)$$

2.1. Forward extrusion deformation force

At forward extrusion process occurs axisymmetrical stress condition whereby the load on the outer surface, or part of the body external surface symmetrically in relation to its rotational axis and equally in all meridian directions. Stress condition in forward extrusion process is shown at fig. 4.

Deformation force can be determined as the product of pressure and the surface on which operates the toll:

$$F = p \cdot A_0$$

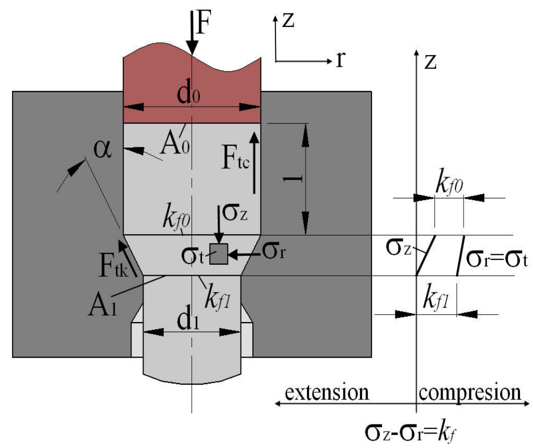

Fig. 4. Stress condition and forward extrusion force

Deformation work force in forward extrusion process also can be obtained by Lange derived formula:

$$F = A_0 \cdot k_{fm} \left[\frac{2}{3}\widehat{\alpha} + \left(1 + \frac{2\mu}{\sin\alpha}\right)\varphi_{\max} \right] + \pi \cdot d_0 \cdot l \cdot \mu \cdot k_{f0} \qquad (2)$$

Experimental derived deformation work force values for listed deformation degrees are: F_1=410kN, F_2=690kN and F_3=820kN [4] Also, at experimental part, real stress was measured in order to calculate deformation force.

2.2. Numerical simulation

For numerical simulation, firstly, it is necessary to design toll and specimen bodies in appropriate CAD/CAM software package, and after that, designed parts convert into readable file for numerical analysis software (step, iges, stl, etc.). In FEM software it is necessary to define all parameters and their correlations. Firstly, discretization of a problem consists of the following steps: describing the element, setting up the element equation, and assembling the element equations. Friction impact at forming zone was taken into account through friction coefficient μ (μ= 0.12). Each FEM software has reach material base. If there is no corresponding material, users are able to describe material plastic flow by appropriate flow curve. All prepared data will be written in database file. After database file

generating, simulation engine reads that file, perform the actual solution calculation, and appends the appropriate data to the database file.
The simulation programme also works seamlessly with the automatic mesh generation system to generate a new FEM mesh on the workpiece. FEM techniques are then applied for obtaining the solution of the global equations.
Numerical simulation for certain deformation degrees is shown on fig. 5., 6. and 7.

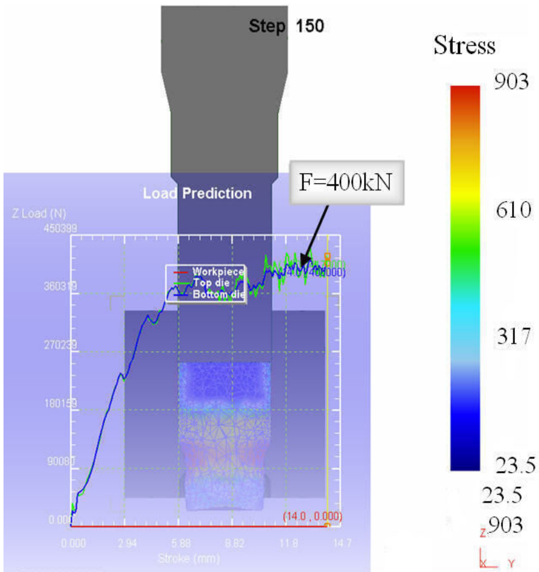

Fig. 5. Numerical simulation of forward extrusion process for deformation degree φ=0.308 (force and stress)

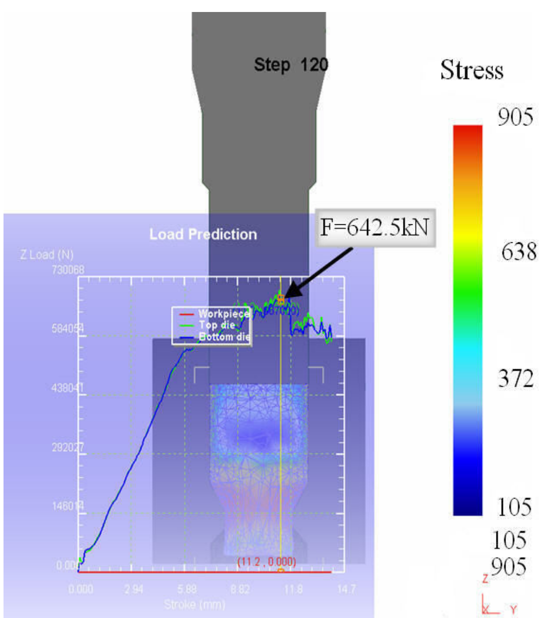

Fig. 6. Numerical simulation of forward extrusion process for deformation degree φ=0.678 (force and stress)

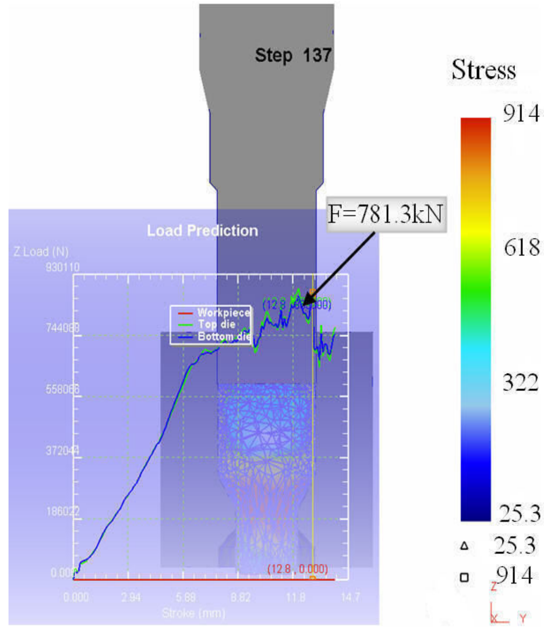

Fig. 7. Numerical simulation of forward extrusion process for deformation degree φ=0.8836 (force and stress)

Comparing the deformation work force values obtained experimentally with the results obtained by numerical simulations can be seen that there is a fractional deviation. For deformation size φ=0.308 deviation at deformation work force values obtained at above mentioned ways is 2.5%, for second deformation φ =0.678, 7% and for third deformation size φ=0.8836 is 4.9%.
The above discrepancies arise because of tribological effects in deformation zone and defined the accuracy of numerical simulations. In spite of the values for deformation work force, at figures 5, 6 and 7 are shown diagrams for effective stress. It can be noticed that the increasing of deformation degree in deformation zone has the influence at the effective stress rise.
By the software for numerical simulation in the plastic area throw analysis of effective stress and strain can be defined limiting (maximum) degree of deformation for product manufacturing from the existing materials by one of the forming processes.

3. CONCLUSION

Comparing the research results at concrete models, through several project iterations of virtual models, by using 3D project solutions, it can be seen all possibilities of optimal solutions of the mentioned task.
Derived numerical simulation on models of steel forward extrusion (material 16MnCr5) has shown that derived relevant results by numerical simulation from the engineering point of accuracy and applicability are satisfactory.
Research has shown that the application of numerical

simulation on concrete models leads to precise engineering and acceptable results. Otherwise, the application of virtual manufacturing, as well as a very efficient and most modern technology has enabled the strong incentive and an innovative process of development of new technical - technological progress in the most developed industrial countries of the world, and in our region is imperative for further development and progress. Computer simulations are excellent tools to predict and evaluate the tool and process design, especially for complex production processes.

4. REFERENCES

[1] Sljivic, M., Stanojevic, M.: *Introduction in production technologies*, University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka, 2003.

[2] Sljivic, M.: *Technology of Plactisity*, University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka, 1998.

[3] Sljivic, M.: *Defining of flow curve for domestic steel 16MnCr5*, First scientific conference „Flexible machining systems for profile production" FOSIP, page 107-112, Bihac, 1988.

[4] Sljivic, M.: *Steel cold forward extrusion technology analysis*, STROJARSTVO 26, page 167-171, Загреб, 1984.

[5] Sljivic, M.: *Rapid Prototyping and Rapid Tooling*, University of Banja, Faculty of Mechanical Engineering, Banja Luka, 2007.

[6] Runde, Ch.: *Konzeption und Einfuehrung von Virtueller Realitaet als Komponente der Digitalen Fabrik in Industrieunternehmen*, Doktor-Ingenier genehmigte Abhandlung, IPA Fraunhofer und Universitaet Stuttgart, Jost-Jetter Verlag, Heimsheim, 2007.

[7] Lange, K.: *Fliesspressen*, Springer Verlag, Berlin, 2008.

[8] Mandic, V.: *Virtual Engineering*, University of Kragujevac, Faculty of Mechanical Engineering, Kragujevac, 2007.

[9] Plancak, M.: *Rapid Prototyping and Rapid tooling*, Universitity of Novi Sad, Faculty of Technical Science, Novi Sad, 2004.

[10] Kobayashi, Sh., Soo-ik, O., Altan, T.: *Metal Forming and the Finite-Element Method,* Oxford University press, New York, 1989.

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ENVIRONMENTAL TECHNOLOGIES AND ECOLOGICAL SYSTEMS

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10th INTERNATIONAL SCIENTIFIC CONFERENCE
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Invited Paper

Crnobrnja B., Budak I., Ilić M., Hodolič J., Kosec B.

ENVIRONMENTAL LABELLING OF TYPE I ACCORDING TO SRPS ISO 14024:2003

Abstract: *Programs for environmental labelling are developed in almost every higher developed country, with the purpose to serve as guides to ecologically more consciousness citizens. Thanks to the development of a national environmental labelling program of Republic of Serbia this issue is becoming very interesting in our country. First is given a review of national and regional environmental labelling programs, as well as a review of the development of the environmental labelling. Paper is based on the basic principles of SRPS ISO 14024:2003 standard, with representation of current situation in this area in the Republic of Serbia.*
Key words: *Environmental labelling, Eco label, Type I, ISO 14024*

1. INTRODUCTION

Environmental (eco) labelling is a voluntary method of environmental performance certification and labelling practiced around the world. As primary reasons for eco labels introduction, may be isolated next three [1]:

- promotion of development, manufacturing, advertising and using products that causes less influence on the environment,
- stimulation of manufacturing which has maximum savings of physical resources using materials liable to recycle, and
- to offer customers total and secure information about impact of a product/service on the environment.

As an answer on appearance, great number of labels and declarations within this area of life cycle considerations, ISO 14020 has identified three broad types of voluntary labels [2, 3]:

Type I - a voluntary, multiple-criteria based, third party program that awards a license that authorizes the use of environmental labels on products indicating overall environmental preferences ability of a product within a particular product category based on life cycle considerations.

Type II - informative environmental self-declaration claims.

Type III - voluntary programs that provide quantified environmental data of a product, under pre-set categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party.

2. TYPE I ECO LABELLING

Standard ISO 14024 was declared in 1999, and it defines Type I eco labels. This international standard is referring to programs of environmental labelling that award eco label to those products which satisfied complex previously defined conditions. In that way label identifies products certified as suitable for the environment, and because of that, usually this type is so called „stamps of approval". Label points out that product ecologically seen more acceptable than products of same category, and purpose is to stimulate buying products that are ecologically acceptable. Type I environmental labelling programs are voluntary. They can be led by public or private agencies and can be national, regional and international [4].

Type I eco labelling program overcomes six basic steps [1, 4]:

- consultations with interested parties,
- product category determination,
- creating, testing and exchanging criteria for environmental products,
- identifications of characteristics of product functions,
- development and implementation of suitable criteria, standards and guiding, and
- certification and licensing.

General characteristic of symbols that are used with this type of eco labels is that should associate on environment, in combination with symbols which are characteristic for some country/region.

3. REVIEW OF THE CURRENT TYPE I ECO-LABELLING PROGRAMS

In this chapter is given summary of some of the most developed national environmental labelling programs, and short presentation of program for eco labelling of European Union, which is regional-international [2].

3.1 National programs for Type I eco labelling

Programs for Type I environmental labelling start to grow previously on national levels, and country (its institutions) mostly was the main initiator and organizer of development and usage of this kind of program. According to this, regional eco labelling systems, with easier way of orientation to customers in buying and choosing services, and because of market coverage begun to develop [3,6]. Today there are approximately 35 national programs. Table 1 gives us a review of some appearing programs of eco labelling, which are the most developed.

Label	*Program*	*Country*	*Starting year*
	Blue Angel	Germany	1977
	TCO Development	Sweden	1980
	Environmental Choice program	Canada	1988
	BRA MILJOVAL	Sweden	1988
	White Swan	Nordic Countries	1989
	Eco Mark	Japan	1989
	Green Seal	USA	1989
	Milieukeur	Netherlands	1991
	Eco Mark	India	1991
	Green Mark Program	Taiwan	1992
	Green Label	Singapore	1992
	Medio Ambiente	Spain	1993
	Prijatelj Okoliša	Croatia	1993
	Kornyezetbarat Termek	Hungary	1994
	Ecologically suitable product	Slovakia	1998

Table 1: Some of the most developed programs for Type I eco labelling

3.2 Regional programs of Type I eco labelling

Ministry of council of Denmark, Finland, Iceland, Norway and Sweden, in November 1989 made a decision about adopting a common programme for ecological valuation and marking by the name "Nordic Swan Label". Use of this programme is in jurisdiction of *„Nordic Eco-labelling Board"*. Program covers 69 groups of products. Label is valid for three years, after which revision of criteria is needed [7].

European Union eco labelling program has come to an agreement by Ministry of environment in December 1991, defined by Council Regulation No. 880/92 in march 1992, and became legal in October 1992. Based on the Council Regulation No. 1980/2000 document, the procedure has been revised in September 2000 [5].

Fig. 1. Label of programme for ecological valuation and marking of Denmark, Finland, Iceland, Norway and Sweden „Nordic Swan Label"

Fig. 2. EU eco label

European Commission is responsible for constituting and revising of the criteria for each group of products by giving mandate to a board made of competent bodies and consultation forum that involves all the relevant interested parties – non-governmental organizations like European Bureau for the Environmental Protection, trade and consumers associations [8]. Each EU member state has its competent body for administrating of the procedure on the national level. Competent bodies that have to be independent and neutral receive requests for obtaining of an eco label and decide whether the products are satisfactory comparing to a number of criteria.

European Union Ecolabelling Board (Competent Bodies & Interest Groups), European Commission, present suggestions

↓

Suggestions are checked (Regulation, Working Plan)

↓

Mandates given to EUEB to develop or review criteria

↓

Drafting of criteria (Taking into account Working Plan and methodology)

Feasibility and Market Study Life Cycle Considerations Improvement Analysis Criteria Proposal	Consultation with Ad Hoc Working Group – regular feedback to EUEB

↓

European Commission proposes Criteria

↓

EUEB

↓

Regulatory Committee

↓

Adoption of Criteria

↓

Publishing of Criteria in Official Journal

Fig. 3. Criteria determination procedure scheme

The manufacturers whose products fulfil their criteria should get registration package that contains clear, step by step directions for obtaining the EU eco label from competent body. Once the application is filled out, it needs to be handed over to the national competent body who, by attaching their argumentation and recommendation, submits it to the European Commission-European Union Eco labelling Board who brings decision by voting. The procedure for getting EU eco label is graphically presented in Figure 4 [5].

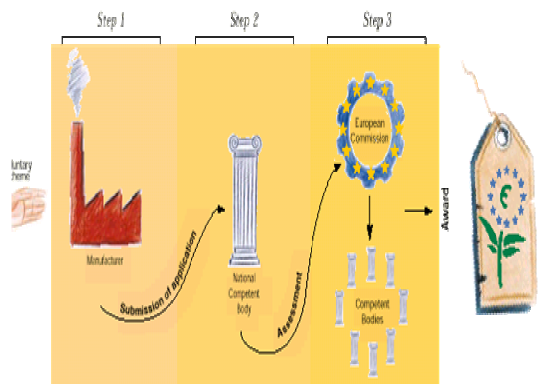

Fig. 4. Procedure for getting EU eco label

The **"Global Eco labelling Network" (GEN)** is a non-profit association, founded in 1994 to improve and develop the eco-labelling of products and services world-wide. The EU Eco label Scheme is a full member of GEN. The mission of the GEN is to [9]:

- serve its members, other eco labelling programs, other stakeholders, and the public,
- faster co-operation and information exchange,
- facilitate access to information,
- participate in certain international organizations,
- encourage the demand for, and supply of, more environmentally responsible goods and services.

Fig. 5. Logo of GEN

4. ECO LABELLING IN SERBIA

First efforts related to this topic in R. Serbia were done by bringing up the Environmental Law, of which paragraphs no. 53 and 54 determine, respectively award and subtraction of eco label. Label is determined for products intended for universal consumption, process and service, except food, drinks and pharmaceutical products, but licence for using provides Ministry of Environment. This label would be part of Award of Licence for Eco label Application Regulation .

In March 2009 was presented and officially published "Rules on closer conditions and procedure for obtaining rights to the use of eco label, elements, layout and use of eco label for products, processes and services" [10], which met the prerequisites for the beginning of the implementation.

Fig. 6. Two versions of eco label of Republic of Serbia

5. CONCLUSIONS

Presented view, which indicates that the countries with national Type I environmental programs, suggests that the current informal tools for the management of environmental protection - is growing. Also, in the paper, through the two regional eco labelling programs, especially for eco labelling of the European Union, clearly points out the advantages of these programs, especially in terms of market globalization.

It is noted in the review that some Member States of the European Union (United Kingdom, Italy, Slovenia, etc.) did not develop their own programs, but have decided for the implementation of the EU as their national. This fact is interesting from the aspect of Republic of Serbia, which established the National Eco labelling Program last year. Although it is, at first glance, in conflict with the approach of above mentioned countries, the fact that "Rules on closer conditions and procedure for obtaining rights to the use of eco label, elements, layout and use of eco label for products, processes and services" made with great respect to the criteria for categorization and evaluation of products from the EU, indicates that Republic of Serbia elected a similar approach. This will ensure not only compliance with the EU program in the future, but also quality and credibility of our program, in terms of easier access of domestic Serbian products to the EU market.

6. REFERENCES

[1] -----: ISO 14024: Environmental Management – Environmental Labels and declarations – Type I Environmental Labelling, International Organisation for Standardisation, Geneva, 1999.

[2] Budak I., Kosec B.: Environmental Labelling of Products and Services, Tempus Project JEP 41156 2006 "Training of Institutions in Modern Environmental Approaches and Technologies" – TIMEA, Novi Sad, (in Press).

[3] Ilić M., Budak I., Crnobrnja B., Hodolič J.: Analysis of Self-Declared Environmental Labels, Materials and Geoenvironment, Vol. 56, No. 1, pp. 74 – 87, 2009.

[4] Budak I., Kosec B., Hodolic J., Ilic M., Crnobrnja B., Sokovic M.: Contribution to the Analysis of Self-Declared Environmental Labels, Proceedings of the 9th International Foundrymen Conference, pp. 32 – 37, Opatija, 2009.

[5] Kutz M.: Environmentally Conscious Mechanical Design, John Wiley & Sons, New Jersey, 2007.

[6] Crnobrnja B., Budak I., Ilić M., Hodolič J., Kosec B.: Analysis of environmental labels and declarations type I - according to SRPS ISO 14024:2003, Proceedings of the Festival of Quality 2009, 4th National Conference on Life Quality, pp. 1 -7, Kragujevac, 2009 (in Serbian).

[7] European Commission: ec.europa.eu

[8] The European Eco-Label Catalogue: www.eco-label.com

[9] GEN Global Ecolabelling Network: www.gen.gr.jp

[10] Rules on closer conditions and procedure for obtaining rights to the use of eco-label, elements, layout and use of eco-label for products, processes and services, Ministry for Spatial Planning and Environment of Republic of Serbia, Belgrade, 2009

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NEED OF PREDICTIVE ENVIRONMENTAL FRIENDLY SYSTEM OF NOISE PROTECTION

Abstract: *This article is about noise protection requirements from industry production in urban environment of the cities. Furthermore it points tools that can be used during proposal phase in order to ensure not only worker, but also inhabitant protection in the surrounding of the industrial facility. As we can see in the article, system approach is very important in this matter.*

Key words: *noise protection, system approach, industry, environment*

1. INTRODUCTION

Manufacturing is one of the dominant activities and is carried out in interior of building objects and also in exterior within urban build-up area. Manufacturing companies arise by various ways:

- as concentrated new buildings (industrial green land)
- as new buildings within current build-up area on free parcels
- by reconstruction of current non functional manufacturing objects (brown parks)
- by reconstruction of various buildings in build-up areas (additional building or superstructure)

Borders of functional urban city zones (living, industrial, transporting, recreational, etc.) are more often loosing and enterprise intentions are in mixed urban city zones. New production brings also negatives in the form of noise and vibrations that have to be solved. Solution is in environmental friendly system of noise protection, which consists of various tools ensuring health, comfort, safety and adequate human's performance in production process or in surrounding inhabitant's buildings. The goal of this paper is to point out only on the noise prediction area from the production during the proposal phase.

2. NOISE AND PRODUCTION FLEXIBILITY

Many noise sources are influencing human in interior or exterior environment. Every source has different influence on human and therefore noise perception is individual. Sound is acoustic vibration that brings up human perception. Intensity of hearing perception is not linear with intensity of acoustic pressure. Relation between volume and rumble level is dependent on the frequency. Sound (or noise) perception from production itself and noise influence on organism depends on various acoustic and non/acoustic factors like:

- noise type produced by sources - the most dangerous is impulse noise, then sustainable noise, cyclic noise and the less dangerous is interruptible noise,
- noise levels - we can divide to relative noise up to 65 dB(A) (influences psychic) and absolute noise over 65 dB(A) which influences vegetative neurons system and hearing organ. Above 120dB(A) causes noise destruction of the hearing organ, pain and impacts central neuros system,
- noise frequency – low frequency noise is not dangerous, the higher frequency, the more damage noise can cause,
- exposition time of the noise – noise has cumulative character and by rising exposition time also count and seriousness of hearing disorders is increasing,
- reference time interval – noise is most unfavorable during night the better it is during evening and day,
- individual organism perception, personal disposition of the human – depends on higher neuros activity, genetic factors, age, sex, health state and so on,
- from subjective relation to the sound (noise), social and economic factors,
- from type of performed activity and surrounding environment

Production activity is the environment of market economy characteristic by frequent changes. Changes are dependent on products demand (volume, type, and speed of production, etc.) which are connected with production devices that are producing noise as side product. Production flexibility is possible not only by assortment change, but also by replacement of production technologies e.g. to less noise one. Flexibility in the time of current global crisis can mean also production depression and by that mean even reduction of environmental noise load.

2. SYSTEM APPROACH IN NOISE PROTECTION

Acoustic assessment of protected environment (2 m in front of facade) by influence of industrial noise can be in general solved by the following steps [1]:

I. determination of the goal,
II. establishment of assessment criterions,
III. assessment of exterior and interior environment of the building,
IV. proposal of noise reduction measures in environment (in the source, transmission pat hot facade of the flat/building),
V. estimation of noise reduction costs in the environment,
VI. monitoring of acoustic environment.

The whole assessment process in the proposal and projection phase has predictive character. Figure 1 shows 3 subsystems.

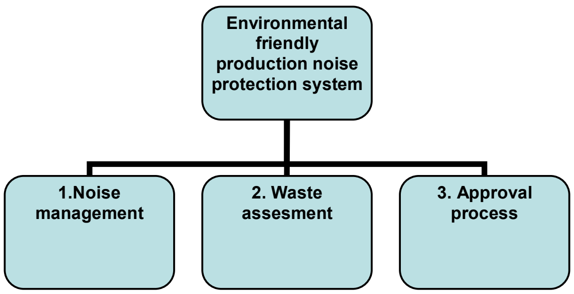

Fig. 1. Subsystems of environmental friendly production noise protection system

3.1 Noise management

Noise management – its operation, coordination and monitoring in environment is essential need for industrial and traffic noise management.

Table 1 Classification of noise management [2].

Noise management classification according to			
area:	**approach:**	**time consequences:**	**solution procedure:**
- global	- fragmental	- planning,	- cause determination
- provincial	- communicative	- designing ,design	- mapping, monitoring
- regional	- integral	- realization	
- urban		- operation	- noise reduction
- zones, (industrial area)			- assessment
- object (facilities...)			

Importance of noise management and other environmental factors in connection with waste assessment is in:

- determination of areas into certain zones from further possible urbanization activities point of view, in prediction, future development determination, etc.
- selection of areas according to environment quality and in consequent assessment – price creation (value of parcels, realities), possibility of various tax payments or discounts and so on.

3.2 Impact assessment

Production activity Impact assessment (industrial noise) and its inherent activities (noise from transport) can be carried out in documents according to table 2.

EIA	Environmental Impact Assessment
EHIA	Environmental Health Impact Assessment
SEA	Strategic Impact Assessment
SIA	Social Impact Assessment
IA	Integrated Assessment

Table 2 Assessment documents

Document EHIA is EU priority, but is not build up on legal bases like EIA, SEA. EHIA shows procedures, methods and tool for noise identification in human population with aim to reduce direct and indirect noise influence to the health. [3] Assessment criterions of admissible values are given in legislative of each EU state.

3.3 Approval process

Complexity of approval process depends on size and character of the production facility project, from its strategic or just local importance. Therefore in approval process can participate state administration (government, ministries), bodies governed by law (hygienist..), local administration (construction administration), non government organizations and other participants (neighbors). Final decision about building placement is often very complicated process and building of big complexes is often medialzed.

3.4 Noise study

Subsystem of noise management and impact assessment is bounded with document – noise study, which determines expected noise imisions in environment from industrial sources during defined inputs. Outputs are noise maps with noise indicator values (with corrections) which are compared with admitted values. Maps are:

classical, common noise maps as a part of noise study for solution of new buildings, reconstructions, etc. on smaller area, with aim to assess influence of new building to the surrounding,

strategic noise maps for bigger areas, for big buildings concerning assessment and control of environmental noise. These are area-wide noise maps that are displaying area noise load. Special types of these maps are conflict plans determining areas in which are action values of noise indicator overrun.

Production variability mirrors also noise study solutions where various operation states, noise character, exposition can occur. Example of the map shows figure 2. Noise prediction from production activity is solved in alternative 0 – original state and in alternative 1,2,3 for new planned state for various areas of building. Further variant counting for reference time, day, evening and night or during winter and summer season can occur.

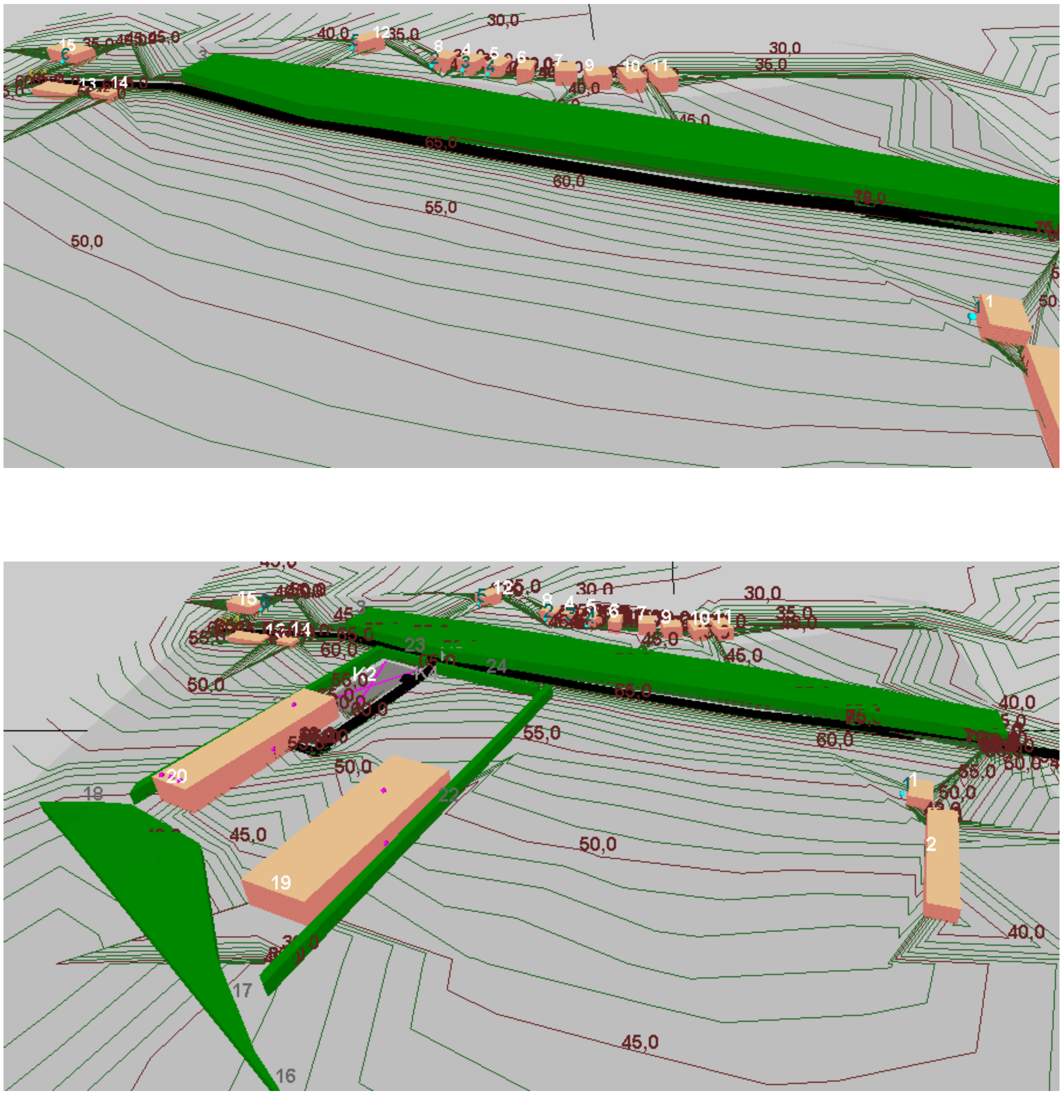

Fig. 2. Course of izophone in area before and after proposed construction of industrial factory

Description of system requirements during design of production workplaces for elimination industrial noise include:

A/ Localization of production building.

B/ Urban – architectonical requirements.

C/ Constructional requirements.

D/ Manager.

E/ Legislative.

F/ Technical.

G/ Technological.

H/ Psycho-social.

I/ Safety.

J/ Architectonical , esthetics and attractiveness of environment.

K/ Energetic requirements .

L/ Environmental requirements.

4. CONCLUSION

System approach in production noise prediction in urban environment during proposal phase has its importance not only in health protection, but also in economic area. Costs and measures for noise elimination during proposal phase are lower than additional measures that have to be done during operation of the factory. Environmental friendly system of noise protection applied by manufacturing companies (investors) also rises their image on the market.

5. REFERENCES

[1] Žiaran.S..: Akustické hodnotenie chráneného prostredia, In: Zborník z 19.konferencie Vnútorná klíma budov 2008, Tatranská Lesná 2.-3.decembra 2008, s.13-20, ISBN 978-80-89216-26-0

[2] Flimel,M.: Manažerské přístupy k hluku. Moderní řízení, ročník 40, č. 7, 2005, s. 32-33.

[3] Koppová.K.: Hodnotenie dopadov na zdravie, Inov.kurz., www.uvzsr.sk

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APLICATION OF ECODESIGN AND LIFE CYCLE ASSESSMENT IN EVALUATION OF MACHINE PRODUCTS

Abstract: *The authors described the concept of balancing both economic development and environmental preservation. In line with this concept, environmental policy has shifted from the end-of-pipe approach to the pollution prevention approach. Industrial products are a major source of today's environmental concerns. Sustainable development entails that manufacturers of industrial products take into account the environmental impacts throughout the entire life cycle of a product, not just focusing on environmental pollutants during the manufacturing of the product.*
Key words: *environmental performance, industrial product, sustainable development.*

1. INTRODUCTION

Permanently changing more and more demanding requirements for the tasks related to the management and preservation of environment, assurance of prosperity of companies as well as increasing pressure from competitors evoke constantly more urgent need of implementation of progressive methods and technologies which should assist to the companies by satisfaction their customers´ needs. The organisations have certain environmental tools to support and quide the positive changes towards better environmetal performance of their products.

Nowadays there are many tools to help to improve the environmental issues concerning the production and products. Among many tools which are known to be used within the Environmental Management Systems following will be focused only to two of them, which are voluntary tools, i.e. not ordered by certain laws:

- Ecodesign,
- LCA,

Both methods can influent a product and production significantly but in various ways.

2. THE DESIGN PROCESS

Most engineers concern themselves with physical products in the broadest sense, i.e. every physical system designed with a certain purpose is a product. A bicycle is a product, but so is a factory, a water treatment facility, a bridge and a new area of a city. All these are physical systems, albeit it on different scales. Designing is the developing and planning of such a product.

Different disciplines have different design processes, though they share some common characteristics. The design process can be characterized by the cycle of design, which describes certain steps present in each design process (Figure 1). When designing for sustainable development, designers should bear it in mind throughout the design process.

The most important decisions concerning sustainable development take place in the initial phase of the design process—analysis; the earlier sustainable development plays a role in the process, the larger its influence. It is much easier to alter the assignment to improve sustainability than trying to increase the sustainability of an already finished detailed design. [3]

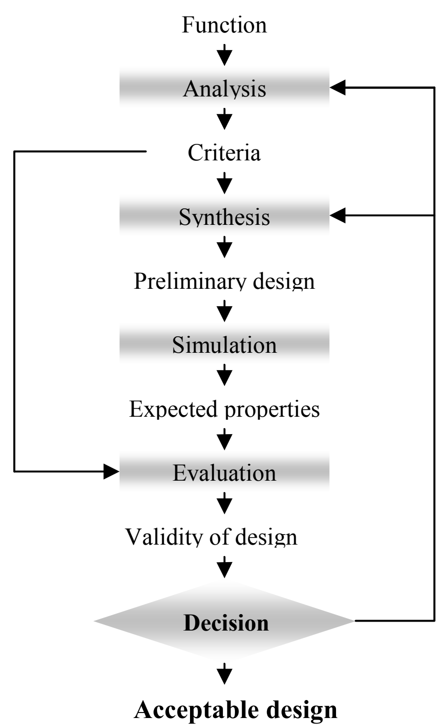


Fig. 1. The cycle of designing

2.1 Analysis

The core of the design process is the function of the product that is to be designed. 'Function' does not only mean the technical function, but also any social, cultural, psychological and economic functions the product will per-form. Although the programme of requirements will contain the main functions, these need to be analysed for further requirements.

Every design process follows from a problem that needs to be solved. It is the designer's job to identify the actual problem, clarify it and express it in a problem statement, i.e. the designer analyses what the real problem is. This often turns out to be a different problem from the one expressed by the commissioner. Only when the problem is defined clearly and in 'do-able' terms can the designer search for the most sustainable way of solving it.

3. ECODESIGN TOOLS

Ecodesign tools are a user-friendly eco-product development tool designed to be used by engineers as an integral part of the product launch activities. It follows both the ISO14062 and ISO 9001 processes for product development programs. The training segments of the tools are designed to train the user in eco-product development in easy stages, using the ACORN eco-management model. This allows the launch teams to learn to the depth that is appropriate for them. The tools analyses are modular so the companies can use just the parts relevant to them. (Figure 2.)

Planning: At the planning stage for a proposed new product the first stage is to know what environmental requirements from legislation, internal, customers etc need to be taken into account during the product launch. Once that has been established than decision has to be made on what extra eco-features should be offered for this product in order to drive continuous improvement?

Contract Review: Once it has been decided what eco-features should be included in the product design, a review should be held preferably with an environmental expert present. Team needs the address whether the product targets set are realistic, and are compatible with other requirements for the product.

Concept Design: At this stage of the product launch different design solutions should be investigated, in order to find the best compromise between ecodesign, costs, quality and other factors. It is often possible to reduce costs whilst improving environmental product performance.

Concept Review: The various concepts should review to decide on the best option. An environmental expert should be present if that is feasible. The team needs to ensure the chosen design will meet the committed ecodesign targets.

Detail Design: At this stage of the product launch the supply chain often becomes a major factor in the eco-performance. It impacts the material content, transportation and packaging. It cans also sometimes effects recyclables and other ecodesign performance metrics.

Design Review: Once the final design has been completed, design review(s) should be held to determine whether all the programme objects have been met. Corrective actions should be put in place to address any issue.

Metrics: Most companies require metrics, so that they can have visibility on how the company is performing and for reporting externally to customers etc.

Requirements: This database holds environmental requirements of the users, companies and legislation for the different industry sectors. User companies can decide either to make their requirement visible to others, or hide them. The requirements are split to individual statements so each requires a single action to satisfy it.

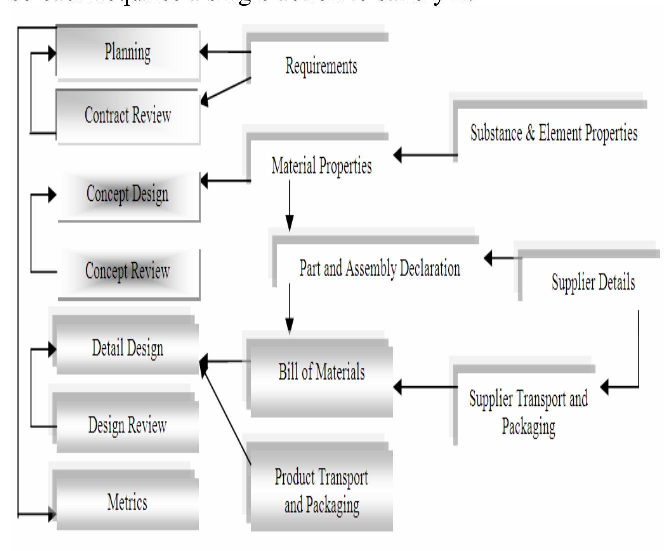


Fig. 2. Ecodesign tools

Material Properties: This database holds not only environmental data, but also general data on composition, mechanical, thermal and electrical properties, application, abbreviations, specifications and trade names. It will therefore be a useful source of information for both engineers and materials scientists.

Part and Assembly Declaration: This database holds the materials composition data for components; materials such as adhesives, solders etc; sub assemblies; and products. Each part are entered under the manufactures part number. It follows the emerging materials declaration industry format standards now being developed. Parts are accessible as read only to those users the part manufacturer has agreed can have visibility. It is hope that most off the shelf parts will be given full visibility to all users.

Bill of Materials: This database holds the list of parts on a user's product. It can either be entered using supplier part numbers, or the company's own part number system. The latter is recommended if parts are multi-sourced. When the Bill of Materials is entered, any parts not in the database are flagged. Data is only visible for read and/or write to those specified by the manager of the product.

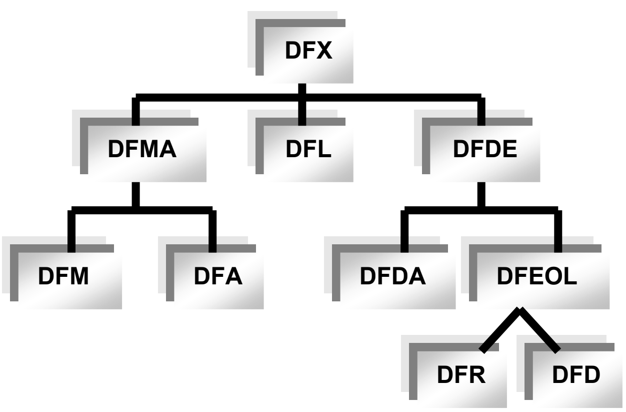
Product Transport and Packaging: This database holds transportation and packaging data by part number for the user's product. It includes modes of transport, kilometers per part, packaging materials and their weight/volume ratio per part, plus reusable packaging with their associated transportation requirements. Data is only visible for read and/or write to those specified by the manager of the product.

Substance & Element Properties: this database holds not only environmental data, but also general data on composition, physical properties, applications; abbreviations and specifications. It will therefore be a useful source of information for material scientists.

Supplier Details: This database holds the contact details for suppliers that have parts listed in this tool. The data includes address, contact name, email, telephone number, web address, region covered and types of product manufactured. This data is available as read only to all users.

Supplier Transport and Packaging: This database holds transportation and packaging data by part number of supplier. It includes modes of transport, kilometers per part, packaging materials and their weight/volume ratio per part, plus reusable packaging with their associated transportation requirements. Data is only visible for read and/or write to those specified by the manager of the product. [2]

The new product development process has various stages as summarized below. The ecodesign team core led by the ecodesign champion, will overview and drive the project at all stages. Other functional participants may be involved at each stage depending on the company and product. Until now, the emphasis in business has been on minimizing the effects of own manufacturing processes or operations; the pressures for ecodesign require additional „life cycle“ thinking. The main life cycle stages are described in figure 3. [4]



LEGEND:
DFMA (Design For Manufacture and Assembly)
DFL (Design For Life)
DFDE (Design For Disassembly and End of life)
DFDA (Design For DisAssembly)
DFE (Design For End of life)
DFR (Design For Recycling)
DFD (Design For Disposal)

Fig. 3. Basic division of ecodesign tools – type DFX

Ecodesign is likely to be most effective if considered and carried out, not as a separate exercise, or as technical activity alone, but as part of an environmental management approach integrated with other business processes and covering the company as a whole. The starting point should be an environmental review, which should identify and evaluate ecodesign and supply chain issues alongside other aspects of environmental performance, and the scope for improvement.

4. PRINCIPLES OF ECODESIGN

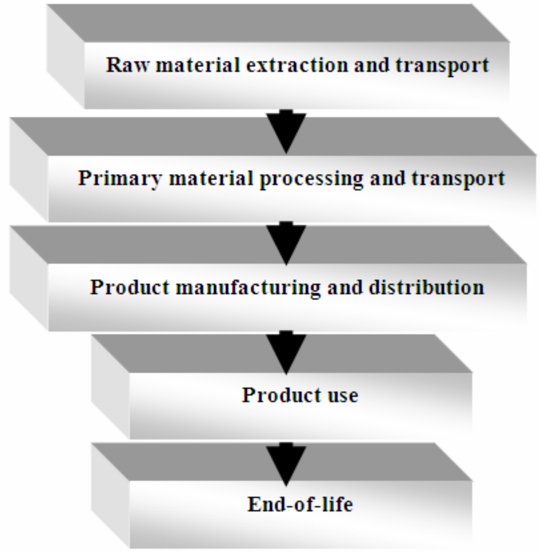


Fig. 4. The main life cycle stages

The new product development process has various stages as summarized below. The ecodesign team core led by the ecodesign champion, will overview and drive the project at all stages. Other functional participants may be involved at each stage depending on the company and product. Until now, the emphasis in business has been on minimizing the effects of own manufacturing processes or operations; the pressures for ecodesign require additional „life cycle“ thinking. The main life cycle stages are described in figure 4. Ecodesign is likely to be most effective if considered and carried out, not as a separate exercise, or as technical activity alone, but as part of an environmental management approach integrated with other business processes and covering the company as a whole. The starting point should be an environmental review, which should identify and evaluate ecodesign and supply chain issues alongside other aspects of environmental performance, and the scope for improvement. [4]

5. LIFE-CYCLE ANALYSIS (LCA)

LCA is a tool that allows the total environmental impact of a design or a product to be analysed. It can be used during different phases of the design process. It can also be used to optimise the environmental performance of a design.

LCA quantifies the environmental impact of a certain product-system. The LCA of an existing product or system can set the bottom line for a new design. The product system encompasses all phases of the product life, i.e.

- Raw materials acquisition and refining (e.g. mining, drilling, agriculture, forestry, fisheries)

- Processing and production of product and production equipment
- Distribution and transport
- Use, re-use and maintenance
- End-of-life landfilling, incineration, litter and recycling. [1]

However, these different forms of environmental impact cannot be added together. In order to calculate one single number as the result of the LCA, weight factors have to be introduced that set the relative priority for each environmental problem. Weight factors can be derived from the relative distance of the current situation in regard to the goals set out in policy documents. Alternative designs and materials can thus be compared.

4.1 The framework of the life cycle assessment

The life cycle assessment must contain this three phases:
I. phase – goal and scope definition
definition of the goals and the boundaries and the content of system which should be assessed. As well as the measures for comparison,
II. phase – inventory analysis
presents identifications and quantifications of all primary material and energy inputs and all the outputs. (wanted – unwanted),
III. phase – impact assessment
it is a quantitative and qualitative evaluation of data obtained in the inventory phase according to the size and the range of an impact.

4.2 The role of life cycle assessment in the environmental performance

A number of customers request their suppliers directly the material supply with environmental labelling and with the guarantee that at their production was no harm made to the environment. Similarly it is developed the relation to the transport, packaging etc.

The life cycle assessment techniques used to control the environmental aspects of products may have different applications. Private companies may use LCA-techniques internally for their development of new products, or optimisation of existing products, to reduce the environmental impact of the products in their whole life cycle.

Externally, the companies may use the assessments to document improvements for the consumer or environmental authorities, or to compare the environmental qualities of their product with those of competing products. The information provided by LCA can also be useful in applying an Eco-label licence.

6. CONCLUSION

In present time of global markets must the companies constantly innovate their products, processes and informational systems to remain on the market. They must collect, store and utilise their intellectual capital. The need of efficient management of the product life cycle is given by competitive pressure and constantly growing demanding ness of customer requirements. Adaptation of existing products may provide relatively little scope for the application of ecodesign. New product development offers opportunities for innovation, environmental improvement and contribution to business success. It is recognized that whiles both environmental product legislation and the environmental requirements of many multi-national companies on their suppliers is increasing dramatically, many companies just do not have the required in-house skills and experience to meet those requirements. Even many large companies suffer from their ecodesign skills existing only at corporate level, with Businesses launching products often not incorporating ecodesign into their products.

The consideration of LCA within decision –making depends on the institutionalisation stage, good justification and especially important of course, economic aspects. The economic aspects consist of different elements, for example the economic situation of the company,net benefits/burdens due to LCA –results. The further development of the tool LCA is one of the answers to the challenge of environmental pollution and deterioration. LCA seems the more complex and sophisticated instrument in the context of environmental improvements of products.

7. REFERENCES

[1] Bras-Klapwijk, R.M., Heijungs, R. & P. van Mourik (2003) *Levenscydusanalyse voor onder-zoekers, ontwerpersenbeleidsma-kers* (Delft, the Netherlands: VSSD, 2003).

[2] Muransky,J. & Badida,M (2005) *Ekodizajn v strojárstve. Základy metodiky*. Technická univerzita v Košiciach, Vydavateľstvo Michala Vaška, Prešov, 2005, 304 s., ISBN 80-8073-119-5

[3] Mihok, J. & Liberkova, L. (2005). *Vyhodnocovanie efektívnosti znižovania miery zaťaženosti ŽP*. In: Moderné prístupy k manažmentu podniku, Bratislava, STU, 2005, s. 360-363, ISBN80-227-2284-7

[4] Tichá, M. (1998). *Design for environment*. Ad-hoc Commitee ASIP Club, Paris, 1998.

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ANALYSIS OF SELF-DECLARED ENVIRONMENTAL LABELS AND DECLARATIONS ACCORDING TO STANDARD ISO 14021

***Abstract**: Today environmental labelling represents one of the most important tools for environmental protection improvement. Expanse of eco labelling in the last years is connected with the invention of firms that care for environment can make a profit. Result was appearance of different declarations, claims and environmental labels on products and service. In the next phase, like response to a number of misleading marketing claims in the late 1980s and early 1990s, in 1993 was the standard ISO 14020. In this article detailed analysis of eco labelling fitting under the Type II, according to standard ISO 14020, is given.*
***Key words:** environmental labels, self-declaration, ISO 14020, type II, claims*

1. INTRODUCTION

More expressive environmental consciousness put the demand to manufacturers that they should offer marketplace products that are pleased by high ecological standards [1]. There is growing interest among consumers, governments, and businesses in the environmental aspects of products, such as product energy efficiency, product take back and recycling, and use of hazardous materials are increasingly a part of the buying decision [2]. This recognition for products with environmentally preferable attributes has prompted green procurement activities in markets around the world and created the need for systematic and standardized communications with respect to environmental claims for products [3].

Environmental labelling is one of results of concern for environment, on local, as on global level. On their expanse the most influence had "invention" of firms that through care ness for environment can make profit. So different declarations, claims and eco labels appeared on products and service. This trend by one side influenced on consumers to find a way to reduce damaging on environment choosing buying, but on the other side provoked confusion of certain consumers.

In response to a number of misleading marketing claims in the late 1980s and early 1990s, in June 1993 a subcommittee of the International Organization for Standardization (ISO) [4] Technical Committee on Environmental Management began work on standards covering environmental marketing claims [5]. Result is defining three type of eco-labelling by ISO [6]:

- Type I - a voluntary, multiple-criteria based, third party program that awards a license that authorizes the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations,
- Type II - informative environmental self-declaration claims, and
- Type III - voluntary programs that provide quantified environmental data of a product, under pre-set categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party.

The basic of environmental self-declared claims is security of reliability. It is important properly conduction of verification, in the aim of interruption negative marketing consequences, such as marketing abutment or unfair practices, which can ensue from disputable and deceivable environmental claims. Method of predication environmental self-declared claims have to be clearly, transparent, scientifically supported, so potential customer of product can be sure in validity of claims [7]. In the following part of this article, detailed analysis of eco-labelling fitting under the type II according to standard ISO 14020 is given [8].

2. BASIC PRINCIPLES, DEFINITIONS AND PROCEDURES OF ENVIRONMENTAL LABELS TYPE II

Significant phase of developing ISO standard about self-declared environmental claims is evolution of ISO 14021, international standard that defines type II labels-self-declared environmental claims, issued in 1999.

A self-declared environmental claim is a declaration, a label or a symbol which draws attention to a certain element of the organizations activities, products or services and which can influence the environment. It is a special type of advertising. It is related to the product, its component or packaging. It can take the form of a statement, a label or a symbol placed on the product or on the products packaging, in the products documentation, in technical bulletins, in advertising and promotion, in TV marketing or possibly by means of digital and electronic media, such as the Internet. It can be issued by producers, importers, distributors, retailers or any other people that might benefit from such declarations. The parameters, environmental aspects which are intended to prove the products environmental friendliness, are chosen by the company-claimant themselves [8].

Environmental claims allow consumers to more easily differentiate between products in the market, so consumers can make better purchasing decisions in relation to the environment. In turn, consumer's purchasing power for such products is a market driver for business - to invest in more sustainable environmental practices [9]. The main advantage of the self-declared environmental claim is the opportunity to attract the attention of all target groups in a simple way, at a very low cost. Other advantages include:

- reducing the uncertainty in the market
- facilitating international trade, and
- wider opportunities for customers, potential customers and users of the product to make a better informed decision when choosing a product.

2.1Procedure for obtaining environmental labels

Before manufacturer decides to use self-declared environmental label, it is important to ascertain if there is some specific law or convention in which is requested how that environmental information need to be issued. Conventions are used for better understanding of minimal postulation, and to assure that claim/label is used properly by potential user.

Since Type II eco-labelling is more liable to an abuse, international standard ISO 14021 are proscribed exact directions for giving this declaration about product [7]. There are three main elements to be taken into account when considering making a self-declared environmental claim:

- the quality of the actual information being communicated (content),
- the way in which the information is presented (presentation), and
- the steps and methods taken to verify its accuracy (assurance of accuracy).

The content of the claim should be:

- correct and truthful,
- relevant,
- specific and unambiguous–especially when making a comparison.

The presentation of the claim should ensure that:

- the claim uses plain language,
- all relevant information is presented together,
- the meaning of any symbols or pictures is clear and relevant.

To ensure accuracy all claims should be:

- substantiated and verifiable,
- reassessed and updated as necessary,
- based on the best agreed standards available,
- supported by information needed to verify its accuracy.

2.1.1Basic demands for correct and true environmental claims

While it might appear obvious that any environmental claim ought to be correct and truthful, this is not always easy to achieve. In particular, an environmental claim can be literally true, but still capable of being widely misunderstood or misinterpreted. This can be sold:

- consider how an ordinary member of the public, not an expert, might understand the claim;
- don't make claims, even when they are literally true, if they are likely to be misinterpreted;
- avoid claims indicating an environmental benefit that, while literally true, is unlikely to happen in practice,
- make sure a single environmental benefit isn't restated using different terminology to infer multiple benefits,
- if a claim relates to a pre-existing, but previously undisclosed aspect, don't make a claim inferring a recent improvement or enhancement,
- make sure that any claim indicating that a product is free of specified substance contains no more of that ingredient than would be found as an acknowledged trace contaminant or background level.

2.1.2 Basic demands for relativity of environmental claims

Relevance is about enabling customers to understand the context within which the claim is made. Environmental claims:

- make sure the claim is relevant to that particular product,
- make sure the claim is relevant to the place where the corresponding environmental impact occurs,
- clearly indicate whether the claim refers to the whole product, or just part of it, or the packaging,
- do not make claims that imply that a product is exceptional when in fact all products in the marketplace share the same characteristic.
- don't make a claim based on the absence of ingredients or features which have never, or have not for some time, been associated with the product category;
- regularly review and update all claims to ensure that they remain relevant in view of changes such as new legislation being enacted, improvement in the environmental performance of competing products and technological advances,
- make sure that any claim is used only in circumstances where there is a net environmental benefit associated with the product.

2.1.3 Basic demands for specific and unambiguous environmental claims

Ensuring that environmental claims are specific and unambiguous will help ensure that customers fully appreciate their intended meaning. The worst examples of this kind of labelling are those that are highly generalized, such as "environmentally friendly" or "nature's friend". It is this kind of poor quality labelling which has, in the past, discredited all forms of environmental labelling. This can be anticipating as:

- Make clear what environmental impact or improvement the claim relates to.
- Make clear the level of environmental improvement or performance achieved.
- If the claim involves a comparative assertion:
  - make clear the basis for the comparison
  - quantify the claim using either percentages or absolute values as appropriate
  - always make a comparison against a

comparable product serving similar functions, either currently or recently in the same marketplace
- only make a claim against: your own prior products or processes or/and another organization's products or processes.

2.1.4 Basic demands about understanding of environmental claims

It is possible for the information associated with a product to meet all the criteria referred to above, and yet still be unhelpful to customers as a result of the way that it is presented. To be sure that none of these cases appear it is need to:

- make sure that any further information needed to understand an environmental claim is not buried in the small print,
- do not use language that exaggerates the advantages of the environmental feature the claim refers to,
- make sure that any symbols or logos are used in a way that their intended meaning is clear, if necessary by adding an explanatory statement,
- symbols used for environmental claims should be easily distinguishable from any other symbols found on products,
- natural objects such as trees, flowers or animals, should only be used if there is a direct and verifiable link between the product, the object and the environmental benefit being claimed. This link should be clearly explained.

2.1.5 Basic demands tied up with exact of environmental claims

There is no requirement to use third party verification or certification before an environmental claim is made, but it should be substantiated and verifiable. A business' own internal procedures may very well be able to perform this function. In addition, information should be retained by the person making the claim and supplied to anyone seeking justification of it.

In the aim of prevention arising of problem in relation with the previous need to be observed by next instructions [9]:

- check that the claim is fair and truthful, whether by testing the product or otherwise,
- don't make a claim if it could only be verified through access to confidential business information,
- document and retain information that others may need to verify any claims made,
- if the claim is a comparative claim, this should include data relating to the product with which the comparison is made.

2.2 Symbols of self-declared environmental labels

Symbols that are used for needs of self-declared claims need to be simple, easily reproduced and by position and size are liable to product.

Usage of environmental labels and symbols serve as important source of information about product and producer. Usage need to be avoided in case they provoke wrongly interpreted definition and meaning of symbol by consumer. If company decides to announce this symbol, need to obligate that symbol owns an advantage qualities over similar products, services and companies. To avoid confusion, should avoid similarity with current official symbols. Explaining of environmental labels, with the definition and meaning need to be on package, promoting and other marketing material, and also instruction where can be find detailed information about label. More details can be found on web site, too. Possibility of checking and verification of evidences that support usage of environmental label must exist. Usage label/symbol to marketing causes must be in accordance with national marketing law, also in advancing defined criteria about ecological environmental claims. „Official labels" need to be mentioned here. Their usage is regulated and observed by competent organs, with advancing defined criterions [10].

2.2 Evaluation and verification procedures of self declared environmental claims

A person stating an environmental claim has to be responsible for evaluation and gathering of data necessary for verification of self declared claims. Prior to designing a environmental claim, additional evaluation measures have to be implemented in order to come to reliable results necessary to verify the statement. Evaluation has to be documented in detail, and person that voices the environmental claim has to adopt documentation in order to make the information public. This has to be applied to a period while the product was present in the market and to a realistic period after that, taking into account products shelf life.

Methods for verification and evaluation of environmental labels have to be supported by chronologically ordered following documents [7]:

- international standards,
- standards easily identified and recognizable as well as internationally accepted and
- industrial and merchandizing methods to which the same examination method will be applied.

In cases where the methods are not in place, the person putting forward an environmental claim can suggest a method, providing that the method is in line with other requests and that it is possible to examine it. Environmental labels are certified only in cases when classified business information has not been used. The labels shouldn't be shown if the only way to verify them is through classified business information. Environmental labels can voluntarily offer to the public information necessary to verify it.

3. THE MOST APPLYING ENVIRONMENTAL LABELS

There has been a number of type II environmental labels developed and actively used. However, among them, according to how often are they used and to which extent they are being recognized globally, there are several which are widely known. They are as follows: Mobius loop, Green dot, Energy star, Pitch in, and Ozone friendly [9] (see Figs. 1 – 5).

Fig. 1. Mobius loop – variations of graphics used for term “recyclable“

Fig. 2. The original image of environmental symbol „Green dot“

Fig. 3. Graphic presentation of the environmental label "Energy Star″

Fig. 4. Format of eco-label “Pitch-in”

Fig. 5. The environmental labels regarding ozone protection

4. CONCLUSIONS

In the European Union and the other developed countries, the programs of the eco-labelling are acting in large and the products without environmental label have difficult passage to the global market or are disabled in some cases.

Very important aspect is, however, a responsible use of environmental labels, otherwise, their use would have little sense, and therefore, the good organization and the efficiency of the system and the institutions are more than necessary.

Important problem is also the development of the infrastructure that should provide the sustainability of the application of these programs. As an example, we can again use the recycling label and green dot, which among the rest include the existence of the recycling machine of the satisfying capacities.

There is an urgent need to give great attention to:

- The education of the manufacturers about their benefits if they apply this sort of eco-labels and about the obstacles they can have if they do not apply it, and
- The education of the consumers for better understanding of the meaning of certain eco-labels and the influence of the labelled products on the environment

Uplifting of the educational level of the mentioned subjects, regarding above cited, will have a synergetic effect to both, rising of the level of ecological consciousness and environmental protection in our countries.

5. REFERENCES

[1] Nowosielski, R., Kania, A., Spilka, M.: *Indicators of technological processes environmental estimation*, Journal of Achievements in Materials and Manufacturing Engineering, 22 (2007) 2, pp. 99 – 102.

[2] Budak, I., Kosec, B., Hodolič, J., Ilić, M., Crnobrnja, B., Soković, M.: *Contribution to the analysis of self-declared environmental labels*, 9th International Foundrymen Conference “Innovative materials and advanced concepts of metal casting production”, pp. 1-6, Opatija: Faculty of Metallurgy, Sisak, June 18-19, 2009.

[3] Hodolič, J., Badida, M., Majernik, M., Šebo, D.: *Mechanical engineering in environmental engineering*, University of Novi Sad, Faculty of Technical Sciences, Novi Sad, 2003.

[4] Senčič, S., Kosec, B.*: Sistem ravnanja z okoljem SIST EN ISO 14001,* Univerza v Ljubljani, Slovenia, 2005.

[5] Whitelaw, W.: ISO 14001 – *Environmental System Handbook*, Elsevier, London, 2004.

[6] Ilić, M., Budak, I., Crnobrnja, B., Hodolič, J.: *Analysis of Self-Declared Environmental Labels*, RMZ - Materials and Geoenvironment, Slovenia, 56 (2009) 1, pp. 74 – 87.

[7] -----: ISO 14021: *Environmental labels and declarations - Self-declared environmental claims*, 1999.

[8] Edwards, A.J.: *ISO 14001 Environmental Certification Step by Step*, Elsevier, Amsterdam, 2007.

[9] Budak, I., Kosec, B.: Environmental labelling of products and services, TEMPUS project IB_JEP-41156-2006 (RS) "*Training of Institutions in Modern Environmental Approaches and Technologies (TIMEA)*", University of Novi Sad, Faculty of Technical Sciences, Novi Sad , 2008.

[10] Borštnik, A. P., Zarnik, M., Žagar, T.: *Odgovorno okoljsko ravnanje – Sistemi ravnanja z okoljem*, SIQ, Ljubljana, 2004.

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APPLICATION OF ACOUSTIC CAMERA IN INDUSTRIAL SITE

Abstract: *The Acoustic Camera was the first commercially viable system using beamforming to visually localize acoustic emissions. The tool is now used in a variety of industries and has a growing customer base worldwide. The advantage of the Acoustic Camera: it is a light-weight, modular and therefore flexible system which is rapidly set up and ready to use. After a few minutes only, you get the first acoustic images on your computer screen. The software allows a clear, exact and fast analysis of noise sources. The benefits of the Acoustic Camera are straightforward: Noise sources are visualized, quality problems are detected and development times are reduced.*
Key words: *Acoustic Camera, Sound absorption, Measurement, Noise.*

1. INTRODUCTION

This article describes some field experience on the use and measurement results and procedures of the Acoustic Camera. By the use of Acoustic Camera in measurements it is possible to differentiate and localize different sources. Acoustic emission monitoring is getting increasingly important with engineering product design. An acoustic camera was recently developed as a new measuring device and constitutes a strong innovation made for localizing noise emissions.

2. TEORETICAL AND PHYSICAL BASE OF ACOUSTIC CAMERA

A digital camera is taking an image of the noise emitting object. At the same time an exactly computed array of microphones acquires and records the sound waves emitted by the object. A special developed software calculates a sound map and combines the acoustical and the optical images of the sound source. The Acoustic Camera can extend the time and frequency selectivity and add a location-selective component. With this method the sound signal is shown and also a sequence of acoustic images can be acquired – acoustic films are generated. Nevertheless the Acoustic Camera comprises traditional analysis methods as well, like A-weighting, one-third octave band and narrow band analysis.

With the Acoustic Camera it can be precisely analysed when, where and which part is occurring the sound emission. The so far used analyses do have an important disadvantage as the location of the emission is limited or not possible. If the sound from several spots of an appliance is to be acquired simultaneously, individual microphones are required for each reading point, and they must be placed very close to the object – a time consuming and costly method.

The whole measurement and subsequent analyses are characterized by:

- high accuracy,
- high speed,
- dynamic operational mode,
- high effectiveness,
- transparent result processing (coloured acoustic maps, movies, records).

The Acoustic Camera is based on beamforming of a conventional delay-and-sum beamforming in the time domain.

$$\hat{f}(X,t) = \frac{1}{M}\sum_{i=1}^{M} w_i f_i\big(X,(t-\Delta_i)\big) \qquad (1)$$

Delay-and-sum beamforming can be performed in either the time or the frequency domain, whereby time domain delay-and-sum is done by separately delaying each microphone signal, making them align before summation and normalization. Acoustic Camera currently uses the time domain delay-and-sum mainly because of the faster processing speed and new signal processing algorithms [2].

$$\hat{p}_{eff}(X) = \sqrt{\frac{1}{n}\sum_{k=0}^{n=1} \hat{f}^{2}(X,t_k)} \qquad (2)$$

Fig. 1. Microphone Arrays (Ring, Star and Sphere)

The transformation between two acoustic camera images can be calculated by putting one image into the coordinate system where the image is on the xy-plane with the positive y-axis along the center line of the image and the center of the arc at the origin.

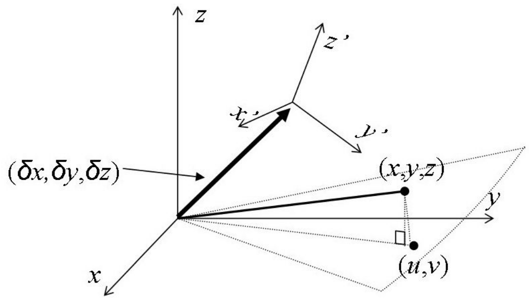

Fig. 1. The imaging geometry of an acoustic camera.

The use of microphone arrays and multichannel data recorders in connection with software for a fast visualization results an Acoustic Camera. Such a device has become popular for the localization of sound sources of machinery and equipment of any kind. An overlay of an optical photo gives the user a fast overview of the dominant noise sources emitted by the device under test.

The underlying common principle of those systems in the far field approach is the delay-and-sum beamforming method. That technique use special time delay sets for the incoming signals to focus the microphone array on a spatial location. The correct delay set results in a coherent overlay by adding up all microphone signals. With that special time delay the region emitting the strongest sound pressure can be found [3].

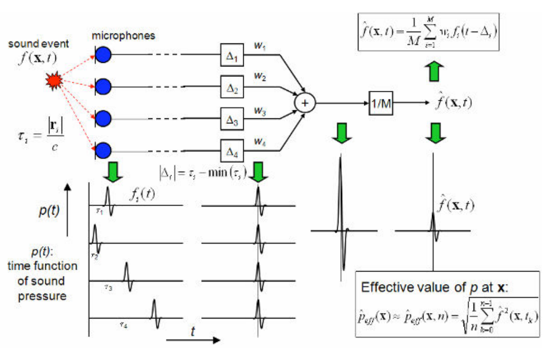

Fig. 3. Overview of the delay and sum beamforming method.

Applying that beamforming technique for each pixel in a measurement plane generates a sound pressure image.

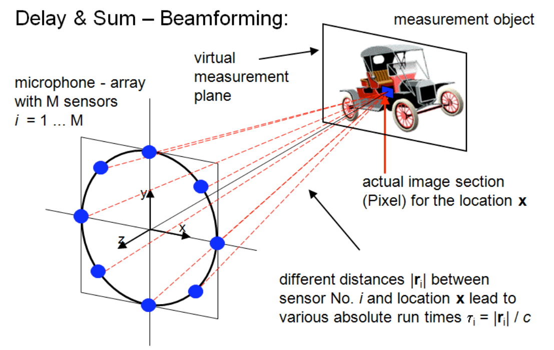

Fig. 4. Delay-sum beamforming and the acoustic camera.

3. SOFTWARE "NOISEIMAGE"

For working with the software „NoiseImage" a complex but easy to operate intuitive concept of interactions between space, time and frequency has been developed. In order to avoid model assumptions about emitter characteristics, only the equivalent sound pressure level is mapped, i.e. in the acoustic image the value is colour coded that would be generated by a point source in a nonreflexive room at the same distance [2].

The recorded time functions can be evaluated according to A-, B- or C-weighting. A universal filter bank allows spectral generalisations. In the spectrogram view, noticeable emissions can be marked temporally and spectrally simply by a mouse move and can instantaneously be shown as acoustic photo or movie to identify the related sound source.

In photos and movies, the reconstructed time function of every location can be saved as wav-file, it can also be displayed as spectrogram or spectrum. All images can be exported as Bitmaps or JPEGs, movies can be saved as AVI. Spectra can be shown in third octave bands. Listening to the time functions of photos and movies is possible by moving the mouse over the picture. This allows to individually recall recordings even many years old. When a film is saved as AVI, the stereo sound from the recorded time functions or alternatively the reconstructed time function of a chosen location in the image can be integrated into the exported movie. The according location is then marked by a microphone icon. For the analysis of stationary emissions, the so called „spectral frames" (a type of spectrally sensitive photo) are an additional tool for interactions between image and spectrum. A mouse click into the picture will immediately show the corresponding spectrum of that location, and vice versa selecting a spectral band from the spectrum will show the related acoustic image covering only those selected spectral components.

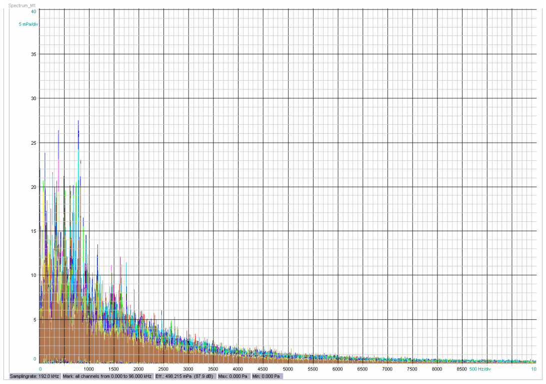

Fig. 5. Spektrum of measuring data.

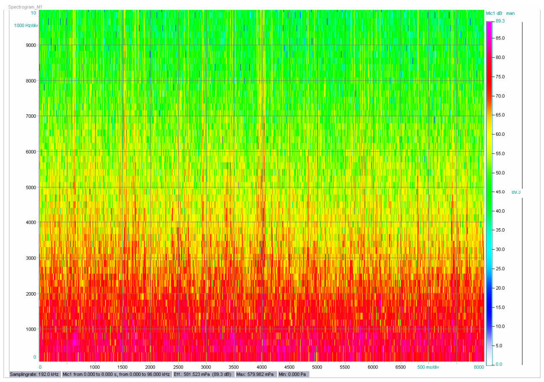

Fig. 6. Spektrogram of measuring data.

The spectrogram is used to generate acoustic photos by studying tonal components and to easily do filtering including playback of selected area, so that the display/generation of the acoustic photo is optimized.

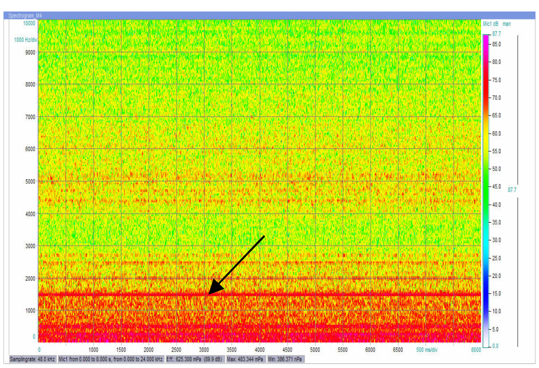

Fig. 7. Spektrogram of measuring data with shining critical frequency.

4. EXPERIMENTAL MEASUREMENTS IN WORK EXPERIENCE

Fig. 8. Installed Acoustic Camera by exhaust plant.

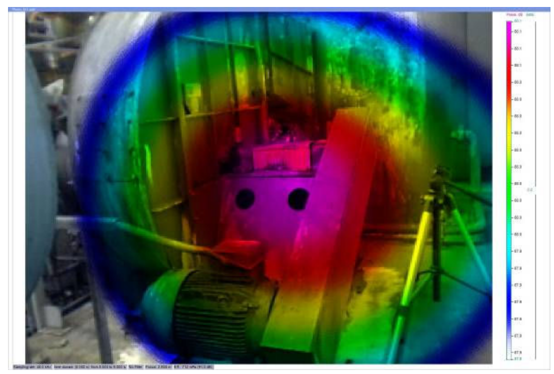

Fig. 9. Acoustic photo of exhaust plant.

In the Acoustic Photo each of the pixels have a corresponding spectra, it is therefore possible to display the spectra for every pixel in the photo. Vice versa another useful post-processing algorithm is the "Spectral Frames", where it is possible to do the opposite. For every part in the frequency spectra it is possible to mark an area and then to display the corresponding location for this part.

Fig. 10. Installed Acoustic Camera by crushing plant.

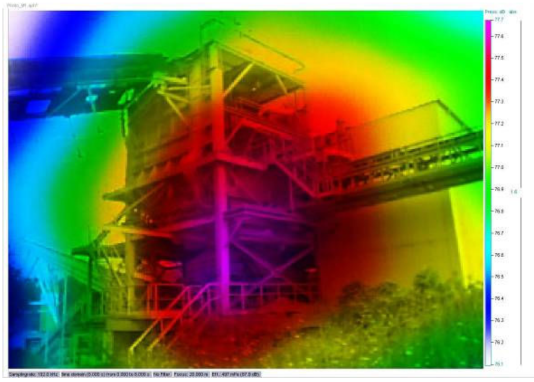

Fig. 11. Acoustic photo of crushing plant.

Fig. 12. Installed Acoustic Camera by tanks in stone guarry.

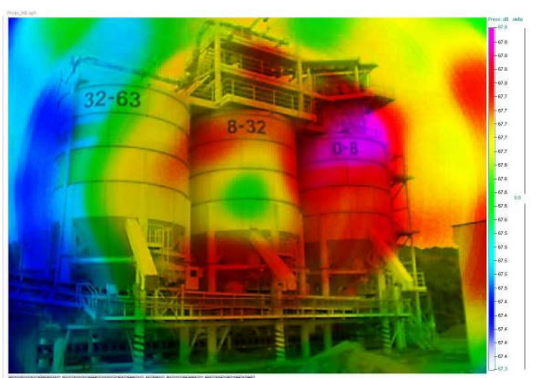

Fig. 13. Acoustic photo of tanks in stone guarry.

5. FINAL REMARKS

By the use of Acoustic Camera in field measurements it is possible to localize different sources, even with other dominating sources present. It is possible to cover a large number of measurements per day if one makes proper preparations. The measurements results from the Acoustic Camera shows good correlation with sound level meter measurements, after applying correction. By the use of the various new evaluation possibilities such as Acoustic Photo, Acoustic Movie and Spectral Frames it is quite possible to localize noise sources, also when these do not really dominate the overall levels.

6. REFERENCES

[1] BADIDA, M. - LUMNITZER, E. - ROMÁNOVÁ, M.: Metodika určovania neistôt merania hluku pri hygienických meraniach. In: Acta Mechanica Slovaca. roč. 10, č. 3 (2006), s. 5-14. ISSN 1335-2393.

[2] DÖBLER, D., Time-Domain beamforming using zero-padding, Berlin Beamforming Conference (BeBeC), 2008.

[3] JAECKEL, O. – SCHRÖDER, R.: Beamforming - Zeitbereich versus Frequenzbereich, Gesellschaft zur Förderung angewandter Informatik e.V. (GFaI e.V.), Berlin.

[4] MORAVEC, M. - LIPTAI, P.: Aplikácia akustickej kamery pri riešení problematiky priemyselného hluku. In: Novus scientia 2007, 10. celoštátna konferencia doktorandov strojníckych fakúlt technických univerzít a vysokých škôl s medzinárodnou účasťou, Košice, SjF TU, 2007, s. 401-405, ISBN 978-80-8073-922-5.

[5] ŠVAČ, V.: Vizuálna výučba automobilové závody. In: EQUAL for Automative. Košice : TU, 2006. s. 36-47. Internet: ISBN 80-8073-702-9.

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CONCENTRATION OF SOLID AEROSOLS IN WORKING ENVIRONMENT

Abstract: *Solid aerosols are very important as one of factor of working environment. Methodology of dust measurement in working environment is not united but some deciding factors must be observed. In the paper there is described possibility how can be realized measurement of concentration solid aerosol in working environment.*
Key words: *measurement, solid aerosols, concentration*

1. INTRODUCTION

There are things floating around in the air. Most of them, you cannot even see. They are a kind of air pollution called solid aerosols. In fact, it may be the air pollutant that most commonly affects people's health.

Measurement of solid aerosols in working environment is unnecessary for assessment of concentration of solid aerosols in working environment and next measures for reducing exposition of solid aerosols.

2. FRACTION OF SOLID AEROSOL

The most important factors of dust measurement are:

- location,
- time,
- time of taking sample.

Particles can come in almost any shape or size, and can be solid particles or liquid droplets. We divide particles into two major groups. These groups differ in many ways. One of the differences is size. For measurement in working environment are desirable divide solid aerosols to two size fractions:

- respirable,
- inhalable.

Respirable fraction is created by the particles with diameter to 2,5 µm. Inhalable fraction is created by the particles which is possible inhalate by the nose or mouth (respirable fraction is included).

3. PROCES OF MEASUREMENT

After the fraction assessment which is going to be measured is necessary to set location for sample taking and have to be executed decision if stationary or personal sample taking will be realized. Stationary sample taking is dust sample taking whole time of measurement realized at one station. This station is chosen by the experienced person or this station is desired by the state institutions.

Equipment for personal sample taking is placed directly to worker and solid aerosol are taking by sampling equipment near the respiratory tract of worker during whole working period.

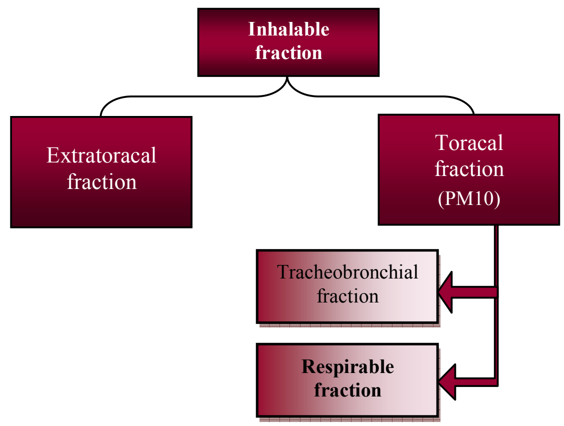

Fig. 1. Fraction of solid aerosols

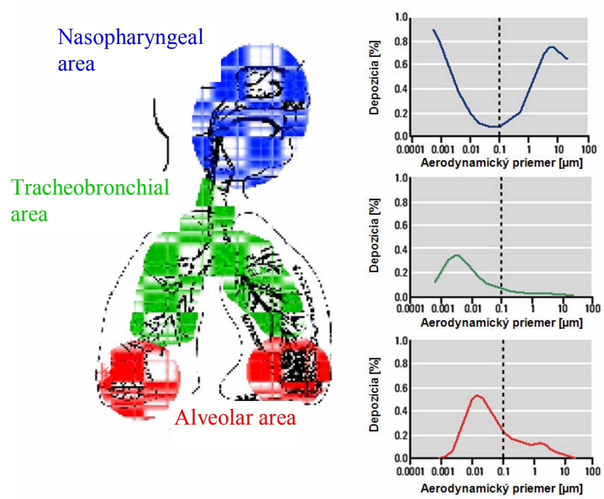

Fig. 2 Assumed deposition of inhalable aerosols in human body

Figures have to be made in high quality, which is suitable for reproduction and print. Don't include photos or color prints. Place figure at the top or bottom of a column whenever possible, as close as possible to the first reference to them in the paper.

On the base of employer request realized measurement of solid aerosol was executed at the determined working stations.

The scope of the measurement was assessment of overall concentration of solid aerosols in the air in working environment during the welding operations and next comparison with limit values.

Acquired value will be decided for workers classification to risk groups.

3.1 Description of working environment

Company where is measurement executed is concerning about production and assembly of steel constructions. Employers are mainly welders, fitter, setter and help workers.

Measurement was executed in component building 90 x 21 m. Building consist of three main parts: storehouse of materials, shearing workstation, assembly workstation where measurement was realized (Fig.2). Building is self ventilated and there are also added air compressors.

Disposition of working station and working places where was measurement executed are displayed in Fig. 3 (P1, P2, P3 are places where measurement was realized).

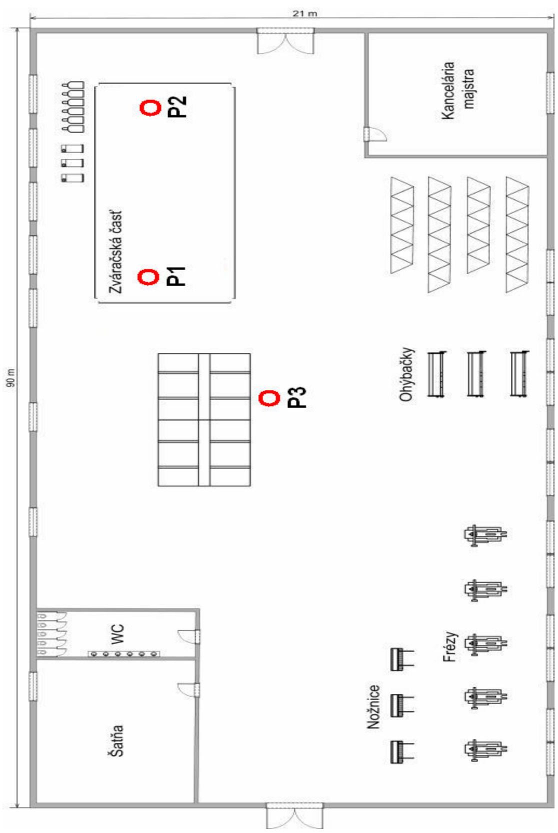

Fig. 3 Disposition of working station and working places

3.2 Execution of the measurement

During welding operations are produced different pollutants, Influence of these pollutant to human health is very negative. Other negative influence to welders is noise, vibrations, physical weight, radiation and unsuitable working positions but the most negative factor is inhalation of solid aerosols.

Unnecessary condition for measurement is important period of measurement. Span of measurement have to be at least 75 % of working period. During this period is acquired sample which is representative. Measurement was scoped for assessment of concentration of solid aerosols by personal sampling.

Used equipment:

- personal sampling pumps AirCheck 2000,
- sampling heads IOM for sampling inhalable and respirable fractions of solid aerosols,
- glass microfibre filters GMF,
- calibrated air flowmeter DC-Lite.

System for sampling is displayed in Fig. 4 with detail of sampling head.

Fig. 4 Sampling system

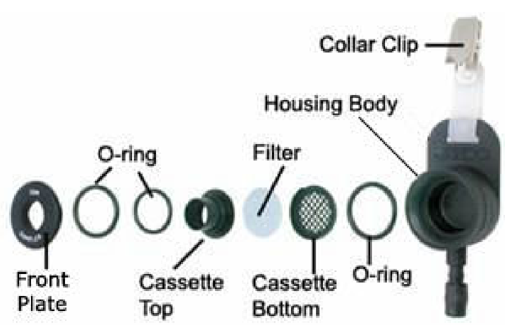

Fig. 5 Detail of sampling head IOM

Concentration of solid aerosols in the air is evaluated by gravimetric method. The case with filter has to by weight before and after measurement. Difference between weigh before and after is weight of solid aerosols. Proportion between weight of solid aerosols and airflow is assessed concentration of solid aerosols in working environment. Personal sampling air pumps were placed to three workers, two welders and one fitter. For each working position was realized three samplings. After the sampling was determined capacity of the air intake air pumps. And after the measurement were always changed filters. The used filters were subsequently in laboratory evaluated by the gravimetric method. Each filter was signed by numeric symbols. Time average concentration of solid aerosols was appointed from acquired three samples.

The concentration of solid aerosols is also based on weather conditions, such as temperature, humidity and wind direction.

During the measurement were captured microclimate conditions. Microclimate conditions during the measurement are displayed in table 1.

Table 1. Microclimate conditions

Time of measurement (h)	Temperature (°C)	Atmospheric pressure (kPa)	Relative humidity (%)	Airflow velocity ($m.s^{-1}$)
P1				
9:30	14,8	98,4	38,3	0,16
11:00	15,0	98,4	35,5	0,15
13:30	15,8	98,4	31,5	0,09
P2				
9:30	14,5	98,4	38,1	0,16
11:00	15,7	98,4	35,1	0,19
13:30	15,6	98,4	32,5	0,14
P3				
9:30	14,7	98,4	36,1	0,13
11:00	15,3	98,4	36,1	0,07
13:30	15,2	98,4	33,6	0,06

During measurement were also captured macroclimate conditions.

Macroclimate conditions were sampling before and after measurement of concentration solid aerosols. Macroclimate conditions are displayed in table 2.

Table 2. Macroclimate conditions

Time of measurement (h)	Temperature (°C)	Atmospheric pressure (kPa)	Relative humidity (%)	Airflow velocity ($m.s^{-1}$)
7:50	4,1	98,4	57,2	0,55
13:40	7,4	98,4	47,8	1,78

4. RESULTS OF MEASUREMENT

In Slovak republic limits of solid aerosols are appointed in government directive. Allowed limit of concentration solid aerosols for welding operations is 5 mg/m^3. After measurement in laboratory was appointed time average concentration of solid aerosols, and concentration was compared with allowed limits.

Results are displayed in table 3.

Table 3. Results of sampling

Sampling point	Time of measurement (h)	Overall concentration of solid aerosol ($mg.m^{-3}$)	Time average of concentration solid aerosol ($mg.m^{-3}$)
P1	8:00 – 9:30	0,173	4,22
	9:30 – 11:00	0,176	3,74
	11:00 – 13:30	0,286	5,37
P2	8:00 – 9:30	0,172	9,54
	9:30 – 11:00	0,176	11,56
	11:00 – 13:30	0,296	7,45
P3	8:00 – 9:30	0,173	5,84
	9:30 – 11:00	0,177	3,66
	11:00 – 13:30	0,296	4,26

Results of sampling and valid limits are compared in table 4. One value is above the limit which is parliamentary.

Table 4. Valid limits

Sampling point	Time-weighted average of overall concentration ($mg.m^{-3}$)	Limit ($mg.m^{-3}$)	Suitable or unsuitable
P1	4,90	5,00	suitable
P2	9,70	5,00	**unsuitable**
P3	4,84	5,00	suitable

Measurement findings show that allowed limits get over for working position P2 – welder and due this reason have to be executed unnecessary measures. Other two working positions (P1 and P3) are under the allowed limit.

4.1 Proposed measures

Due the reason of exceeded allowed limits (almost double) have to be executed next measures:

- increase performance of air climate equipment,
- use personal protective equipment (for example: respirators),
- change the risk group of workers (replaced from 2nd group to 3rd) and it means often medicine control, wage supplements.

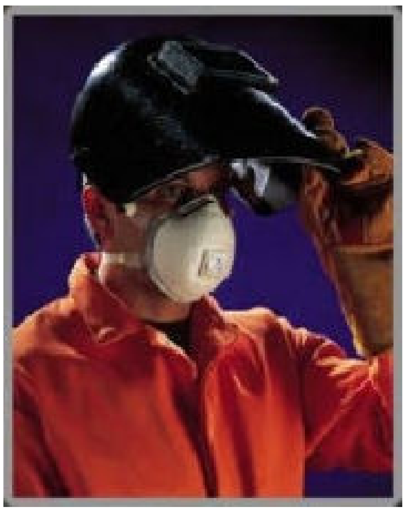

Fig. 6 Personal protective equipment

5. CONCLUSION

Final decision which measure will be realized in the concrete workstation is up to management. If measures are sufficient, will be shown after the next measurement of concentration solid aerosols. Very important are also preventive arrangements (modification of technological process, modification of exposition).

6. REFERENCES

[1] BADIDA, M. et all.: *Strojárska výroba a životné prostredie*, TU Košice, ISBN 80-7099-335-9, Košice, 2009.

[2] KRÁLIKOVÁ, R., BADIDA, M., HALÁSZ, J.: *Technika ochrany životného prostredia*, Elfa, ISBN 978-80-8086-062-2, Košice, 2007.

[3] LUKÁČOVÁ, K.: *Prašnosť v pracovnom prostredí a jej vplyv na zdravie človeka*. Písomná práca k dizertačnej skúške, Košice, 2009.

[4] LUMNITZER, E., BADIDA, M., ROMANOVÁ, M.: *Hodnotenie kvality prostredia*, Elfa, ISBN 978-80-8073-836-5, Košice, 2007.

[5] STN EN 689: 2000: *Ovzdušie na pracovisku* – pokyny na hodnotenie inhalačnej expozície chemickým látkam na porovnanie s limitnými hodnotami a stratégia merania.

[6] Zákon č. 355/2007 Z.z. o ochrane, podpore a rozvoji verejného zdravia a o zmene a doplnení niektorých zákonov.

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COMPLEX EVALUATION OF THE QUALITY OF THE WORK ENVIRONMENT OF SELECTED FACTORS AND WORKPLACES IN ENGINEERING INDUSTRY

***Abstract**: In the article are described actually monitored working environment factors, their allowable values, harmful effects on human and longterm effects. The originally developed methodology for multicriterial evaluation of the factors is assessing final working environment load on human health. There is also an example of the load assessment in the case of machinery production.*
***Key words:** working environment indicators, evaluation technique*

1. INTRODUCTION

There exists number of working environment factors and also factors of work itself, which have influence on human body and which enter mutual interactions. According to these interactions, the efects of the factors can sum, multiply, reduce or eliminate.

Generaly we think about physical, chemical, biological, psychological and socioeconomic factors. From the human health point of view, we can divide them to cumulative pathogenic, acute pathogenic, traumatogenic and terminal. [2]

For working environment load evaluation methodology it is necessary to deal with limited number of indicators, which sufficiently represents polution level and are relatively easy to measure and to treat further statisticaly. So selection of indicators is an exact task, which has expert character and relates with selection of elements in statistical file. [3]

For statistiocal data tratment is essential, that it is possible to quantify each indicator, what means, that its numeric value level has corresponding effect on working environment. If the effect is characterised as monotonous, the indicator can be used by the evaluation methodology.

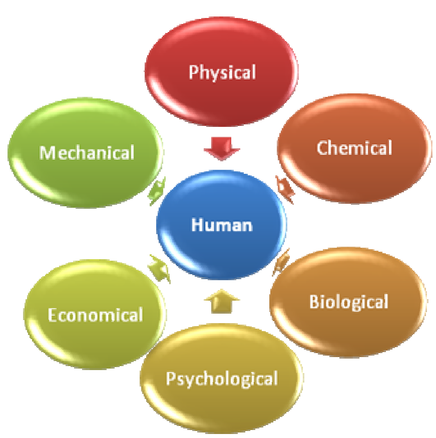

Fig.1. Influences of the working environment factors on human being

2. INDICATORS

To the most frequently used working environment indicators in the conditions of
industrial operation we can consider:

1 Physical factors
1.1 Noise -steady (dB), variable, pulse
1.2 Vibration, quake (Hz)
1.3 Microclimatic condiotions - air temperature (Δ oC), air humidity, air circulation, air presure, radiant-type heat, vapor, air quality (mg/m3), emissions –(gases -(SOx, NOx, CO), liquid aerosols, dust particles)
1.4 Lighting -intensity (Δlx), stability, luminosity, contrast, shielding and unshielding, light color, insolation
1.5 Radiation – infrared, ultraviolet, ionising – (corpuscular, alfa, beta, gama, neutron), electromagnetic - wave (airwaves, X-ray (Rg))
2 Toxic substances - toxic aerosols (j.m./ m3)
3 Biologic factors – viruses, bacteria (KTJ), fungi, parasites
4 Ergonomics - work physiology (points), anthropometrics, somatography, perimetry, exhaustion
5 Safety factors - safety technique (probability), personal working protective means
6 Working interior - architectural interior design, transport means, aesthetics
7 Socio-psychological factors - working motivation, working satisfaction, working attitudes and working ethics, interpersonal relations on workplace, leader personality, management style, monotony (%)

Theorethic principle of evaluation technique:

We start from matrix (1)

$$Y=(Yij \qquad (1)$$

which contains basic information about working environmnet load level. It is necessary to include all posible indicators, because aproximation of effect by the technique is closer to total, if the matrix consists more elements and if n is greater. [1]

Each element Yij contains quantitative parameters, it means values, which object i=1,2,..., m reach in indicators j=1,2,..., n .

The columns j, which working environmnet effects are clearly pozitiv, we revers through multiplying by minus one. We reach matrix A = (aij). Comparability of vectors is solved in a way, that we ad one more column, which represents hyphothetic object, called artificial vector U=(uj) and which serves as calculation base and generally consists of allowable values of indicators. Formed matrix we label A+.

$$U=(u1, u2, ..., un) , \qquad (2)$$

to be valid, that

$$uj<aij \qquad (3)$$

Then it is possible to compare real objects vectors with this vector, because is surely smaller, as any real object vector, whereby it is valid, that

$$aij-uj<0 \qquad (4)$$

Summation posibilities, it means elimination of different unit of measurement and differences in numbers dimensions was solved on a base of discrimination, in a way, that positive difference (aij - uj) is divided by standard deviation sj, which dimension is such, as has values, from which was counted and it adjust also numbers dimension, whereby

$$s_j=\sqrt{\frac{\sum(a_{ij}-\bar{a}_i)^2}{n}} \qquad (5)$$

From the elements of matrix A we will reach through transfromation elements B.

$$b_{ij}=\frac{a_{ij}-u_j}{s_j} \qquad (6)$$

Matrix elements B = (bij) are already mesurable non-dimensional numbers, so possible to sum. Standard deviation in denominator serve. besides that, even as significance of indicator. [1]

Question of interrelation between indicators is incorporated trhough correlation matrix R=(rjl), which returns data for calculation of reduction constants. We count their values from relations

$$r_{jl}=\frac{\sum_i(a_{ij}-\bar{a}_j)(a_{il}-\bar{a}_l)}{\sqrt{\sum_i(a_{ij}-\bar{a}_j)^2\sum_i(a_{il}-\bar{a}_l)^2}} \qquad (7)$$

$k_1=1$

$k_2=(1-|r_{12}|)$

$k_3=(1-|r_{13}|)\,(1-|r_{23}|)$

$k_4=(1-|r_{14}|)\,(1-|r_{24}|)\,(1-|r_{34}|)$

. ...

. ...

$$k_n=(1-|r_{1n}|)\,(1-|r_{2n}|)\,...\,(1-|r_{n-1n}|)\,. \qquad (8)$$

These reduction constants exclude multiple counting of the effect, which would appear in evaluation of working environment load level in different variants of different indicators.

Final proposed relation following (6) and (8) has form:

$$Q_i=\sum_j\frac{a_{ij}-u_j}{s_j}.k_j \qquad (9)$$

Eventually

$$Q_i=\sum_j b_{ij}.k_j \qquad (10)$$

itemized for example for new object

$$Q_i=\frac{a_{i1}-u_1}{s_1}.k_1+\frac{a_{i2}-u_2}{s_2}.k_2+...+\frac{a_{in}-u_n}{s_n}.k_n \qquad (11)$$

where Qi we named working environment load value, so score of i object, where

aij is adjusted value of j-indicator in i-object,

uj is value j-element of artificial vector,

sj standard deviation of adjusted j-indicator,

kj reduction constants. [1]

The exaple of working environment complex evaluation

As a example of working environment complex evaluation we proposed system of indicators, by which we describe influence of single workplaces of machinery production on human health. Their selection was reduced on the base of authors experiences in the area. In general is selection possible to realize by factor analysis techniques.

indic. / workplace	1 dB	2 Hz	3 ^oC	4 mg/m^3	5 lx	6 p/m^3	7 KTJ	8 point	9 true	10 %
1.	102	8	2,5	6	8	5	5	-67	0,47	-13
2.	42	300	0	12	5	9	13	-68	0,34	-10
3.	37	1	1	1	6	4	6	-86	0,68	-9
23.	98	348	3	34	74	36	12	-79	0,32	-37
31.	34	95	5	47	84	25	18	-94	0,43	-14
32.	58	98	1	75	21	41	19	-79	0,41	-47

Table 1. Table of measured value

uj	6	1	0	1	2	1	1	-98	0,19	-85
āj	61,72	212,44	3,02	43,06	27,31	22,41	8,28	-68,97	0,50	-32,28
sj	31,15	226,03	2,16	46,43	32,44	21,40	4,63	25,27	0,20	21,21

r[x,y]	x: 1	2	3	4	5	6	7	8	9	10
y: 1										
2	0,089									
3	0,030	-0,231								
4	0,313	0,428	-0,175							
5	0,009	-0,115	0,129	-0,022						
6	0,057	0,023	0,251	-0,032	0,153					
7	-0,061	-0,039	0,065	-0,081	0,071	0,027				
8	-0,399	-0,289	0,225	-0,108	-0,070	-0,311	0,120			
9	0,088	-0,266	0,194	-0,248	-0,121	0,231	-0,121	0,148		
10	-0,282	-0,382	-0,035	-0,544	-0,077	-0,179	0,028	0,277	0,305	

Table 2. Correlation matrix.

k1	1
k2	0,91128328
k3	0,745924192
k4	0,324596738
k5	0,746700579
k6	0,565668452
k7	0,700979668
k8	0,166731245
k9	0,205301221
k10	0,072024807

Table 3. Calculation of reduction constants.

Q1	5,586637
Q2	5,138844
Q3	**3,100796**
Q4	6,39359
Q5	8,092056
Q6	9,580812
Q7	3,506021
Q23	**10,28187**
Q31	8,925371
Q32	7,617143

Table 4. The load value of working environment

Result from the above noted is, that form cumulative view on working environment effects on human is the best workplace number 3 with score Q3 = 3,1007, because it shows the best relative values of indicators and vice-versa the worst workplace is number 23 with score Q23 = 10,2818. To find out the reasons of the reached order of workplaces, so which indicators determine this score and on what significance level is their mutual effect is possible by further analysis of complete file.

3. CONCLUSION

We can conclude, that above mentioned technique is appropriate for complex cumulative evaluation of working environment for multicriteria indicators, because it accumulates extensive complex of their effects to final score with the result, that in counting are eliminated correlative effects, numeric values of indicators and variability of group of them. For practical use is also important to work with larger groups of evaluated workplaces and to standardize evaluation indicators, to be possible in a whole range apply law of big figures.

Suitable culture of the work environment is one of the fundamental premises of the healthy development of modern person and primarily increasing the level of living. To improve the quality of the work environment over the minimal level which is given by the legislation, not only the governments are striving towards it but also social partners in the European Union. Because they realize that in spite of the huge number of EU directives and regulations for improvement of safety on workplaces, the situation still remains unsatisfactory.

For the conduct of the proposal of optimum conditions for securing comfort by work, an essential meaning has a complex evaluation of the load on the work environment. Today the complex evaluation of work environment factors is misjudged even though only this form of evaluation can be considered as objective, because all the negative factors influence the human organism at the same time, this can cause a synergic effect and the response of the organism to partial trouble free values of the factors by their overall effect can be accelerated.

4. REMARK

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5. REFERENCES

[1] Badida, M., Majernik, M., Šebo, D.,Hodolič, J.(2001): *Strojarenska výroba a životne prostredie*, Edícia vedeckej a odbornej literatury Vienala, TU Košice, Strojnicka fakulta, Košice.

[2] Muransky, J. ,Badida, M..(2000)*Trvalo udržateľný rozvoj,* Edícia vedeckej a odbornej literatury Vienala, TU Košice, Strojnicka fakulta, Košice.

[3] Verebová, H. (2002): *Faktory v pracovnom prostredí a ich vplyv na ľudský organizmus,* Factors in work-bench and their impression on human organism, VII.Vedecká konferencia doktorandov strojníckej fakulty, TU Košice, Slovakia.

[4] Verebová, H. (2004): *Štrukturálnaanalýza parametrov pracovného prostredia*, VII. Vedecká konferencia doktorandov strojníckej fakulty, TU Košice, Slovakia.

[5] Yutaka Tochihara, (2005) environmental Ergonomics – *The ergonomic of human of human comfort, health, and performance in the thermal environment,Department of Ergonomics*, Faculty of Design, Kyushu University, Fukuoka, Japan, Hardbound, 500 pages, publication date:APR-ISBN-13:978-0-08-044466-6,ISBN-10:0-08-044466-0

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OPERATING EXPERIMENT OF WASTEWATER CLEANING AROUND THE BLAST FURNACE IN THE USS-KOSICE

Abstract**:**. *Operating experiment of waste water cleaning around blast furnacet in USS-Kosice, was carried out on orders of USS-Kosice, s.r.o, in order to reduce pollution of wastewater provided by Mechanical engineering faculty from the Technical University of Košice. Treatment was provided by the pilot facility constructed using solutions of patent and utility model. Conducted was by experimental treatment with various types of electrodes (3 sets) and testing performed in three modes and provide an analysis of 23 samples of purified water and sludge samples 9.*
Key words: *Wastewater cleaning, various types of electrodes*

1. INTRODUCTION

Operating in the experiment of waste water cleaning around blast-furnace USS-Kosice, was carried out on order of USS-Kosice, in order to reduce pollution of wastewater. It was provided by Mechanical Engineering Faculty from the Technical University of Košice with subcontractors company Sebex Slovakia sro Kosice.

Contractor for the pilot facility used solutions of patent and utility model which are natural carriers of persons involved in the implementation and the loan provider (and not the property of the provider). Experimental treatment conducted for various types of electrodes (3 sets) and testing was performed in three modes provide an analysis of 23 samples of purified water and 9 sludge samples.

2. PRINCIPLE OF USED TECHNOLOGY

The principle of the technology used is based on electrolysis by a patented electrode design, which will effect the reduction reactions of organic substances by flotation and sedimentation effects of flocculants electrode materials, thereby significantly reducing soluble and insoluble substances in water.

Metal electrodes were placed in a universal holder which allows changing the type of material of electrodes, their distance and their involvement. Metal electrodes have dimensions of 330x330 mm and 2 mm and 3 mm thick plates. The experiment used two types of electrode material and the steel and aluminum sheets. Spacing of the electrodes was 80 mm. Features of the experiment are listed in charts.

3. TERMS / BASIC PARAMETERS OF INDIVIDUAL EXPERIMENTS

Sample 1 is prepared from water washing of blast furnace gas.

Sample 2, 3, 4 - water is treated discontinuously electroplated with varying duration of matter at electrodes combined Al-Fe in the design Fig. 1.Rozmery electrodes were 330 x 330 mm, the distance of 80 mm pitch, duration, and electrolysis are recorded in the flow charts. Samples were collected after the prescribed period of sedimentation / 10 min. /. The parameters of the experiment are recorded in charts Figure 1 to 5.

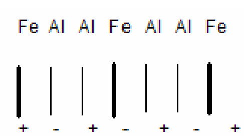

Fig.1. Route 1 and the imposition involving electrodes I

Fig. 2 Star electrode construction for water waste cleaning of the blast radius of SO

LEGEND:

RE – electro coagulating reactor

VC - discharge pump
KH - sludge management
D - blowers
Z - one source. El. current
V - choke
M - submersible pump

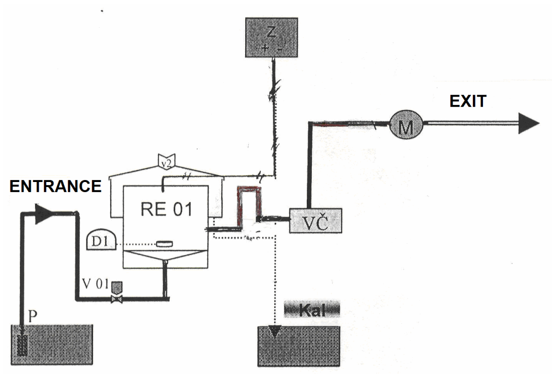

Fig. 3 Involvement of experimental equipment for the wastewater range of the blast

Fig. 4 Design of experimental equipment for the wastewater cleaning

Characteristic changes of soluble substances can analyze to chart 1 Figure 5; the individual salt residues were changed only marginally.

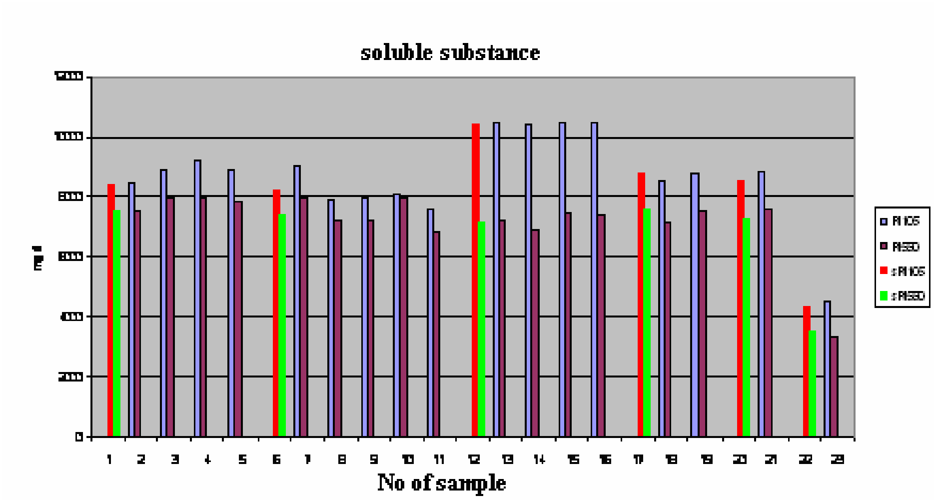

Fig. 5. Characteristic changes of soluble substances can be analyzed at Graph 1, the individual salt residues were changed only marginally.

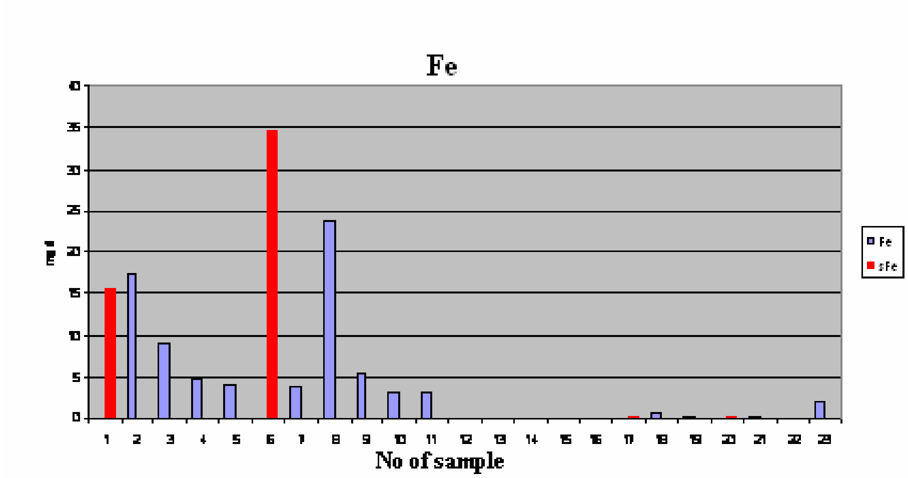

Fig. 6. Characteristic changes in iron Fe can be analyzed at Graph 2, it is likely that the iron content of the electrolysis decreases, clearly, after allowing to stand, prípadenej sedimentation and filtration of waste water.

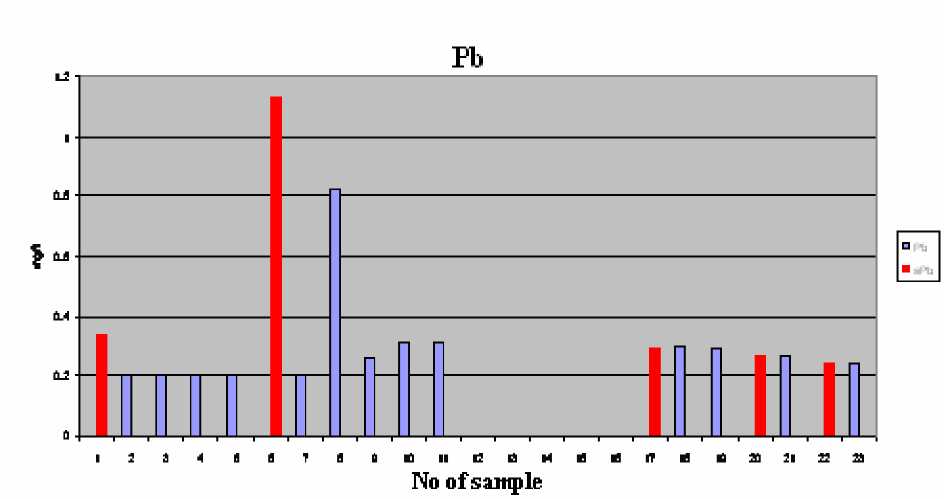

Fig. 7. Characteristic changes in Pb containing lead can be analyzed at Graph 3, it appears that the contents of the electrolysis decreases, clearly, after allowing to stand, prípadenej sedimentation and filtration of waste water.

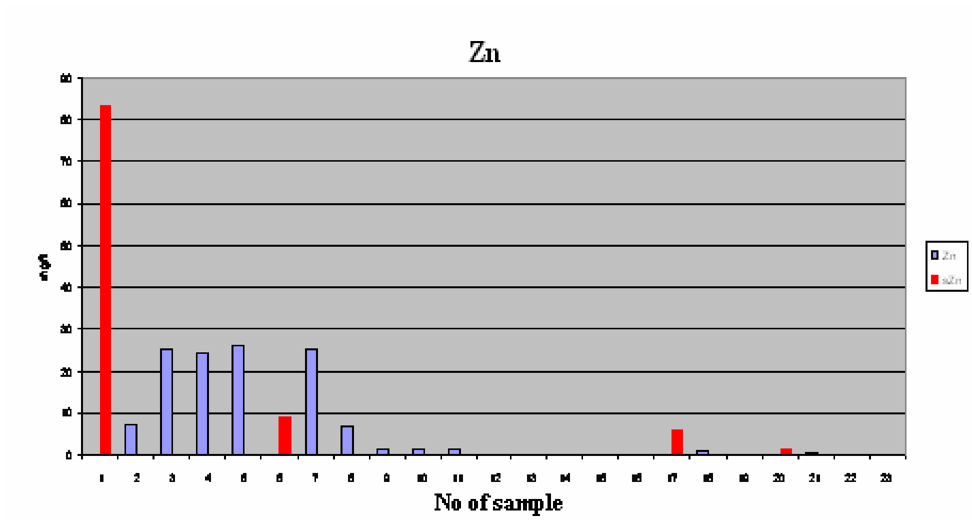

Fig. 8. Characteristic changes in zinc content Zn was analyzed at Graph 4, it appears that the contents of the electrolysis decreases, clearly, after allowing to stand, without prejudice to prípadenej sedimentation and filtration of waste water.

4. CONCLUSIONS

Performed experiments and measurements confirm the expected results from electrolytic wastewater cleaning methods. Based on the protocols and measurements (annex 1 to 32) can be stated that this electrolytic method **is suitable for**:

-Removal of cations (metal cations) Collection. III. to XIII. PSP. ,

- NL to accelerate sedimentation by about 66%

- Removal of soluble substances, colloidal particles of organic nature,

- Removal of soluble substances in the lower concentration of RL (anions and cations)

and **is little suitable for**:

- Removal of chlorides, alkali metals and alkaline earth.

Proposals for solutions:

1) continue to experiment with electrolytic methods in combination with other methods of cleaning wastewater
2) under the procedures of paragraph 1) to establish a pilot plant technology cleaning line with a capacity of 1 / 10 of the required flow rate (about 100m3/hod)3.) at start-up pilot plant line item
3) used as input water blast water after one cycle of charge in exchange circuit (in the current state2.) under the procedures of paragraph 1) to establish a pilot plant technology cleaning line with a capacity of 1 / 10 of the required flow rate (about 100m3/hod)
4) at start-up pilot plant line item 2) used as input water blast water after one cycle of charge in exchange circuit (in the current state

5. LITERATURA

[1] BADIDA, M., MAJERNÍK, M., ŠEBO, D. HODOLIČ J.: Strojárska výroba a životné prostredie, Vienala, ISBN 80-7099-695-1, Košice, 2001,

[2] ŠEBO, D., HRÁDOCKÝ, L., KRÁLIKOVÁ, R.: Nekonvenčný spôsob čistenia odpadových vôd v tepelnej energetike. AtaP JOURNAL, Banská Bystrica, 1998, č. 8.

[3] BADIDA, M., ŠEBO, D. MAJERNÍK, M., MOLNÁR, P.: Multifunkčné elektrokoagulačné čistenie odpadových vôd v priemysle, Strojárstvo, ISNN 1335 2938, č. 2/1999,

[4] MAJERNÍK, M., ŠEBO, D., MOLNÁR, P.: Účinnosť elektrokoagulačného čistenia odpadových vôd v celulózovo-papiernickom priemysle. Strojárstvo, ISNN 1335 2938, č. 4/2000,

[5] ŠEBO, D., PAULÍKOVÁ A.: Likvidácia a úprava technických a technologických kvapalín. . Strojárstvo, ISNN 1335 2938, č. 11/2003,

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10th INTERNATIONAL SCIENTIFIC CONFERENCE ON
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PROCEEDINGS

TOPIC:

OTHERS AREAS

Novi Sad, October 2009.

Invited Paper

Balos S., Grabulov V., Sidjanin L.

50CrV4 STEEL AS A MATERIAL FOR PERFORATED PLATES IN BALLISTIC APPLICATION

Abstract: *50CrV4 steel in different heat treatment conditions was ballistically tested for application as a perforated plate for add-on armour on armoured vehicles. Ballistic behaviour was tested using 12.7 mm M8 API ammunition. Perforated plate samples were placed by means of a steel frame over a armour steel plate. Target damage was correlated to ballistic resistance of the whole armour. It was found that, peforated plates made from 50CrV4 offer a considerable armour protection and may cause frequent fracture of the penetrating core. This debris is unable to penetrate the basic plate, offering a high mass effectiveness.*

Key words: *50CrV4 steel, perforated plate, ballistic resistance, fracture mode*

1. INTRODUCTION

Add – on armour has always been a highly attractive mean od improving passive protection of armoured vehicles. One of the main concerns was the increase in weight of the vehicle, overstressing automotive components, causing a crucial loss of mobility and reliability. Having this in mind, add-on armour should have a particularly high mass efficiency, higher than steel or aluminium alloy armour that forms the structure of the vehicle. Furthermore, multi - hit protection is needed, to provide protection from selective fire [1,2]. In this respect, ceramic materials are not particularly effective due to their brittleness, but one of their drawbacks is high cost as well. In both respects, peforated plates may offer a potentially more effective solution, due to their higher ductility, as well as crack propagation from impact point to the nearest hole, leaving a larger portion of the armour intact [3,4]. Perforated plates defeating mechanism reles on inducing bending stresses in the hard but brittle projectile penetrating core, which may cause its fracture. Fractured debris is then unable to penetrate the basic plate of the vehicle [5].

In this paper, an attempt was made to investigate the potential of a commercially available 50CrV4 steel for perforated plate in ballistic application.

2. EXPERIMENTAL

In this study, 50CrV4 steel perforated plates in two teat treatment conditions and two types of mounting was tested. Chemical composition was as follows: 0.55 % C, 0.36 % si, 0.82 % Mn, 0.99 % Cr, 0.20 5 Ni, 0.033 % P, 0.013 % S, 0.13 % V and balance Fe. Width and height of all tested plates was 700 x 400 mm respectively and their thickness was 6 mm. The drilling od 9 mm holes was done in annealed condition, while the sistance between the hole centers was 13.5 mm. After that, the perforated plates were heat treatet. The plates were quenched at 840°C in oil and subsiquently tempered at 170 °C and 450°C, for achieving two levels of tensile properties, hardness and impact strength. Mechanical properties of these materials were tested at room temperature (20°C) and are given in Table 1**.**

	50CrV4 tempered at 170°C	50CrV4 tempered at 450°C
Hardness BHN [kgf/mm^2]	598	465
Ultimate tensile strength [MPa]	1885	1470
Yield strength [MPa]	1845	1410
Elongation [%]	3	6
Contraction [%]	14	21
Impact strength [J]	5	14

Table 1 Mechanical properties of tested materials

All perforated plates were placed by means of two steel frames at the maximum distance of 400 mm and 100 mm from the basic 13 mm RHA plate (Fig. 1). This basic RHA plate, at 0° from vertical, protects from 7,92 mm SmK (*Spitzgeschoss mit Kern*) hardened steel core [6]. Perforated plates were in vertical or at a 20° angle between the normal to the plate and the projectile trajectory.

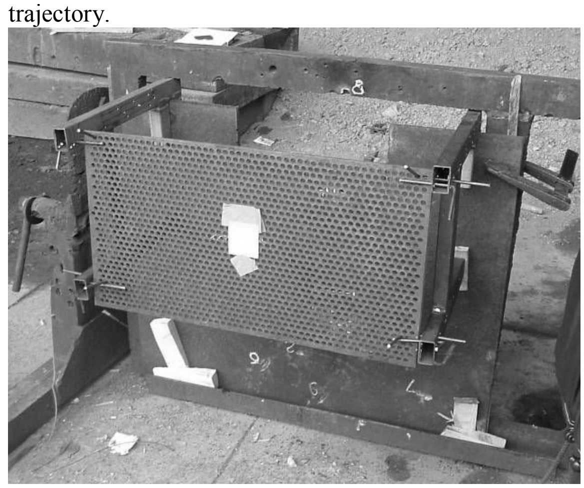

Fig.1 Test setup

For more convinience, a designation system for the separate tests in the experiment is presented:

- 50CrV4 steel, 170°C tempering temperature, placed at 0° from the incoming projectile (C170-0),

- 50CrV4 steel, 450°C tempering temperature, placed at 0° from the incoming projectile (C450-0),
- 50CrV4 steel, 450°C tempering temperature, placed at 20° from the incoming projectile (C450-20),

Ballistic testing was performed by using M8 API ammunition. This ammunition is used in accordance with the standard procedures described in the 1985 Technical regulations for RHA plate acceptance [6]. This ammunition was fired from a Browning M2HB 12,7x99 mm heavy machine gun placed on a tripod, from a 100 m distance. For each test, five shots were fired, where penetration criteria was that no projectile penetrates the basic RHA plate [6]. BS-850 radar was used to determine muzzle velocity at 10 m from the muzzle.

The obtained results of basic plate damage on its front and back sides were correlated with perforated plate damage area.

Perforated plate damage is represented by the area covering the sufficient overlap between the core and the remaining plate. This overlap is 0.34 (h/R, R – core radius), since if it is smaller, the fracture of the core is not assured, as found by Chochron et al. [5]. This is the most unfavourable case, since even if the projectile impacts within the overlap, the stochastic nature of impact may cause the projectile to yaw and impact the basic plate sideways. This way, the penetration of the basic plate is not assured, but nevertheless possible. Damage area was calculated by using a CADD program, by using schemes as on Fig.3.

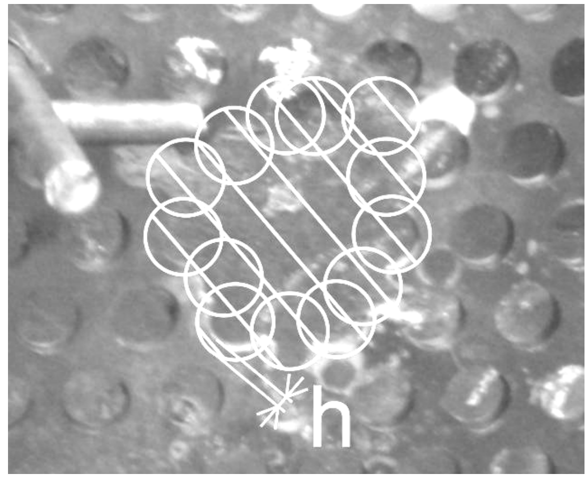

Fig. 2 Damaged area scheme

Fracture surfaces were examined by JEOL JSM-6460LV scanning electron microscope (SEM), operating at 20 kV. Furthermore, energy dispersive X-ray analysis (EDX) was performed, using an Oxford Instruments INCA Mycroanalysis system.

3.RESULTS AND DISCUSSION

Ballistic testing results are shown in table 2. Number of interconnected holes and damaged area indicate the multi – hit resistance of the add-on armour.

Target	No.	v_{10} [m/s]	Number of interconnected holes	Damaged area on the perforated plate [mm^2]	Description of basic plate damage
C170-0	1	870.3	6	485.74	Smooth bulge
	2	857.9	6	465.25	Hole normal
	3	851.2	12	802.52	Smooth bulge
	4	863.3	5	327.20	Smooth bulge – core fractured in 2 parts
	5	859.2	1 (shot next to shot 1)	120.70 additional damage area	Cracked bulge
average			**7.25**	**520.18**	
C450-0	1	864.1	7	548.83	Hole normal
	2	862.4	2 (impact on the edge of the perforated plate)	-	Smooth bulge – core fractured in 2 parts
	3	869.3	4 (shot next to shot 1)	259.32 additional damage area	Smooth bulge – core fractured in 2 parts
	4	875.3	6	466.35	Smooth bulge – core fractured in 2 parts
	5	873.4	6	460.58	Cracked bulge (two cracks)
average			**6.33**	**491.91**	
C450-20	1	872.3	Impact on the edge of the perforated plate-	-	Smooth bulge – core fractured in 2 parts
	2	863.3	5	330.56	Cracked bulge (two cracks)
	3	865.7	7	520.74	Smooth bulge – core fractured in 2 parts
	4	870.1	6	470.24	Smooth bulge
	5	867.5	6	469.57	Smooth bulge
average			**6**	**447.78**	

Table 2 50CrV4 perforated plate results

It can be seen that the average number of interconnected holes and average damaged area are the highest on sample C170-0, which is the result of a lower ductility of this sample, tempered at a lower temperature. Although parameters as average number of interconnected holes and average damaged area are obviously less important than the effect of the perforated plate on penetration core, that is, ballistic resistance of the whole armour model, they may be decisive factors if two perforated plates offer the same or similar performance. According to the obtained results, in case of C170-0 shot 5 and C450-0 shot 3, multi-hit resistance of perforated plates is significant. In both occasions, projectiles impacted at the edge of damaged areas by previous shots. As a result, a cracked bulge and smooth bulge with fractured core occurred at the basic plate, respectively. This is in a strong contract with homohenous metallic armour, where a shot within two projectile diameters of a previous shot is automatically rejected.This is because the material is damaged in this area, so its protection level is therefore much lower. On the other hand, this case is very rare, since the dispersion of projectiles in selective fire is higher than the two projectile diameters. This proves that multi-hit resistance of perforated plates is significantly higher compared to homogenous types of metallic amour.

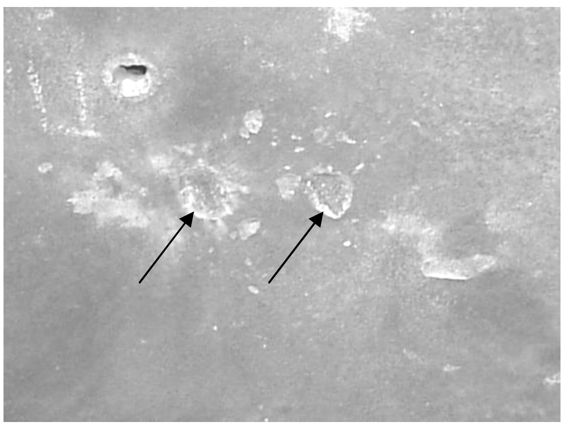

Fig.3 Double dents on the basic plate, as the result of core fracture.

Ballistic performance of these two differently heat treated 50CrV4 steels is slightly different. Although both vertical armour models, C170-0 and C450-0 suffered one penetration (hole normal), other results clearly indicate that core fracture is more frequent on a more ductile material (C450-0, three our of four). When the core is fractured, Fig.3, the damage on the basic plate is lower, indicating a much higher multi – hit resistance. Add-on amour model set at an angle (C450-20) performed better than both vertical armour models (no penetration occured), since it is impossible for the penetration core to impact two hole edges at approximately the same moment and with the same section of ogival. However, if the core fracture is considered, it may be seen that it occurs less frequently than when the perforated plate is vertical.

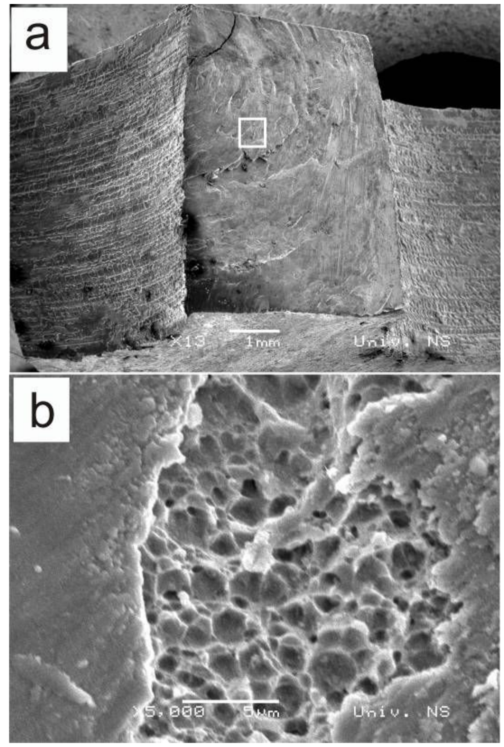

Fig.4 SEM fractograpghs showing smooth surface (a) and dimples (b).

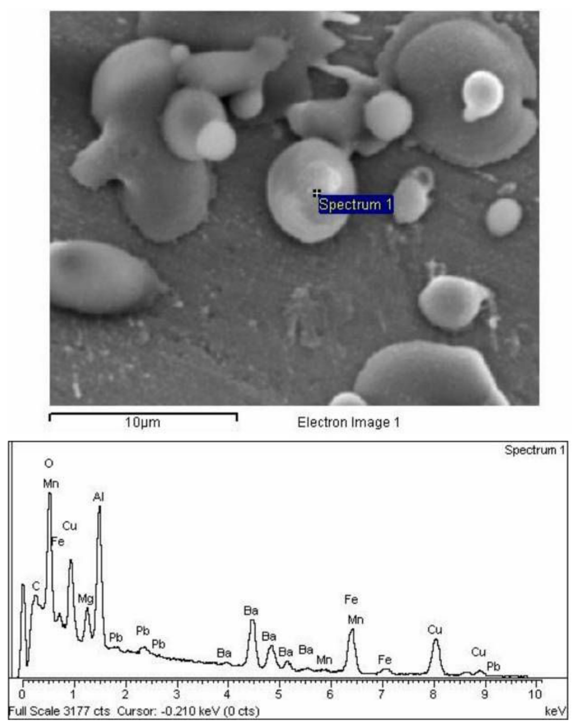

Fig.5 EDX results of incendiary mixture debris.

According to Fig 4, regions with dimples on their fracture surfaces are seen. Smooth regions of fracture surfaces are the result of heavy shear deformation of dimples along the direction of shear stress. EDX analysis shown that the surface is covered with debris, containing barium, copper, aluminium and magnesium, Fig.5. These elements come from the projectile jacket (copper) and incendiary mixture: IM-11 consists of 50 % barium-nitrate $Ba(NO_3)_2$ and 50 % magnesium-aluminium alloy.

Mass effectiveness of C450-20 may be calculated from the plate weight, combined with basic 13 mm plate weight, using areal densities. Areal density of RHA plate that offers protection against 12.7 mm M8 API is 212 kg/m^2, while areal density of 13 mm RHA basic plate is 102 kg/m^2. C450-20 perforated plate areal density is 20 kg/m^2, which means that its mass effectiveness is 5.56. Mass effectiveness of the whole package is 1.74, which means that the basic plate with perforated plate is 74 % lighter than one thicker plate, offering the same protection.

4.CONCLUSIONS

According to the obtained results, some conclusions can be drawn:

- Perforated plates are a very cost-effective solution for add-on armour applications.
- Multi-hit resistance of all tested samples is higher than on any kind of homogenous metallic armour .
- 50CrV4 tempered at a higher temperature, having a higher ductility, offered smaller number of interconnected holes and damaged area, and consiquently a higher multi-hit resistance.
- The optimal sample was C450-20. Its resistance is the highest, although vasic plate damage by non-penetrative impacts is higher than on sample C450-0.
- 50CrV4 steel, although not intended to be used as armour and not particularly ductile compared to other tempering steels, is a good choice for add-on armour in form of a perforated plate.

5.REFERENCES

[1] R. M. Ogorkiewitz. Armor for Light Combat VehiclesAdvances in armour materials, International Defence Review July/2002 41-45

[2] P. Marjanovic. Razvoj oklopa za borbena vozila, Vojnotehnicki glasnik 1/1996, 113-121

[3] Paul J. Hazell, Colin J. Roberson, Mauricio Moutinho. The design of mosaic armour: The influence of tile size on ballistic performance, Mater Design 2008; 29: 1497-1503

[4] Mustafa Übeyli, R. Orhan Yıldırım and Bilgehan Ögel. On the comparison of the ballistic performance of steel and laminated composite armors, Mater Design 2007; 28: 1257-1262.

[5] Chocron S, Anderson Jr CE, Grosch DJ, Popelar CH. Impact of the 7.62-mm APM2 projectile against the edge of a metallic target. Int J Impact Engng 2001; 25: 423-437.

[6] SNO 1645 Pancirni lim od celika HPA-10, Technical regulations for RHA plate acceptance, 1985, p.11.

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Invited Paper

Rajnovic, D., Sidjanin, L., Eric, O.

PROCESSING WINDOW AND AUSTEMPERABILITY OF ALLOYED AUSTEMPERED DUCTILE IRONS

Abstract: *The present study investigated the effect of austempering conditions and alloying elements on the mechanical properties, processing window and austemperability of Cu and Cu+Ni alloyed ductile irons. The obtained results show that alloying with Cu+Ni produce ductile grades of ADI, while alloying with Cu provide the grades of higher strength. Moreover, alloying ductile iron with Cu+Ni the austemperability can be increased significantly. The established processing window depends on the austempering parameters and alloying elements, as well as standard used. Compared to ASTM standard the EN standard give a larger processing window.*

Key words: *austempered ductile iron, mechanical properties, processing window, austemperability*

1. INTRODUCTION

Ductile iron is a type of cast iron with spheroidal graphite embedded in the metal matrix. After heat treatment (austempering), metal matrix of ductile iron is transformed into an ausferrite, a mixture of ausferritic ferrite and carbon enriched retained austenite [1-3]. Material with this unique microstructure is referred as austempered ductile iron (ADI). The ADI possesses remarkable combination of high strength, ductility and toughness together with good wear, fatigue resistance and machineability [3]. For that reason, as-cast ductile iron (DI) and ADI are used in many wear resistant and engineering components, and in many different sectors including automotive, trucks, construction, earthmoving, agricultural, railway and military [2, 3].

During the austempering process, the ADI undergoes a two stage transformation process. In the first stage, the austenite (γ) decomposes into mixture of ausferritic ferrite (α) and carbon enriched retained austenite (γ_{HC}), a product known as ausferrite. If the casting is held at the austempering temperature too long, then the carbon enriched retained austenite (γ_{HC}) transform into ferrite (α) and carbides [1-3]. The carbides makes material more brittle and therefore, that reaction must be avoided [1]. The optimum mechanical properties can be achieved upon completion of the first reaction, but before second reaction started. The time period between the end of stage I and the start of stage II is called processing window. In addition, according to Elliot [2], processing window is the time interval over which the standard grades of ADI material can be produced.

Another important consideration in production of the ADI material is the maximum section size that can be austempered without the formation of pearlite or ferrite. The austemperability (i.e. the ability to quench without forming pearlite) is primarily controlled by alloying elements (Mn, Cu, Ni, Mo etc.). Previous studies [3-6] have shown that alloying elements influenced the initiation time and completion of the austempering reaction, and thereby affording a larger processing window and ease off control of the reaction.

In this study, a processing window according to ASTM and EN standards have been established and influence of Cu and Ni on mechanical properties and austemperability have been investigated.

2. EXPERIMENTAL PROCEDURE

The ductile irons alloyed with Cu and with Cu+Ni have been examined in as-cast and austempered condition. The chemical compositions of as cast materials are given in Table 1.

Selected alloys have been produced in commercial foundry and cast into the standard 25.4 mm (1 inch) Y block sand molds. The samples for mechanical testing were machined from the lower parts of Y blocks in order to avoid any segregation or porosity. After machining, the samples were heat treated to produce an ADI material. The samples were austenitized at 900°C for 2 hours in protective atmosphere of argon and then rapidly quench in salt bath at an austempering temperature of 300, 350 and 400°C and hold for 1, 2, 3, 4 and 6 hours.

Conventional metallographic preparation technique (mechanical grinding and polishing followed by etching with nital) was applied prior to light microscopy (LM) examinations of samples cut from Charpy impact specimens. For microstructural characterization, a “Leitz-Orthoplan” metallographic microscope was used. The volume fraction of retained austenite in ADI material ($V\gamma$) was determined by x-ray diffraction technique using “Siemens D 500” diffractometer with nickel filtered Cu $K\alpha$ radiation. For all samples mechanical properties, namely, tensile properties (R_m-ultimate tensile strength, $R_{p0.2\%}$-proof strength, A_5-elengation, EN 10002), impact energy (K0, EN 10045) and Vickers hardness (HV10, ISO 6507) were determined at room temperature.

In addition, a Jominy test was used in order to establish an austemperability, i.e. the critical bar diameter of as-cast material that can be austempered without pearlite formation.

3. RESULTS AND DISCUSSION

Light micrographs of ductile iron and corresponding ADI alloyed with Cu and with Cu+Ni are given in Fig. 1-3. The spheroidisation of graphite in all specimens was more than 90%, with average graphite volume fraction of 10.5%, nodule size of 40 to 55 μm and nodule count of 50 to 80 per mm^2, Fig. 1. As-cast microstructure of ductile iron alloyed with Cu was dominantly pearlitic with up to 10% of ferrite, Fig. 2a, whereas ductile iron alloyed with Cu+Ni was fully pearlitic, Fig. 2b. The representative microstructure of the ADIs alloyed with Cu austempered at 350°C /2h and Cu+Ni austempered 350°C /3hare shown in Fig. 3. The microstructure is fully ausferritic consisting of mixture of ausferritic ferrite and carbon enriched retained austenite. However, alloying the ADI with Cu+Ni, the acicular appearance of microstructure obtained in ADI alloyed with Cu (Fig. 3a) have change to more plate-like morphology of ausferritic ferrite (Fig. 3b). Furthermore, alloying austempered ductile iron with Cu+Ni delays the transformation kinetics of austenite, shifting the maximum of retained austenite from 2 hours to 3 hours and promotes the increase of retained austenite volume fraction.

The microstructures for the other austempering conditions are discussed in detail elsewhere [7, 8].

Table 1 Chemical composition of as-cast material [mass %]

Material	C%	Si%	Mn%	Cu%	Ni%	Mg%	P%	S%
DI Cu	3.64	2.49	0.30	0.46	-	0.066	0.014	0.014
DI Cu+Ni	3.48	2.19	0.26	1.57	1.51	0.060	0.020	0.012

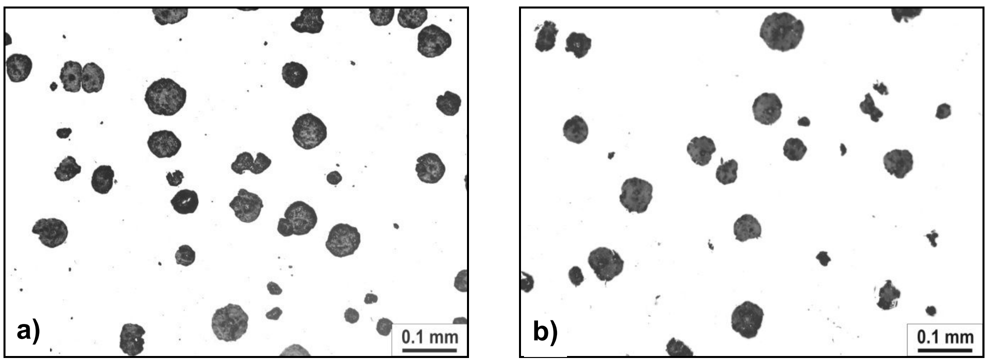

Fig. 1 Microstructure of ductile iron (polished surface): a) DI Cu, b) DI Cu+Ni

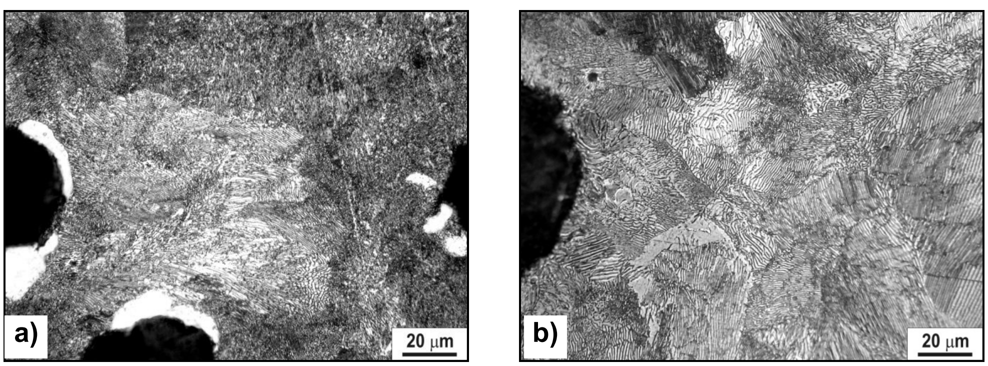

Fig. 2 Microstructure of ductile iron (etched surface): a) DI Cu, b) DI Cu+Ni

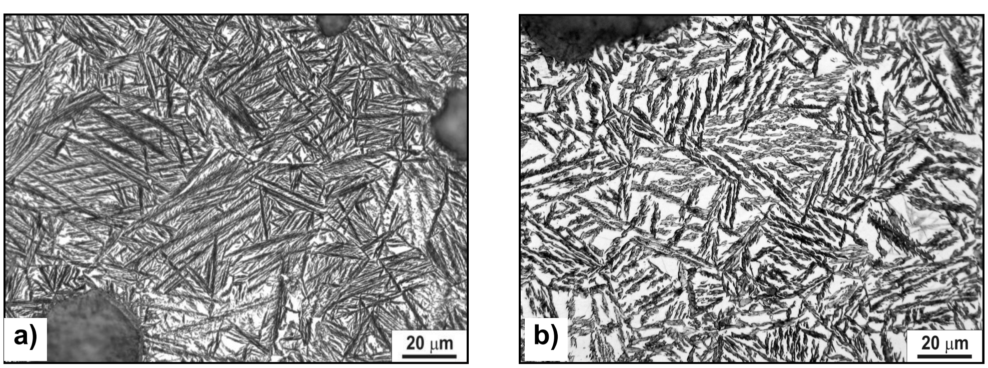

Fig. 3 Microstructure of austempered ductile iron (etched surface):
a) ADI Cu austempered at 350°C for 2h, b) ADI Cu+Ni austempered at 350°C for 3h

Table 2 Mechanical properties of as-cast material

Material	R_m [MPa]	$R_{p0,2\%}$ [MPa]	A_5 [%]	K0 [J]	HV10	ASTM A536-84	SRPS EN 1563:2005
DI Cu	770	514	4.9	21.4	270	100-70-03 (M-689-483-03)	EN-GJS-700-2
DI Cu+Ni	880	677	3.2	20.5	296	120-90-02 (M-827-621-02)	EN-GJS-800-2

Table 3 Mechanical properties of ADI alloyed with Cu

Austempering		R_m	$R_{p0,2\%}$	A_5	K0	HV10	Vγ [%]	ASTM A897M-03	SRPS EN 1564:2005
Temp.	Time	[MPa]	[MPa]	[%]	[J]				
300°C	1 h	1427	1315	1.4^{A}	52.6	452	6.8	-	EN-GJS-1400-1
	2 h	1428	1346	3.4	59.7	451	7.1	1400/1100/02 (4)	EN-GJS-1400-1
	3 h	1445	1342	3.7	76.9	378	11.0	1400/1100/02 (4)	EN-GJS-1400-1
	4 h	1481	1391	3.1	71.5	406	8.7	1400/1100/02 (4)	EN-GJS-1400-1
	6 h	1412	1345	2.7	69.4	436	8.7	1400/1100/02 (4)	EN-GJS-1400-1
350°C	1 h	1158	1026	4.7^{AE}	85.6	402	13.9	-	-
	2 h	1112	998	7.9	106.1	373	16.6	1050/750/07 (2)	EN-GJS-1000-5
	3 h	1109	993	7.1	105.1	350	16.4	1050/750/07 (2)	EN-GJS-1000-5
	4 h	1205	1121	5.9	100.8	391	12.3	1200/850/04 (3)	EN-GJS-1000-5
	6 h	1160	1066	5.3^{A}	91.6	420	11.8	-	EN-GJS-1000-5
400°C	1 h	977	760	6.3^{AE}	86.3^{A}	345	14.9	-	-
	2 h	984	834	7.1^{AE}	89.4^{A}	344	15.5	-	-
	3 h	987	820	6.2^{AE}	56.5^{A}	327	13.7	-	-
	4 h	1007	804	4.5^{AE}	23.0^{A}	332	0.0	-	-
	6 h	1019	884	2.0^{AE}	20.4^{A}	364	0.0	-	-

^{A} mechanical property is below minimal value required by standard ASTM A897M-03
^{E} mechanical property is below minimal value required by standard SRPS EN 1564:2005

Table 4 Mechanical properties of ADI alloyed with Cu+Ni

Austempering		R_m	$R_{p0,2\%}$	A_5	K0	HV10	Vγ [%]	ASTM A897M-03	SRPS EN 1564:2005
Temp.	Time	[MPa]	[MPa]	[%]	[J]				
300°C	1 h	1390	1180	3.5^{A}	52.6^{A}	454	8.4	-	EN-GJS-1200-2
	2 h	1354	1176	4.5	59.7^{A}	414	10.8	-	EN-GJS-1200-2
	3 h	1369	1159	5.5	76.9	384	16.3	1200/850/04 (3)	EN-GJS-1200-2
	4 h	1375	1182	5.6	71.5	424	16.0	1200/850/04 (3)	EN-GJS-1200-2
	6 h	1325	1205	3.4^{A}	69.4	462	7.0	-	EN-GJS-1200-2
350°C	1 h	1111	824	5.4^{A}	46.1^{A}	415	6.6	-	EN-GJS-1000-5
	2 h	1109	931	10.0	90.2^{A1}	383	14.9	1050/750/07 (2)	EN-GJS-1000-5
	3 h	1070	901	11.1	122.1	308	18.9	1050/750/07 (2)	EN-GJS-1000-5
	4 h	1043	892	10.1	106.1	351	15.2	900/650/09 (1)	EN-GJS-1000-5
	6 h	1042	822	6.1^{A}	50.3^{A}	380	14.2	-	EN-GJS-1000-5
400°C	1 h	973	642^{A}	10.6	100.2	308	19.7	-	EN-GJS-800-8
	2 h	989	708	10.9	94.3^{A}	322	19.9	-	EN-GJS-800-8
	3 h	950	677	7.7^{AE}	82.5^{A}	344	15.9	-	-
	4 h	986	723	7.1^{AE}	78.4^{A}	361	15.3	-	-
	6 h	959	695	5.6^{AE}	57.8^{A}	438	3.5	-	-

^{A} mechanical property is below minimal value required by standard ASTM A897M-03
^{E} mechanical property is below minimal value required by standard SRPS EN 1564:2005

The results of tensile, impact and hardness testing, as well as the retained austenite volume of ADIs are given in Table 2, 3 and 4, for ductil irons, ADI alloyed with Cu and ADI alloyed with Cu+Ni, respectively.
The processing window was determined by comparing measured mechanical properties with minimal values required by standard ASTM A897M-03 and SRPS EN 1564:2005 (Table 3 and 4). The processing window is narrower in case of ASTM, as it requires higher values of mechanical properties, especially ductility. On the other hand, the EN standard provides larger processing windows, as its requirements are not so severe. Alloying ductile iron with Cu and Cu+Ni influence the mechanical properties and the processing window. The standard grades of ADI Cu+Ni have a greater ductility, but lower strength. In addition, processing window is larger. The ADI Cu has narrower processing window and achieved standard grades are of higher strength and lower ductility.
The Jominy end quench curves for alloys containing Cu and Cu+Ni are presented in Fig. 4. The addition of 1.57% of Cu and 1.51% of Ni greatly influence austemperability of ductile iron as the hardened zone was extended over 35 mm from quench end. In case of material alloyed only with the 0.46% of Cu the high hardness were obtained only at small dept, to the approximately of 5 mm. This results are in good agreement with literature [3, 4, 6].

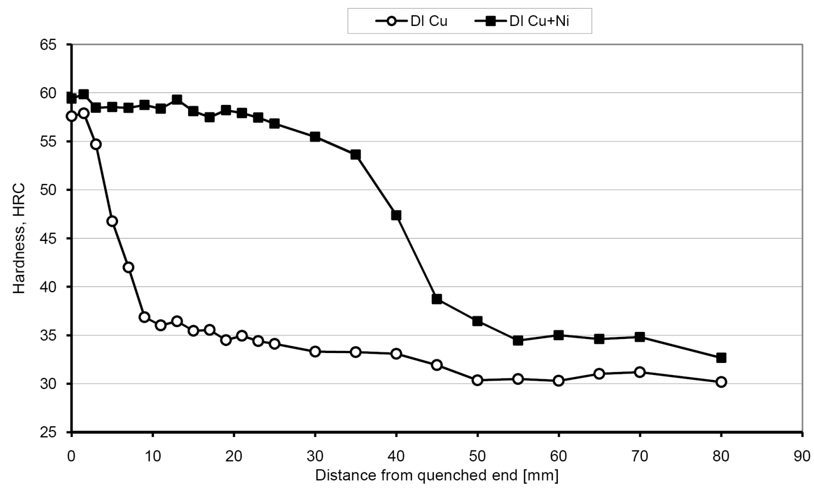

Fig. 4 Hardness profile obtained in end quenched specimens of DI Cu and DI Cu+Ni

4. CONCLUSIONS

The results obtained show that the processing window depends on the austempering parameters and alloying elements, as well as to appropriate standard. The EN standard give a larger processing window compared to ASTM standard. Alloying DI with Cu+Ni produce grades of ADI that are more ductile, while alloying with Cu provide grades of higher strength. In addition, austemperability can increase significantly by alloying ductile iron with Cu+Ni.

5. REFERENCES

[1] Sidjanin, L., Smallman, R.E.: *Metallography of bainitic transformation in austempered ductile iron*, Materials Science and Technology, 8, (1992) 1095-1103

[2] Elliot, R.: *The Role of Research in Promoting Austempered Ductile Iron*, Heat Treatments of Metals, 3, (1997), 55-59

[3] Harding, R.A.: *The production, properties and automotive applications of austempered ductile iron*, Kovove Materialy, 45, (2007), 1-16

[4] Shih, T.S., Chang, C.H., Hwang, L.Z.: *Mechanical Properties and Microstructures of Austempered Alloyed Ductile Irons*, AFS Transactions, 107, (1991), 793-808

[5] Bosnjak, B., Radulovic, B., Pop-Tonev, K., Asanovic, V.: *Microstructural and mechanical characteristics of low alloyed Ni-Mo-Cu austempered ductile iron*, ISIJ International, 40, (2000), 1246-1252

[6] Zahiri, S.H., Davies, C.H.J., Pereloma, E.V.: *Simultaneous prediction of austemperability and processing window for austempered ductile iron*, Materials Science and Technology, 19, (2003), 1761-1770

[7] Eric, O., Rajnovic, D., Sidjanin, L., Zec, S., Jovanovic, M.T.: *An austempering study of ductile iron alloyed with copper*, Journal of the Serbian Chemical Society, 70, (2005), 1015-1022

[8] Eric, O., Rajnovic, D., Zec, S., Sidjanin, L., Jovanovic, M.T.: *Microstructure and fracture of alloyed austempered ductile iron*, Materials Characterization, 57, (2006), 211-217

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Balos S., Grabulov V., Sidjanin L.

PATENTED WIRE MESH AS ADD-ON ARMOUR

Abstract: *In this paper, patented wire mesh was investigated for add-on armour application. The fence made from patented wire was tested by firing 12.7 mm M8 API ammunition at four add-on armour models: two with parallel wire arrangement, one mounted at a 90^o angle from the incoming projectile and the other at 70^o; and two with zig – zag wire arrangement, one mounted at a firm 90^o angle and the other hanging. Fence damage was correlated with 13 mm RHA basic plate damage. The parallel wire arrangement has shown to have a considerable potential as an improvised add-on armour, the most effective model being the hanging mesh. However, the most convenient was found to be the armour model with the zig – zag wire arrangement fixed in vertical position.*
Key words: *patented wire, ballistic resistance, add-on armour*

1. INTRODUCTION

Traditional vehicle field modifications in terms of add-on armour protection comprise a wide variety of measures. Some are consisted of mild steel or rolled homogenous steel plates, other even use wooden boards or sand-bags. However, these types of add-on protection either are too heavy, or their effectiveness is questionable. Therefore, a solution for increasing armour protection is needed, that will not add too much weight to the vehicle, but would increase its armour protection to the next level [1]. If machine-guns are used, multi – hit protection is of a very high priority. Furthermore, it is very important to use locally or readily available resources and manufacturing processes (off-the-shelf principle of design). Having all this in mind, pne very convenient way of making the projectile less effective is inducing yaw. Such an add-on armour may be designed even by a simple spaced armour, used during World War II. Roughly twice as effective was a wire mesh, called *Thoma Schuerzen*: 5.5 mm thick mild steel wires placed 13.5 mm apart used in the final stages of this conflict [2].

In this work, an attempt is made to investigate the possibility of using patented high tensile strength wire as a basic destabilizing element of an improvised add-on armour. This material is widely available and used for reinforcing pre-stressed concrete structures [3].

The present work was carried out as a part of a continuing programme at the University of Novi Sad, in collaboration with the Military Technical Institute – Belgrade to study and develop different types of ballistic protection systems for the defence industry.

2. EXPERIMENTAL

The functional element of wire meshes tested in this experiment was patented wire having the following chemical composition: C 0.77 %, Si 0.22 %, Mn 0.61 %, Cr 0.25 %, P 0.03 %, S 0.03 %, V 0.05 % and Fe – balance. The diameter of the wires was 5 mm, average yield strength (0.2 % off set line) 1410 MPa, ultimate tensile strength 1630 MPa, elongation 9.5 % and maximum contraction in radial direction 48 %. They were suspended in a welded L-profile mild steel frame. Add-on armour model dimensions were: width 700 mm and height 400 mm. 53 vertical patented wires were placed through drilled holes in horizontal L-profiles (15x15 mm). The whole package was welded to a L-profile welded frame. Two different applique armour models were manufactured: with holes drilled in a parallel pattern, as shown in Fig. 1, with 12.5 – 13 mm distances between them, leaving 8 – 8.5 mm spaces between the wires, and the other, as shown in Fig. 2, with a zig-zag pattern where every other wire is 4 mm closer to the incoming projectile. Both add-on model armours were attached to the basic plate by means of two steel frames at the maximum distance of 400 mm. This basic RHA plate, at 0^o from vertical, provides protection from 7,92 mm SmK (*Spitzgeschoss mit Kern*) hardened steel core [4].

Fig.1 Testing arrangement with add-on armour model with parallel wires

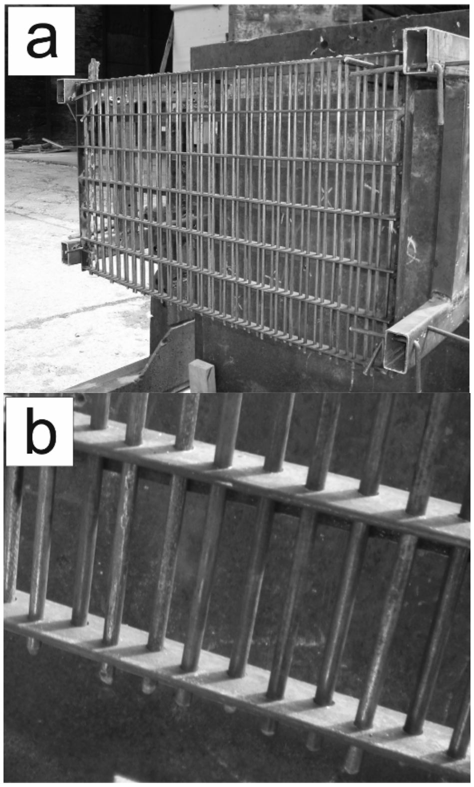

Fig. 2 Zig-zag wire target (a) and wire arrangement (b)

For testing, the following add-on model armours were tested:

- parallel wire arrangement, stiff mounting, vertical position, 90^o from the incoming projectile (marked as PSV, Fig. 1 and 3a),
- parallel wire arrangement, stiff mounting, vertical position, but at 20^o measured in vertical plane and 70^o from the incoming projectile (PS20), see (Fig. 3b),
- zig-zag wire arrangement, stiff mounting, vertical position, 90^o from the incoming projectile (ZSV, Fig. 2 and 3c), and
- zig-zag wire arrangement, free hanging with initial vertical position, 90^o from the incoming projectile (ZHV), (Fig. 3d).

In ZHV target arrangement, the mesh was hung by two rings each with a diameter of 100 mm, made of rebar with a wire diameter of 5 mm. These rings were supported under a 25 mm bar, firmly mounted by using two U-shaped hooks, over the frames used for armour model mounting in previous tests.

Ballistic testing was performed with 12,7 mm M8 API ammunition (API-Armour Piercing Incendiary), as suggested by the standard procedures described in the 1985 Technical regulations for RHA plate acceptance [4]. This ammunition was fired from a Browning M2HB 12,7x99 mm heavy machine gun placed on a tripod, from a 100 m distance. Five shots were fired at each applique armour model. Projectile muzzle velocity was measured by a BS-850 muzzle velocity radar, at 10 m from the muzzle. Description of fence damage may give indication where the projectile impacted. Description of target damage was carried out according to STANAG 4146 [5].

Fracture surfaces were examined by JEOL JSM-6460LV scanning electron microscope (SEM), operating at 20 kV. Furthermore, energy dispersive X-ray analysis (EDX) was performed, using an Oxford Instruments INCA Mycroanalysis system.

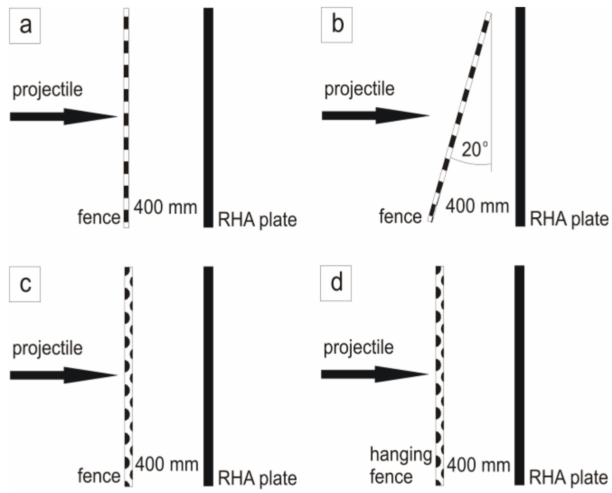

Fig.3 Testing arrangement of add-on armour models: a)PSV, b) PS20, c) ZSV, d) ZHV

3.RESULTS AND DISCUSSION

The results of ballistic testing are shown in table 1.

It can be noticed muzzle velocity does not influence the add-on mesh and basic plate damage. Mesh damage may be either on one or two wires with wire deformation or fracture. Mild steel frame was found to offer some degree of protection itself.

PS20 target has shown to be more resistant than PSV target (tables 1 and 2). The main reason is its angled nature, which does not allow the projectile to impact the wires simultaneously with a similar *ogival* section. This effectively induces yaw on the projectile even when two wires are impacted. Therefore, the penetration core passes through the mesh and impacts the basic plate sideways, Fig.4. This way, the tip of the penetrating core does not impact basic armour, while the area that is in such a case impacted is higher, enabling the basic plate to withstand the impact without penetration. On the other hand, ZSV target (table 4), designed to emulate this effect with a more convinient ertical add-on position od the mesh, failed to offer protection of the basic plate in one instance (ZSV-1). However, in this case, penetrating core impacted one wire, most probably near its centerline and fractured it, probably without much yaw that was not sufficient to prevent penetration of the basic plate. And finally, ZHV target proved to offer the highest protection level, higher than PS20 target, as could be seen according to basic plate damage, table 5. However, this arrangement is the most difficult to mount on an actual vehicle.

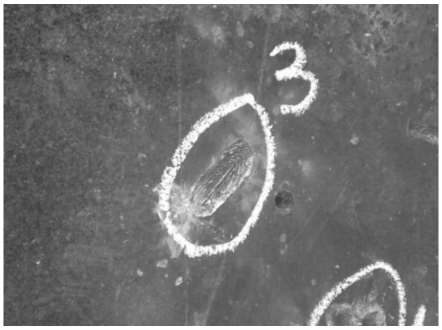
Fig. 4 ZSV-3 showing the elongated dent on the basic plate

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Target	**No.**	v_{10} **[m/s]**	**Number of interconnected holes**	**Damaged area on the perforated plate [mm^2]**	**Description of basic plate damage**
C170-0	1	870.3	6	485.74	Smooth bulge
	2	857.9	6	465.25	Hole normal
	3	851.2	12	802.52	Smooth bulge
	4	863.3	5	327.20	Smooth bulge – core fractured in 2 parts
	5	859.2	1 (shot next to shot 1)	120.70 additional damage area	Cracked bulge
average			**7.25**	**520.18**	
C450-0	1	864.1	7	548.83	Hole normal
	2	862.4	2 (impact on the edge of the perforated plate)	-	Smooth bulge – core fractured in 2 parts
	3	869.3	4 (shot next to shot 1)	259.32 additional damage area	Smooth bulge – core fractured in 2 parts
	4	875.3	6	466.35	Smooth bulge – core fractured in 2 parts
	5	873.4	6	460.58	Cracked bulge (two cracks)
average			**6.33**	**491.91**	
C450-20	1	872.3	Impact on the edge of the perforated plate-	-	Smooth bulge – core fractured in 2 parts
	2	863.3	5	330.56	Cracked bulge (two cracks)
	3	865.7	7	520.74	Smooth bulge – core fractured in 2 parts
	4	870.1	6	470.24	Smooth bulge
	5	867.5	6	469.57	Smooth bulge
average			**6**	**447.78**	

Table 2 50CrV4 perforated plate results

Multi hit protection of wire mesh was proved to be higher than that of the homogenous It can be noticed muzzle velocity does not influence the add-on mesh and basic plate damage. Mesh damage may be either on one or two wires with wire deformation or fracture. Mild steel frame was found to offer some degree of protection itself.

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In the case of PSV-4 (Table 2), the cracked bulge occured, with a dent over the PSV-1 dent, indicating a considerable multi hit – capability, Fig 6, while according to the 1985 Technical regulations for RHA plate acceptance [13], an impact within two diameters of the previous hit or dent is not valid due to the fact that the material is weakened in this zone.


Fig. 4 ZSV-3 showing the elongated dent on the basic plate

According to Fig 5, regions with dimples on their fracture surfaces are seen. Smooth regions of fracture surfaces are the result of heavy shear deformation of dimples along the direction of shear stress. EDX analysis shown that the surface is covered with debris, containing barium, copper, aluminium and magnesium, Fig.6. These elements come from the projectile jacket (copper) and incendiary mixture: IM-11 consists of 50 % barium-nitrate $Ba(NO_3)_2$ and 50 % magnesium-aluminium alloy.

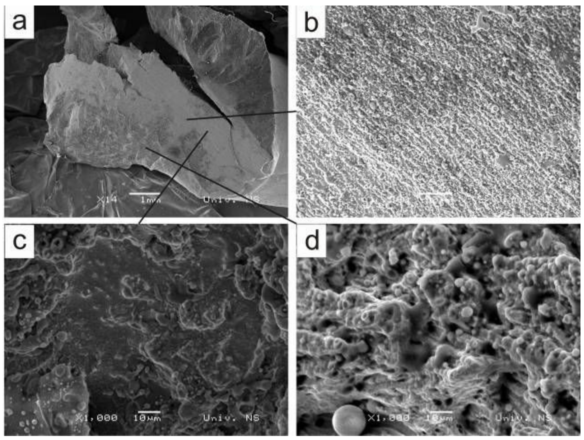

Fig.5 SEM micrograph of patented wire fracture surface.

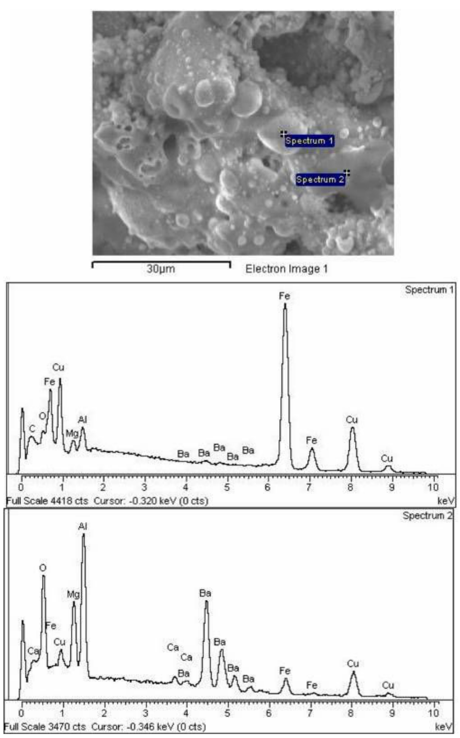

Fig.6 EDX results of incendiary mixture debris.

Tested fences, made from high strength patented wire and mild steel L-profiles, had a weight of 6765 g, or an areal density of 24.16 kg/m^2 (PSV, ZSV and ZHV applique armour models), while for the inclined PS20, areal density was 25.71 kg/m^2. The basic RHA plate had an areal density of 102.05 kg/m^2, while the areal density of the combined basic RHA plate with the fence was 126.21 kg/m^2, or an equivalent of a RHA steel plate 16.08 mm thick. According to [4], an RHA plate that offers protection from M8 API ammunition fired from a Browning M2HB machine gun has an areal density of 211,95 kg/m^2. With armour models PSV, ZSV and ZFV, mass efficiency of the whole RHA and applique armour model was 1.68, while for PS20, due to the inclination of the fence, the mass efficiency was 1.58.

4.CONCLUSIONS

Patented wire has shown a high potential as a functional element of a mesh add-on armour. It is readily available off-the shelf material and a very effective yaw – inducer. The penetrating core, after passing through the mesh becomes tilted and this yaw forces it to impact sideways into the basic plate. In such a case, the penetration could not occur, making the relatively thin basic plate resistant to the tested ammunition. Furthermore, multi hit resistance of such an unhomogenous add-on armour is used.

Zig-zag wire arrangement was proved to be superior to parallel arrangement, because this prevents the projectile to impact two wires with a similar portion of the ogival at approximately the same time, pushing and deforming the wires similar to each other.

If the efficiency of the applique armour is considered to be the highest priority, ZHV applique armour model has shown the highest potential. However, a ZSV – like armour with zig – zagged wires is probably the most convenient compromise between efficiency and ease of mounting on an actual armoured vehicle.

5.REFERENCES

[1] Kemp I, Biass EH. The trend, Armada International – complete guide 2006; 1: 1-32.
[2] Jenz T , Doyle H. Drachtgeflectschuerzen, AFV news may-august 2002; 37: 6-8
[3] Chen S, Wang X, Jia Y. A comparative study of continous steel-concrete composite beams prestressed with external tendons: Experimental investigation. J Constr Steel Res 2009; 65: 1480-1489.
[4] SNO 1645 Pancirni lim od celika HPA-10, Technical regulations for RHA plate acceptance, 1985, p.11.
[5] STANAG 4146 Annex D, 1998, p.D-1.

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Bashir Raddad , Mohieldeen Abdel-Rahman, Said Al-hashani

AN INVESTIGATION ON THE FLOW BEHAVIOR OF METALS WHEN FORGING SPECIMENS HAVING DIFFERENT CROSS SECTIONS

Abstract: *Experiments were carried out to generate data on cold compression of solid copper and aluminum specimens having different cress section shapes (cylindrical, hexagonal, square and rectangular) and height –to-diameter ratios (from 0.5 to 1.5 between flat dies at two degrees of surface condition (dry or lubricated). Different cross section shapes and surface conditions are expected to create different loading characteristics and modes of deformation during this process.*
Experimental results showed load/displacement/ curves consisted of many stages: the metal begins to overcome the frictional force at the interface in the first stage and the metal begins to flow after reaching the yield point. This stage is characterized by a steep rate of increase of load. In the second stage, the load was less in the lubricated specimens. And this *stage showed the different in load due to the different Ho/Do ratio.*
Key words*: Compression, flow behavior of metals, forging different sectioned Specimens, flat dies*

1. INTRODUCTION

Forging is a metal forming process by which metals can be worked into the desired shapes by compressive forces (hammering or pressing) while they are cold or hot **[1]**. The forging operation can be carried out in the cold, warm or hot conditions. Typical parts made by forging are crankshaft and connecting rods for engines, turbine discs, gears, wheels bolt heads, hand tools, and a great variety of structural components for machinery and transportation equipment. The three basic categories of forging are: Open – die, impression – die, and closed – die forging. Open die forging (like in compressing between two flat platens) represents a basic forming operation in many manufacturing processes **[2]**.
In this work, forging between two flat platens will be carried out for Aluminum and coppers specimens having different section shapes to generate data on the material behavior in forging. Effect of material, section shape and height – to – diameter (Ho/Do) ratio will be investigated.

2. EXPERIMENTAL WORK

High purity copper and commercial Aluminum were used as work material.

Cylindrical, hexagonal, square, rectangular cross section specimens were prepared on the lathe- from an original bar having 1 inch (25.4 mm) diameter. The cylindrical specimens were turned on a center lathe to 22 mm diameter. The specimens of different cross sections had approximately the same area. CNC shaping center was used to prepare the non-circular specimens. The initial height-to-diameter (Ho/Do) ratios were 0.5, 0.75, 1.0, 1.25 and 1.5, corresponding to initial heights of 10, 15, 20, 25 and 30 mm respectively for the cylindrical specimen. Other shapes kept the same Ho. Steel flat platens, 80 mm diameter, 60 mm height and 55 RC were prepared.

Special fixture was used to ensure coaxiality of dies and specimens on the machine. A computer-controlled Zwick/Roell universal testing machine, maximum load of 1000 KN and maximum displacement of 100 mm, was used for the compression experiments. Cross head speed was kept at 5 mm/min. Grease was used as a lubricant in lubricated experiments. Dimension measurements were carried out by a Vernier caliper, 0.01 mm accuracy.

Experimental program was as follows:
Specimens were compressed between 2 flat platens with 5 different Ho/Do ratios in 2 different surface conditions. Three sets of specimens were tried for each case. The mean value of the results of the three specimens was taken. Compression was carried out at room temperature till 50% height reduction of each specimen. i.e., 0.69 natural strain

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figs. (1,2,3 and 4) show the load / displacement curves of compressed of Copper specimens with different cross section (circular, hexangular, square, rectangular) between (2 dry) dies with different Ho/Do ratios in the dry condition. No surface cracks were obtained till 50% height reduction. For all shapes, Outer surface had the common bulged contour, the typical form in compression between flat dies [**3**].

Figs. (5,6,7 and 8) show the same curves for compressed Copper specimens between lubricated dies. **Figs. (.9,10,11, and 12)** shows the load/displacement curves of compressed Aluminum specimens with different cross section (circular, hexangular, square, rectangular) and different Ho/Do ratios between 2 dry dies.

Figs. (13,14,15, and 16) show the same curves for compressed Aluminum specimens between lubricated dies. For all the Copper and Aluminum compressed specimen curves, load is increased as displacement Increases and this is due to strain hardening. But the slope of the second stage of deformation differs as material changes and as the Ho/Do ratio increases. Strain hardening characteristic of the material affects the forming behavior. Copper specimens generally had higher loads than Aluminum ones.

Generally, for the ductile materials, the curves consist from three stages:

1-**The first stage**: at which the metal begins to overcome the frictional force at the interface.

2-**The second stage**: at which the metal begins to flow after reaching the yield point. This stage is characterized by a steep rate of increase of load vs. displacement.

3-**The third stage**: at which the load is increased in a high rate due to the increasing contact area which means an increase in frictional forces.

This conforms with many works in the literature [**4-5.**]. For all the specimens in the first stage of deformation, a very slight difference could be noticed in spite of the different section shape or the Ho/Do ratio. The frictional force seems to be the most effective in this stage. But after this preliminary stage, differences become more evident. Lubricated specimens had less load values. This is because the less force necessary to overcome friction due to the presence of lubricant which reduces the coefficient of friction. The Ho/Do ratio also controls the load/displacement curve shape. As Ho/Do ratio increases, the slope of the curves decreases for the same displacement value. This is due to the fact that as the Ho increases the strain decreases, which results in less load required to achieve such strain. .

Figs. (17 and 18) present the effect of Ho/Do on the load value at certain fixed displacement in the second stage of deformation for copper specimen having different cross sections in the dry and lubricated conditions respectively. The same curves for Aluminum are given in **Figs.(19 and 20**) in the dry and lubricated conditions respectively.

4. CONCLUSION

From the results of the experiments carried out on compression of high purity copper and commercial purity aluminum specimens between 2 flat dies having different Ho/Do ratios and different surface conditions (dry and lubricated), the following conclusion can be drawn:

1-Different specimen geometry, Ho/Do ratios had led to different loading conditions. Cylindrical specimens gave the highest loads, while rectangular ones gave the smallest load.

2-Friction condition at the specimen /die interface affected the load, shape, and mode of material flow in forging . When lubricated specimens were used, load decreased due to the fact that the coefficient of friction decreases, and hence the friction force decrease.

3-The height to diameter (Ho/D0) ratio also had a noticed effect: As Ho/Do increases, load at constant displacement decreases. This may be referred to the fact that as Ho increases, the strain is decreased. Flow mode was of the bulged type, a typical for forging between flat dies.

4-At constant displacement, the load level is decreased as the (Ho/D0) ratio increase.

It is clear that as the Ho/Do ratio increases, the level of load decreases for the same displacement. Again the load values for lubricated specimens are less than for the dry ones. Change of specimen material had led to a change in the load values.

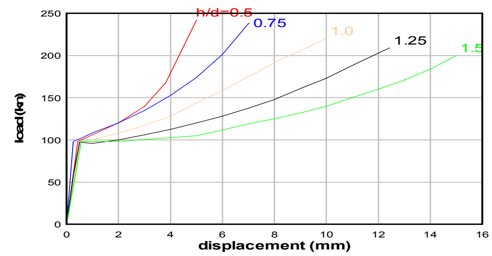

Fig (1): Collective load /displacement curves for Copper specimens, cylindrical, dry

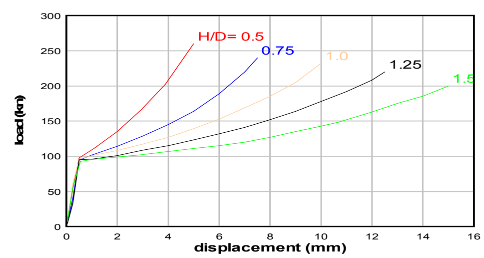

Fig (2): Collective load / displacement curves for Copper specimens, hexagonal, dry

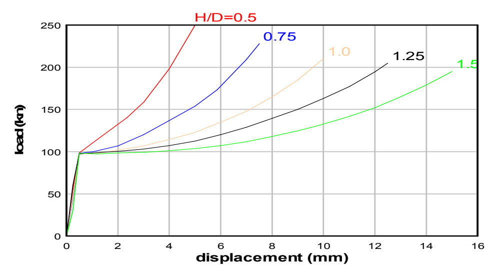

Fig (3): Collective load / displacement curves for Copper specimens, square, dry

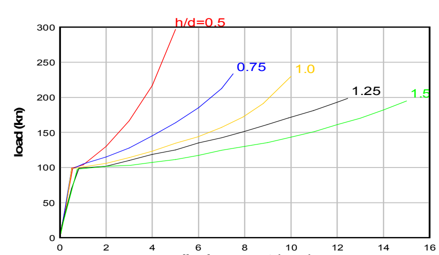

Fig (4): Collective load / displacement curves for Copper specimens, rectangular, dry

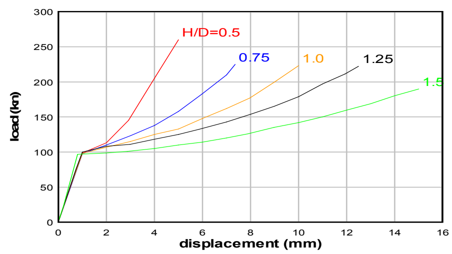

Fig (5): Collective load /displacement curves for
Copper specimens, cylindrical, lubricated

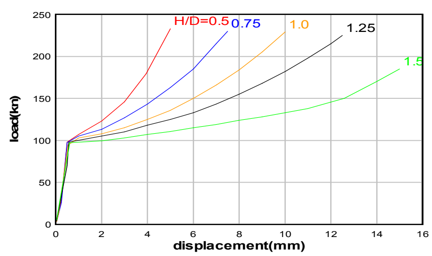

Fig (6): Collective load /displacement curves for
Copper specimens, hexagonal, lubricated

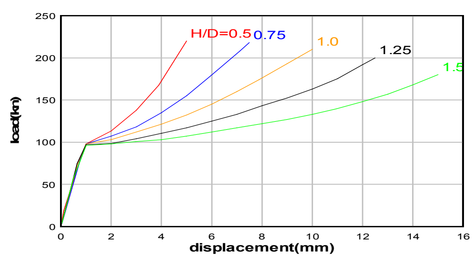

Fig (7): Collective load /displacement curves
for Copper specimens, square, lubricated

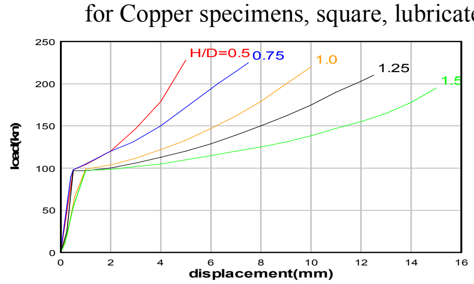

Fig (8): Collective load /displacement curves for
Copper specimens, rectangular, lubricated

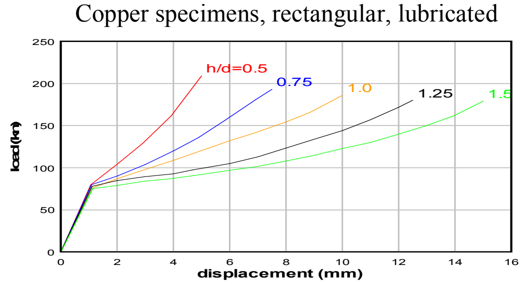

Fig (9): Collective load /displacement curves for
Aluminum specimens, cylindrical (dry)

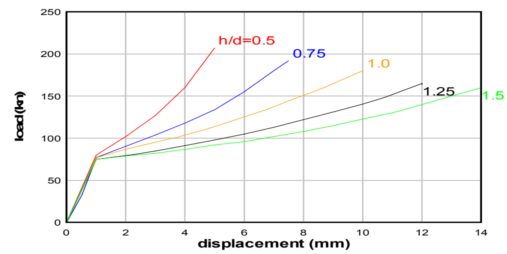

Fig (10): Collective load / displacement curves for
Aluminum specimens, hexagonal, dry

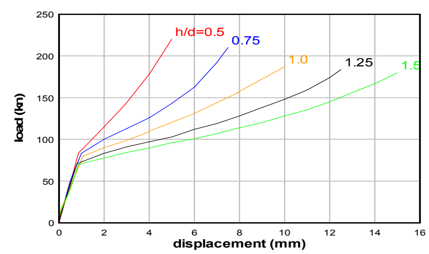

Fig (11): Collective load / displacement curves for
Aluminum specimens, square, dry

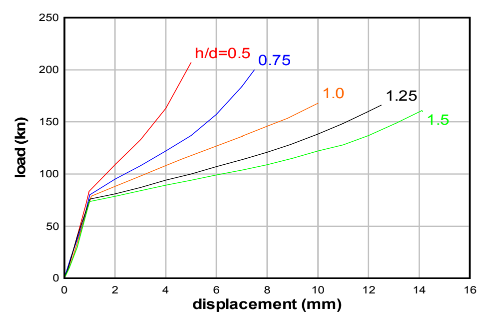

Fig (12): Collective load / displacement curves for
Aluminum specimens, rectangular, dry

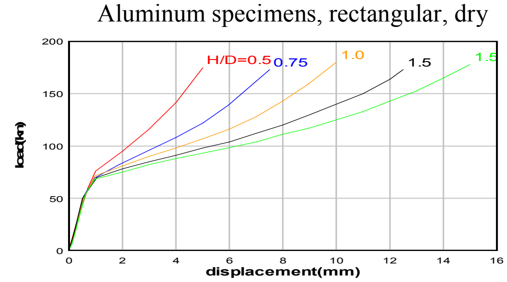

Fig (13): Collective load / displacement curves , Aluminum
specimens, cylindrical, lubricated

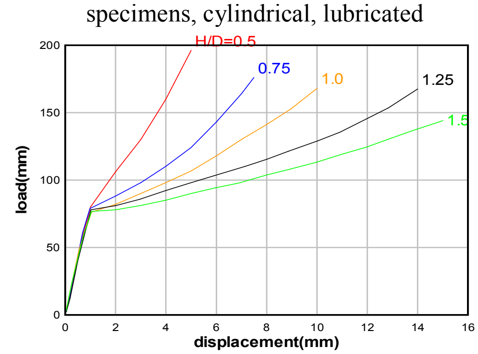

Fig (14): Collective load / displacement curves for
Aluminum specimens, hexagonal, lubricated

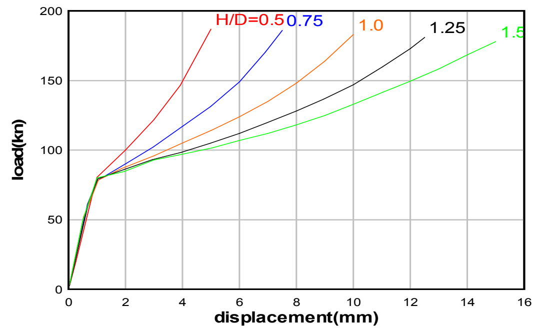

Fig (15): Collective load / displacement curves for Aluminum specimens, square, lubricated

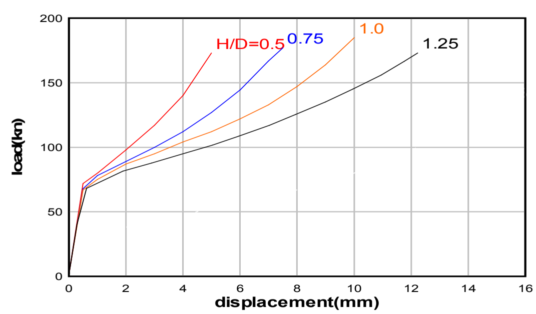

Fig (16): Collective load / displacement curves for Aluminum specimens, rectangular, lubricated

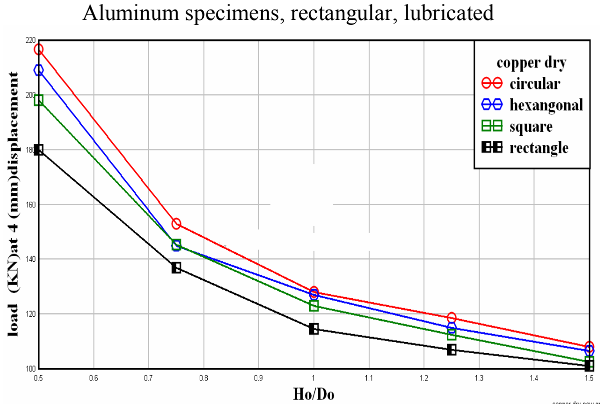

Fig 17: Effect of Ho/Do on the load at fixed displacement level of 4 mm, Copper, dry

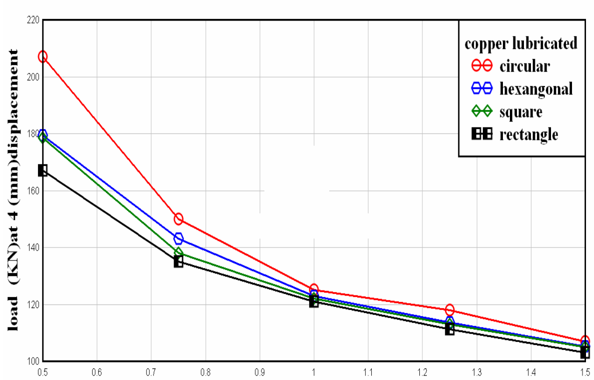

Fig. 18 : Effect of Ho/Do on the load at fixed displacement level of 4 mm, Copper, lubricated

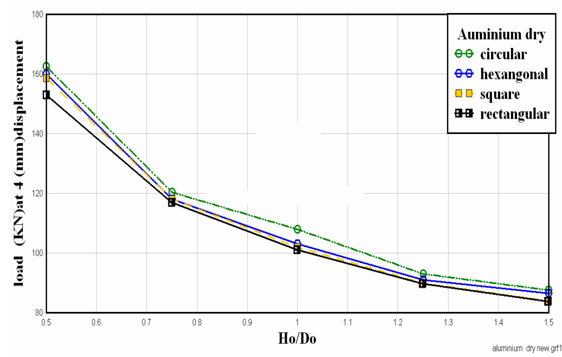

Fig 20: Effect of Ho/Do on the load at fixed displacement level of 4 mm, Aluminum, dry

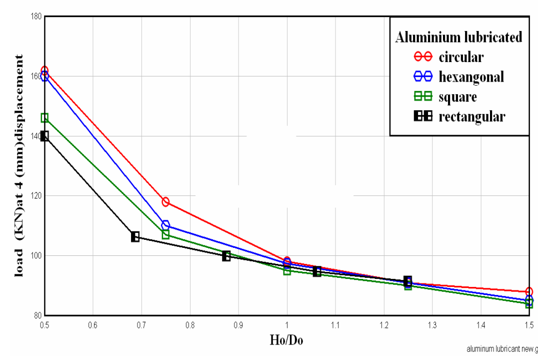

Fig 19: Effect of Ho/Do on the load at fixed displacement level of 4 mm, Aluminum, lubricated

5. REFERENCES

[1] G. E. Dieter, Mechanical Metallurgy, ASM, Materials Park, OH, (1986).

[2] Sadhu Singh, theory of plasticity and metal forming process, Khanna Publishers, 3rd editionm, Delhi, India (2003).

[3] K. Manisekar and R. Narayanasamy, "Effect of friction on barrelling in square and rectangular billets of Aluminum during cold upset forging" Materials and Design, vol. 28, issue 2, 2007, pp 592-598.

[4] M. Abdel-Rahman, Free and Constrained Upsetting of Cylindrical Billets", A M. Sc. Thesis, Minia University, Minia, EGYPT, 1983.

[5] K. Manisekar and R. Narayanasamy, "Effect of friction on barrelling in square and rectangular billets of Aluminum during cold upset forging" Materials and Design, vol. 28, issue 2, 2007, pp 592-598

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NEW PRODUCT DEVELEOPMENT BASED ON MULTICRITERIAL DEMANDS

Abstract: *A modern automobile is a complex product which integrates a wide variety of components. These components are based on contemporary knowledge in conformity with legal, normative and ecological regulations. Accordingly, a process of automobile development, as the most desirable product, has resulted in a high technical level of a modern automobile. Therefore, any further development within the meaning of technological and technical performance improvement is possible only through comprehensive research based on the methodology of product development, which results in larger demands for considerable investment in development and research. Inadequate solutions are excluded from the process in the early phase of development which cuts costs of a product development process.*
Key words: *product development, automotive, fuel supply pipe*

1. INTRODUCTION

Since it came into being until today, one of the most wanted and desirable product is a car. This request is acquit by an urgent need for a modern vehicle that will be comfortable and safe. From the same reason, a car was constantly adjusted to customers' desires, law regulations in terms of safety and technological achievements. This kind of an automobile development resulted in that a modern car has a so high technical level where at further progress in a sense of updating technological and technical performances is exclusively possible with the universal investigations based on the methodology of a product development and it has bigger demands for the increase of investments in the domain of development for research as consequences. The situation is specifically expressed for the car components that are in the inter action relation with the fuel supply system.

In the last decade, new types of Otto-engines with internal combustion (FSI and TSI) are invented, and it comes to the change in the way of injecting and combustion of fuel. This way of combustion requires more precise working conditions in terms of higher operating temperatures and pressures in the fuel supply system and the system for combustion of fuel mixture. On the other hand, finding solutions for higher demands of energy-generating products resulted in the frequent use of renewable or alternative power supplies. Current trend is adding different alternative fuels in terms of alcohol (Methanol, Ethanol, Propane gas) into petrol fuels and bio diesel into diesel fuels. All this defined additional requirements in the construction of the existing fuel supply system.

2. FUEL SUPPLY SYSTEM

Fuel supply system, Figure 1, in automotive construction, is one of the most sensitive systems, if it is viewed from the side of the passengers' safety and the protection of natural environment.

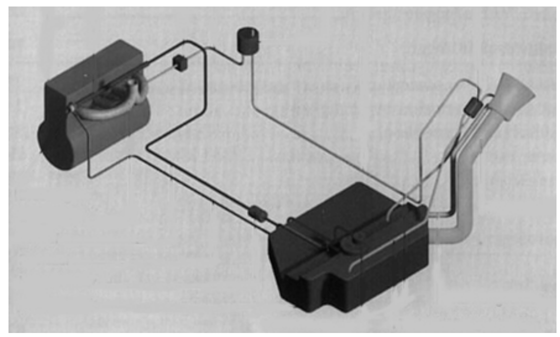

Fig. 1. The fuel supply system

The most sensitive part of the fuel supply system is a fuel supply pipe, Figure 1, that is composed of a metal pipe and a flexible pipe, herein after the fuel supply pipe, and whose function is to absorb vibrations while the engine is still working.

2.1 Fuel supply pipe

As is mentioned earlier, the fuel supply pipe is a connection between a metal pipe and a car engine, where at it has a function to transport fuel to the car engine and it possesses resistance on dynamic, hydrostatic and temperature-based loads that are occurred during a normal functioning. As an additional request, to which fuel supply pipes require to react, are securing aspects of special loads that are caused by car collisions or by fire. In Figure 2, it is presented the pipe that was applied in the car series until 2002, but they do not fulfill the requirements.

Until 2002, the concept of the pipe that was used for a fuel supply was conceived by three different layers of rubber and which has three functions:

- Internal layer (NBR rubber)-the protection of fuel evaporation so-called permeation.
- Bearing layer (CO rubber)-responsible for the rigidity of pipes.
- Covering layer (CR rubber)-the heat protection, the protection of open fire and mechanical deformations.

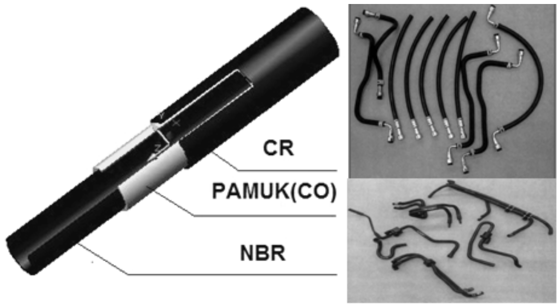

Fig. 2. The structure of fuel supply pipe

The process of the production of the fuel supply pipe is performed by the vulcanization.

3. NEWLY DEFINED DEMANDS OVER FUEL SUPPLY PIPE

It was necessary to adjust the automobile components to define acts considering the fact that in 2000 it defined some legal acts which has a direct impact on the automotive characteristics and its components. One of the most important acts is the direction of European Parliament 2000/EG/53 in 2000 whose regulations came into effect in June 2005. The basic condition of the regulation is to remove lead and lead mixtures from the car components, which directly meant that till then fuel supply pipes, could not any more satisfy new demands.

As it was confronted with a new enormous search for energy-generating products in the last couple of years, it significantly rose a usage of the mixture of conventional fuels with renewable fuels (in effect was shown that these mixtures were much aggressive) so this too represents one of the criterion that a new product should fulfill conditions.

Unless these conditions, producers themselves obtrude new conditions ahead their products to make them more attractive and these conditions are usually referred to the safety aspects of the product.

In Table 1, according [2], there were displayed newly resulted demands concerning the fuel supply pipe. Amongst the technical requests, there is one economic demand which command the product development team to determine about two the most economic solutions which will be questioned in detail while still at an early stage. In this way, it is tried to reduce the costs in the product development. According to [2], the plan for the fuel supply pipe development is divided in three units:

I. defining the problem, collecting the data associated with the possible technological solutions of the problem, the selection of two the best constructive solutions, creating conceptual solutions for new product,
II. experimental investigations of possible solutions, the analysis of the achievements and accommodation towards the proposed criterion, the selection of the best constructing solution,,
III. examination of functional abilities in real conditions.

Seq. no.	Object of criterion	Defined values
1.	Material	Persistence on the most aggressive petrol and diesel fuel
2.	Economy	Questioning of only two the most economic solutions, while previously satisfied ecological conditions
3.	Material	Operating temperature: Min. low -40°C Min. high 130°C Max. high 150°C
4.	Material	Removing lead and lead mixtures
5.	Product	Unique product that will satisfy all conditions of the whole palette of used engines (the diesel engine as well as Otto-engine) with internal combustion
6.	Minimal radius of bending a pipe	>50 mm for a pipe Ø7,3×3,0 mm
7.	Minimal right way to the first curve of the pipe	min. 50 mm
8.	Possibility of a pipe calibration	min. 20 mm
9.	Length of the finished product	min. 500 mm
10.	Product	Working pressure prad=8 (bar)
11.	Material	Fulfilling all unconditional tests
12.	Permeation	for 40ºC 2 g/100 cm^2 for 24 h for 60ºC 5 g/100 cm^2 for 24 h for 80ºC 8 g/100 cm^2 for 24 h
13.	Permeation	for 40 ºC 0,5 g/24 h hours by test
14.	Permeation	for 23 ºC 0,049 g/24 h hours by test
15.	Material	Persistence on dynamic loads under working conditions and 3000 working hours
16.	Material	tensile strength ≥ 8 MPa after 35 days of storage on the temperature of working environment fracture strain ≥ 300% of storage on the temperature of working environment
17.	Material	Persistence on open fire: DIN 73379 t≥120 sec; AA3343 t≥60 sec; XAY J 2027 t≥90 sec;
18.	Material	Persistence of the chosen solution at real conditions and 100.000 driven kilometers

Table 1. Newly defined criteria for a fuel supply pipe

4. PRODUCT DVELOPMENT BASED ON MULTICRITERIAL CONDITIONS

Based on the previously displayed concept that has been applied for the product development, in the first phase are collected information about available solutions that could eventually satisfy fitted conditions in Table 1, and there were chosen two conceptual solutions of construction material that will be questioned in detail, and these are:

- construction material A (FPM/ECO/AR/ECO),
- construction material B (THV/ ECO /AR/ ECO).

Two chosen potential solutions have four layers unlike previous, where at they have the same bearing-protective layer and they also comply conditions from 1 to 9 from Table 1.

In the second phase, it is accomplished the testing on:

1. Testing on the tightness of the testing object (criterion 10),
2. Testing of the permeation of the testing object (criteria 12, 13, 14),
3. Testing of the persistence of the testing object on dynamic loads (criterion 15),
4. Testing the mechanical characteristics of the testing object upon long lasting abode on high temperatures (criterion 16),
5. Testing the persistence of the testing object on open fire (criterion 17).

During the tests, there are used these fuel mixtures:

- FAM B – petrol mixture
- RME – diesel mixture

It is ought to refer that both constructing materials fulfilled enforced research whereat hereinafter are shown detailed results of the tests 2 and 4.

4.1 Permeation testing

The permeation testing was done according to directions of the standard DIN 73379, upon 35 measurements for every test point. Elaborated statistical data of obtained results are shown in Figure 3.

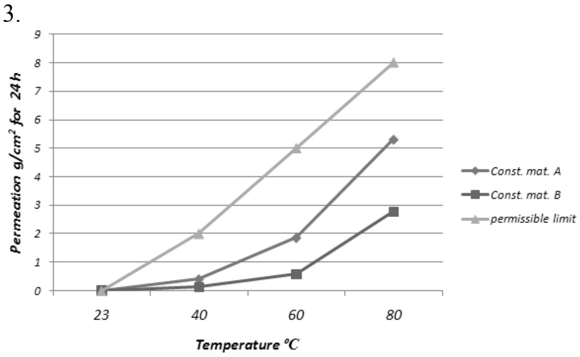

Fig. 3. Permeation intensity of constructing materials

From these data, it can be concluded that both constructing materials satisfy minimal values of permeation on the different check temperatures, but they also have appreciable safety rate, Table 2, with regard to the limiting value.

Materia	Temperature			
	23 ºC	40 ºC	60 ºC	80 ºC
A	1	4,88	2,69	1,51
B	1	15,38	8,62	2,89

Table 2. Safety rate of permeation for constructing materials A and B

4.2 Testing mechanical characteristics of testing objects upon long lasting exposure on high temperatures

Considering the activity conditions of discussed fuel supply pipes, especially a combination of the factor on high temperatures and high strains that they were exposed, the testing of mechanical characteristics of bearing layer was also practiced under mentioned working conditions. The testing of mechanical characteristics was accomplished according to DIN 53504 standard and storaging test tubes under testing temperatures (130°C and 150°C) within the proposed time of 35 days. With the mentioned research, it was attempted to fortify functional dependence of short lasting and long lasting persistence of the tensile strenght of the bearing layer of the examined fuel supply pipe in function of adopted temperature area. In Figures 4 and 5 are displayed the results of enforced research.

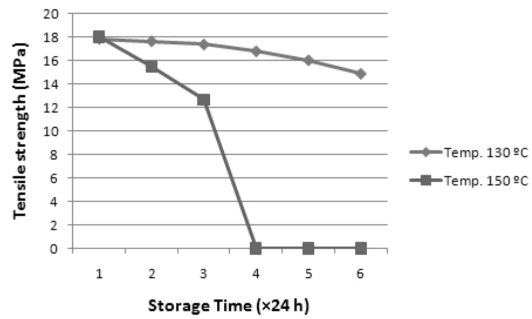

Fig. 4. Functional dependence of the tensile strength and storage time under adopted temperatures

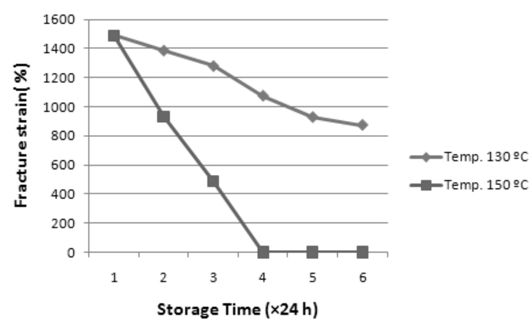

Fig. 5. Functional dependence of the fracture strain and storage time under adopted temperature

According to obtained results, it can be concluded that a bearing layer is for a short time persistent on the bracing under the temperature of 150°C, while it is a long time persistent on the temperature of 130°C and it does not exceed limiting values proposed by criterion 16.

4.3 Choice of final solution

Based on obtained results, a scoring of obtained characteristics of constructing materials according to the following criteria:

- 1 point - if parameters are under 33,33% of

maximum available value of the best constructing material,
- 2 points - if parameters are between 33,33…66,67% of maximum available value of the best constructing material,
- 3 points - if parameters are between 66,67…100% of maximum available value of the best constructing material.

In Table 3, it is displayed the grade of the characteristics of constructing materials A and B.

Seq.No.	Criterion	Constructing material	
		A	B
1.	3	3	3
2.	6	3	2
3.	7	3	2
4.	8	3	2
5.	9	3	1
6.	10	3	3
7.	12	1	3
8.	15	3	3
9.	16	3	3
10.	17	3	3
TOTAL		28	25

Table 3. Grade of the characteristics of constructing materials

Based on Table 3, it can be concluded that a constructing material A has constructing assets above a constructing material B.

In the last phase of a constructing material A are created real prototypes that will be subdued to the last testing under normal conditions on the testing object. This examination is based on the testing of the object of research when it has more than 100,000 kilometers in a different climate and field conditions, as well as different fuel mixtures and driving modes. With the obtained research, it is included the whole I period of a car life-cycle, as well as the tested product, and besides the beginning of the period II apropos the period of the normal exploitation of the product, Figure 6. For the research, it is used 5 equal testing objects.

During the research, on the testing object were not noted any changes, defects or weaknesses. So, the final report toward the ordering party was positive with relation that all criteria were satisfied so this construction can be put into the serial production and serial embedding serial installation of the targeted car series.

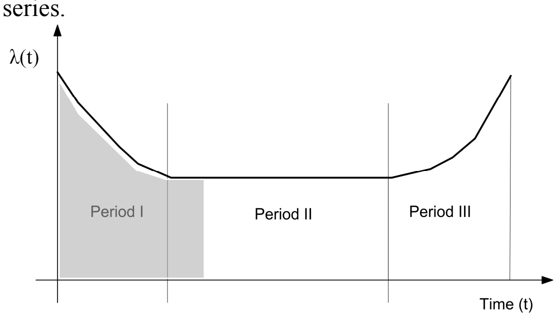

Fig. 6. Period of prototype testing of new product

5. CONCLUSION

The new product development constitute a complex and long lasting process in all industrial areas, especially in the car industry where demands are highly expressed, to the safety longevity, quality, etc. The presented example represents methodological approach in the development of the new product the fuel supply pipe based on multi criteria requirements.

Developed fuel supply pipes of the type FPM/ECO/AR/ECO not only fulfill the set requirements but also have significant capacity reserves whereby it is additionally assured the safety of passengers and living environment.

6. REFERENCES

[1] M. Ognjanović: *Razvoj i dizajn mašina*, Univerzitet u Beogradu, Mašinski fakultet, Beograd, 2007.

[2] Š. Ćelović.: *Razvoj novog proizvoda na osnovu višekriterijalnih zahtjeva*, Magistarski rad, Univerzitet u Tuzli, Mašinski fakultet, Tuzla, 2009.

[3] Dž. Tufekčić, M. Jurković: *Fleksibilni proizvodni sistemi* , Mašinski fakultet u Tuzli, Tuzla, 1999.

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PROPERTIES OF SPRAY FORMED TOOL STEELS

Abstract: *The spray forming for microstructural refining can be very beneficial for the production of tool steels. Spray forming process shortens the production time. Properties of spray forming steels are between conventional and powder metallurgy steels. The spray formed high speed steel has a finer and more uniform microstructure than the conventionally cast steel. Spray formed tool steel shows smaller abrasion wear, better impact energy and static banding stress.*

Key words*: spray forming, tool steels, carbides*

1. INTRODUCTION

All industrial branches are faced with the necessity to reduce the cost of their production. One suitable method is to extend the performance of the tools. The chances to develop new tool steels by simply adjusting their chemical composition to the increased demands are restricted. The application of the innovative spray forming technology promises a high potential in the development of new tool steels as well as in the improvement of existing tool steels. During the past decades spray forming has been developed to a technology, which today is suitable to produce high alloyed tool steels on an industrial scale.

The most frequently used method to produce tool steels is conventional ingot casting or alternatively continuous casting of the melt followed by forging or rolling processes. Tool steels produced in that way cover a wide range of applications. If higher demands on properties such as ductility, homogeneity or cleanliness have to be fulfilled usually remelted tool steels are applied. The used metallurgical technologies are the electro-slag remelting (ESR) or the vacuum-arc-remelting (VAR) process. In all these technologies the range of producible steel compositions is limited. Segregations, which are unavoidable during the solidification, limit the steels hot formability and thus the industrial applicability of such steel. The development of powder metallurgy (PM) allowed to intensively widen up the limits of steel compositions. Due to the rapid solidification of the powder particles the development of segregations is suppressed to a high extend. Therefore the development of PM tool steels concentrated on high alloyed steel compositions with very high carbide contents.

Similar to the PM technology spray forming is based on the atomization of a melt, which allows using the benefits of a rapid solidification. The main difference to PM is that spray forming directly produces a solid billet whereas in PM the powders have to pass a complex and expensive process of classification, mixing, and compaction in order to achieve a solid block of steel. As a new technique spray forming is able to provide materials with well-balanced compositions allowing to meet customers demands with a spectrum of properties between conventional and PM tool steels.

Such a spray formed material is free of macro-segregations and cavities. It has a refined structure and achieves density values above 99% of its theoretical density. Spray forming is a production technology especially suitable for many highly alloyed tool steels such as high-speed tool steel or extremely wear resistant cold-work tool steels. Similar to powder metallurgy spray forming offers the chance to widen up the range of producible alloy compositions but as the comparison or different production routes in Fig. 1 shows, with definitely less steps in the process [1].

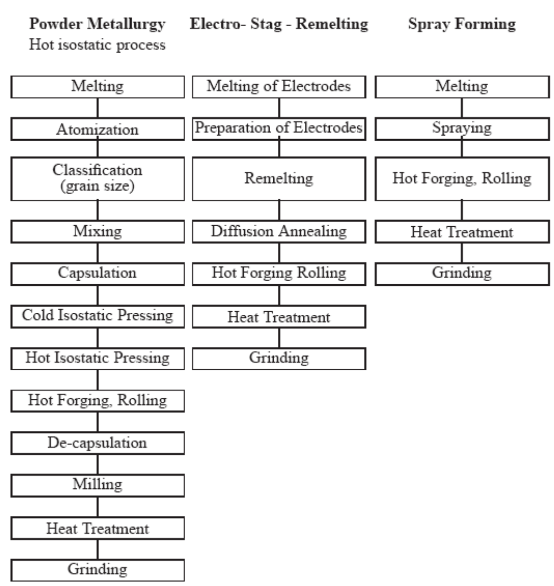


Fig. 1. Comparison of different processing routes.

2. SPRAY FORMING

Melting occurs in the induction furnace under an inert gas atmosphere (nitrogen) using classified scrap, pre-alloys and further additions. After the chemical composition and casting temperature have exactly been balanced the melt is poured into the casting furnace. Via the furnace's bottom- tapping the melt is transferred into the atomizing unit with oscillating atomizing nozzles ("Twin Atomizer"). Here the gas stream atomizes the melt into droplets of approx. 5–500 µm. Nitrogen is used as atomising gas in the spray chamber.

The stream of droplets is accelerated from the two oscillating nozzles to a rotating target. The adjustable oscillation of the nozzles and the rotation of the target allow a uniform compaction of the atomized particles and thus homogeneous growth of a round billet. The presently most discussed model of deposition and solidification of the atomized melt droplets is described in Fig. 2. The globular droplets with diameters varying between 50 and 500 µm solidify at different rates.As small particles might solidify completely during the flight medium sized particles might be partly solidified and larger still completely liquid. A properly adjusted downward movement of the growing billet allows for a permanently constant distance between the atomizing unit and the billet during spray forming. The billet dimension is a maximum of 500 mm in diameter and 2,5 meter in length, with a weight of approximately 4 tons.

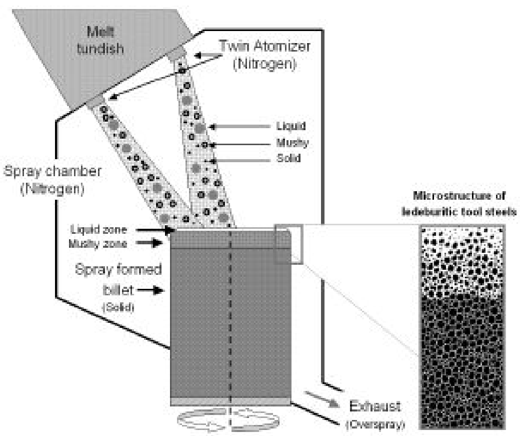


Fig. 2. Solidification process during spray forming [21]

The productivity of the spray forming technology is very high. A four tone spray formed billet can be produced in significantly less time than with the PM or ESR routes, see Fig. 3 [1].

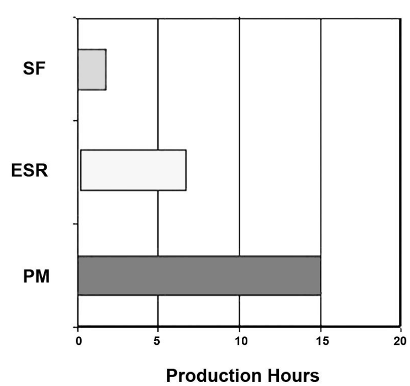
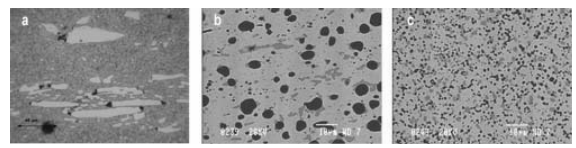


Fig. 3. Productivity compared between the different technologies.

3. MICROSTRUCTURE

The high cooling rates in combination with an extremely fast solidification of the atomized molten particles lead to the formation of a fine-grained microstructure with a homogeneous distribution of the alloying elements.

As an example the microstructure is compared between a high alloyed 8%Cr-1.5%Mo-10%V steel produced via PM and spray formed, Fig.4 , clearly illustrate the difference in the microstructure when traditionally cast steel, spray-formed steel and PM materials. The carbides in the traditionally cast steel are clustered in large strings and the sizes can be up to 100 µm in length. This can be a main reason for brittleness and this steel is often hardened to lower hardness in order not to lose too much ductility.



(a) (b) (c)

Fig. 4. High alloyed Cr-Mo-10%V steel traditionally cast steel (a), spray-formed steel (b) and powder metallurgy (PM) steel (c) [1].

Figure 5 shows the typical solidified structure of the ledeburitic coldwork tool steel X155CrVMo12-1 (Mat.-No. 1.2379, AISI D2). It reveals a fine and homogeneous globulitic structure with an extremely fine ledeburitic carbide network with a mesh size of approx. 5 – 40 µm.

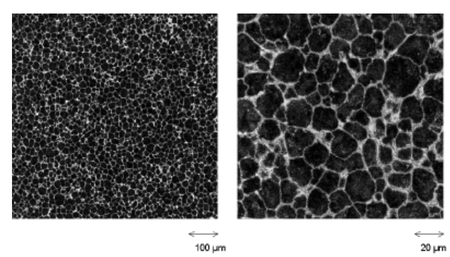
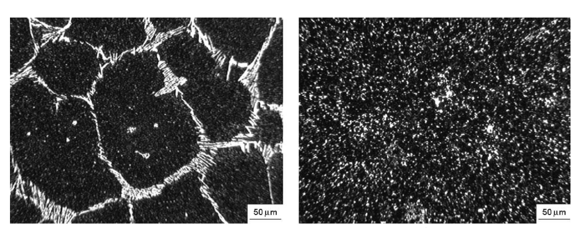


Fig. 5. Microstructure of a ledeburitic cold-work tool steel in the as sprayed condition [2]

The as-cast microstructures of conventionally cast and SF M3:2 steel are compared in Fig. 6. The SF steel microstructure is considerably finer than that of conventionally cast steel due to increased capacity of heat extraction during SF solidification.



(a) (b)

Fig. 6. As-cast microstructure of (a) conventional and (b) spray formed high speed steels [3].

All microstructures are light microscopy etched with nital 4%.

4. WEAR RESISTANCE

The wear resistance of a tool steel is closely related to the carbide type, carbide amount, size, and distribution of the carbides embedded in the steels matrix. An increasing amount of carbides improves the wear resistance of a steel, an increasing size of the carbides reduces it. The influence of the carbide size also explains the different behavior of conventional and PM tool steels. The very fine distribution of fine carbides lowers the wear resistance of the PM tool steels

The carbides which appear in high alloyed tool steels are M_6C and MC carbide, and the morphology differs for conventional and sprey formed high speed steel.

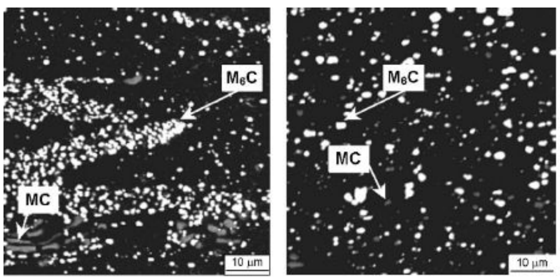


Fig. 7. Scanning electron microscopy images of carbides in (a) conventional and (b) spray formed M3:2 high speed steel. Back scattered images of samples [3]

High alloyed 8%Cr-1.5%Mo-10%V steel produced conventionally, via PM and spray formed results in a fine and homogeneous distribution of small, hard and wear resistant vanadium rich carbides (MC with hardness 2800HV). Abrasion wear was done with pin-on-disc test with SiO_2 paper. Results are shown in Fig. 8, where a comparison of various steels manufactured via different processes is visualized. The larger MC carbide in the spray formed version results in very good abrasive wear resistance [1].

Very uniform distribution of fine carbides offers almost no resistance against abrasive wear. Larger carbides in a networks tructure do not improve the wear resistance as the network does not protect the matrix against wear. Best wear resistance can be achieved if the carbides have reached a certain size and are evenly distributed in the steel.

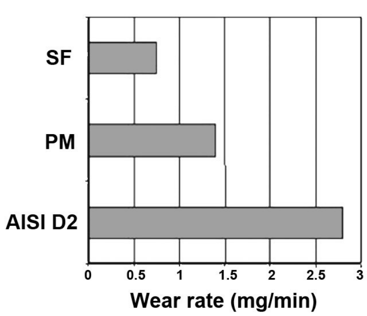


Fig 8. Weight rate for some cold work tool steels[1].

5. MECHANICAL PROPERTIES

Impact energy with unnotched specimens for some cold work tool steels, was shown in Fig. 9. The steels are manufactured by different metallurgical processes and heat treated to 60–61 HRC. Results of the PM and spray forming method, a much higher safety against chipping/cracking of the tool part is achieved compared to conventional manufactured high alloyed steels

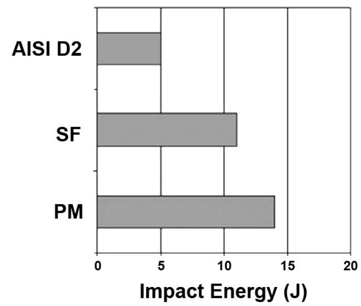


Fig. 9. Impact energy for some cold work tool steels[1]

Carbides and precipitates are small and evenly distributed within spray formed alloys, but an increased nitrogen concentration in the standard alloys must be considered during heat treatment and negatively affects the toughness [4].

The differences in carbide size and distribution are most evident and most likely to influence the mechanical properties of the steels. Bend strength was testing on specimens with section of 5 mm x 7 mm, from mid-from of longitudinal and transverse direction of 116mm squared bar, heat treated to hardness between 63.8 and 64.3 HRC.

The results shown in Fig.10 are directly related to microstructure and carbide distribution. In conventional M3:2,the reduced isotropy is related to the coarse carbide network. In longitudinal stressing, cracks propagate throughout the material crossing the carbide cells. Carbide size may have a larger influence on longitudinal toughness rather than carbide distribution. The similar carbide size in SF and conventional M3:2 may thus explain the similar longitudinal values.

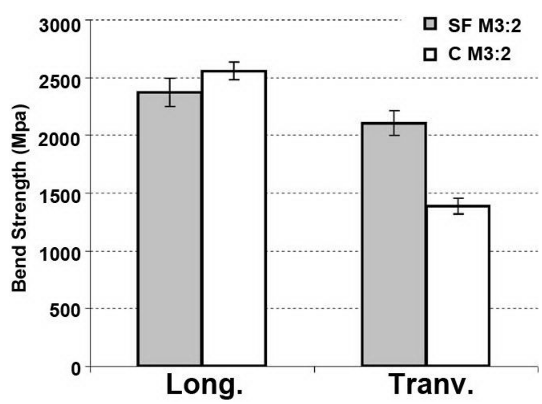


Fig. 10. Bend strength results, longitudinal and transverse direction Error bars represent standard deviation of results[3].

For transverse stressing, however, fracture occurs when cracks propagate parallel to carbide cells or stringers. In this situation, the coarse carbide networks of conventional material are preferential locations for crack propagation, thus decreasing toughness. In SF M3:2, carbide arranges are uniformly distributed and therefore longitudinal and transverse direction bend strength is similar. The SF M3:2 microstructure offers important benefits over conventional steels, considering real tooling conditions.

During complex states of stresses, better isotropy of SF high speed steel may lead to improvements in tool performance.

Coarse carbide distributions also have consequences during heat treatment. Such regions have different thermal expansion and, as a consequence, may cause distortion. The uniformly distributed carbide micro structures of SF high speed steel may also reduces heat treating distortions.

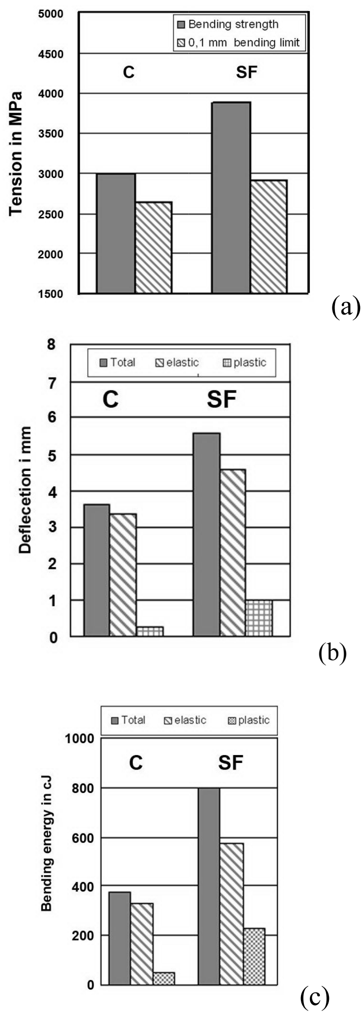


Fig 11. Ductility of cold-work tool steel 1.2379, measured in static bending tests – spray formed vs. conventional production (hardness: 58 HRC) [2].

The fine and homogeneous microstructure of a spray formed cold-work tool steel is of advantage for many properties. Fig. 11 clearly points out that the spray formed cold-work tool steel reveals a better ductility even if it was less deformed. This improvement is related to both the elastic as well as plastic deformation of the steel.

6. CONCLUSION

Spray forming has been developed to a new and interesting technology for the production of high grade and high alloyed tool steels, with highest productivity

Fast solidification of the atomized molten particles lead to the formation of a fine-grained microstructure with a homogeneous distribution of the alloying elements.

Related to carbide distribution, the spray formed high speed steel has a finer and more uniform micro structure than the conventionally cast steel. In small diameter bars, SF material has no carbide stringers.

High speed steel produced through spray forming has higher transverse direction properties, that lead to higher isotropy in mechanical properties.

During complex states of stresses, better isotropy of SF high speed steel may lead to improvements in tool performance.

Spray formed tool steel reveals a better abrasive wear, impact energy, and static banding stress

Compared to conventionally cast materials the improved mechanical, technological and processing properties of spray formed materials open chances to many new alloying and application concepts.

7. REFERENCES

[1] Spiegelhauer, C.: Industrial production of tool steels using the spray forming technology, 6th Int.Tooling Conference, pp 1101-1109, Karlstad, Sweden,2002

[2] Schruff I., Schüler V., Spiegelhauer C.: Advanced tool steels produced via spray forming , 6th Int.Tooling Conference, pp 1159-1174, Karlstad, Sweden, 2002.

[3] Mesquita R.A, Barbosa C.A. : Spray forming high speed steel—properties and processing, Materials Science and Engineering A 383 (2004) 87–95

[4] Schulz A.: Nitrogen pick-up during spray forming of high-alloyed steels and its influence on microstructure and properties of the final products, Materials Science and Engineering A 383 (2004) 58–68

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INFLUENCE OF THE TECHNOLOGICAL HERITAGE ON LIFE CYCLE OF MACHINE ELEMENTS

Abstract: *In the last few years, more interest has been shown in researching the technological heritage and its connection to exploitation properties of elements. The basic parameters of machine elements, inherited during a technological process, can be classified into two groups: those related to material, and those related to micro- and macro-geometry indicators of machined surfaces. The first group includes parameters characterizing chemical composition, structure and stress condition of the material of individual pars and units, structure of surface layers, surface energy etc. Parameters from the second group characterize micro- and macro-geometry of machined surfaces (roughness, corrugation, oval-shaped surfaces, and so on). This paper shows the influence of technological heritage on the life cycle of a hunting carbine parts during the manufacturing process.*
Key words: *technological heritage, hutch, fractures.*

1. INTRODUCTION

High demands of modern mechanical engineering, in terms of quality and reliability of machine elements, have substantially changed the approach to their designing, manufacturing technology, and maintenance. In the last few years, more and more interest has been shown in researching the technological heritage and its connection to exploitation properties of elements. Technological heritage refers to physical-mechanical characteristics of machined surfaces of elements, resulted from preliminary and final technological operations. The basic parameters of machine elements, inherited during a technological process, can be classified into two groups: those related to material, and those related to micro- and macro-geometry indicators of machined surfaces. The first group includes parameters characterizing chemical composition, structure and stress condition of the material of individual pars and units, structure of surface layers, surface energy etc. Parameters from the second group characterize micro- and macro-geometry of machined surfaces (roughness, corrugation, oval-shaped surfaces, and so on). Unlike technological heritage, the exploitational heritage maintains the connection between parameters characterizing the process of losing the working ability of the products, their life cycle, and stress conditions. Depending on exploiting conditions of a product, the initial structure of machine elements' material will change, as well as their micro- and macro-geometry, the rigidity of joints and moving couplings, and kinematics and dynamics of individual units and mechanisms.

Hence, there is a full correlation between technological and exploitational heritage, and by researching this dependency it becomes possible not only to consider the relevant phenomena during the designing phase, but also to manage the process of losing the working ability of machine elements. Beside the barrel, hutch is the most important component of any hunting carbine, its quality being one of the key factors contributing to overall reliability of a weapon.

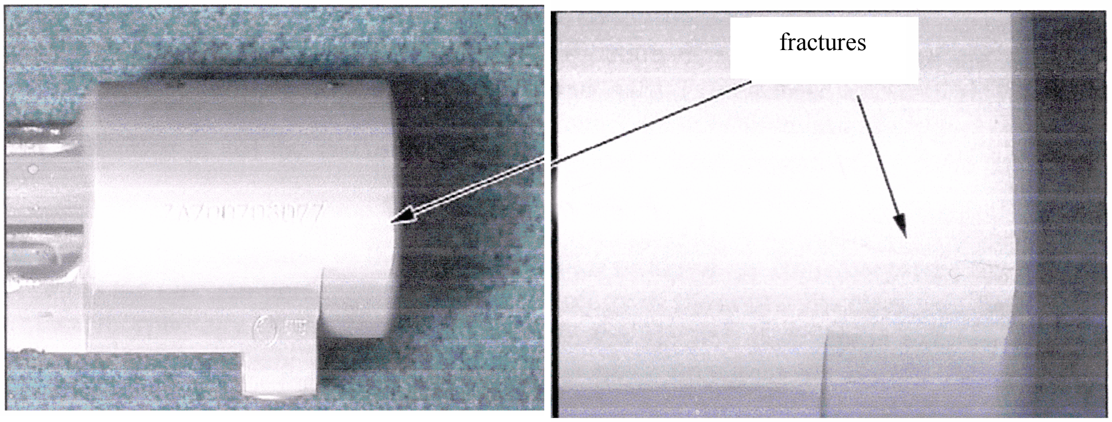
2. EXPERIMENTAL RESEARCH

The research has been conducted in the premises of Products Development department of "Zastava oružje AD" factory, in Kragujevac. The firing function, safety mechanism, and bolt function have been tested on the sample of 70 stainless steel carbines (divided into groups of 10 samples with different calibers).

Testing conditions:

- each carbine has been treated with 10 bullets
- standard ammunition, manufactured, by **"**Prvi partizan", Užice**.**

After the initial functional testing, two Cal 7mm Rem carbines have been identified as defected, with visible fractures on hutches. On carbine #1, a fracture was detected along the right side of the trigger, on the front part of the hutch. This fracture is shown on Figure 1. On carbine #2 there was a fracture on the top side of the hutch, between the openings for optical scope mounting. The fracture is shown on Figure 2.



a) sample #1 b) sample #2

Fig.1 Occurrence of fractures on hutch #1

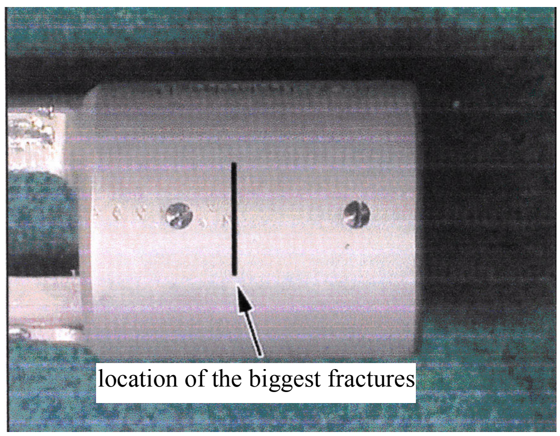


Fig.2 Occurrence of fractures on hutch #2

3. THE RESULTS ANALYSIS

According to the adopted technological procedure, the hutch is manufactured using X22CrNi17 (Č4570 steel). Forging operation is conducted according to the following technological procedure:

- preheating up to 760/816 °C,
- uniform heating up to 1027/1200 °C,
- forging,
- cooling the forged steel in dry ash or lime,
- annealing to 732/780 °C
- cooling the parts in the oven.

After mechanical processing, the pieces are subjected to thermal processing operation, which is conducted according to the following procedure:

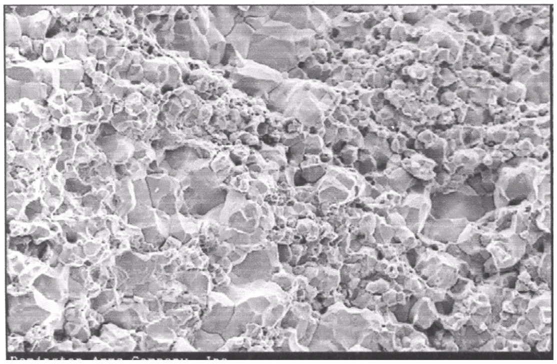
- preheating T = 760-790 °C,
- austenization T = 981-1061 °C,
- double loosening T= 230-370 °C, in neutral atmosphere,
- hardness 42-48 HRC

Table 1 - The results of measuring the hardness of the fractured hutches

Hardness of the hutches HRC							
Measuring No.	1	2	3	4	5	average	st.dev.
sample #1	46.7	47.3	46.9	45.3	46.6	46.6	1.6
sample #2	46.4	44.7	43.7	44.0	47.4	45.3	0.8

First, the hardness analysis of the fractured hutches has been made. Each hutch has been measured five times along the front side, to the left of the trigger. Table 1 shows the results of measuring the hardness of the two fractured hutches. Apparently, the hardness values fall within the prescribed limits (42-48 HRC), while the material composition analysis has shown that the hutches were indeed made of the prescribed material X22CrNi17 (Č4570 steel).

By investigating the rupture of the hutch #2 fracture, its morphology was found to be 100% intergranular (see Figure 3-a). The morphology was then compared to the morphology of a separate rupture, made in the same hutch through the ejection channel. It was established that the two morphologies were different. The morphology of the rupture made in the area of the ejection channel showed the small degree of intergranularity and was mostly consisted of various transgranular dilatable concavities and cleavages (see Figure 3-b).



a) sample #1

b) sample #2

Fig.3 SEM photo of the hutch

The structure and different shapes of defects in the material, developed during both the manufacturing process and the technological process of making the final product, have significant effect on the product quality. If improper structure is formed, the physical-mechanical properties of the product will be reduced, as well as its life cycle, regardless of high level of its final mechanical processing. The inherited structure results in forming of interior fractures, which broaden during the usage of the product and eventually lead to its complete breakage. The changes in the material, which occur during forging and thermal processing phases, are the main reason for hutch fractures.

4. FINAL REMARKS

The proper technological cycle was not strictly followed during the forging and thermal processing of the hutch. As a result, the unfavorable structure was formed inside the material, leading to its poor physical-mechanical properties and its short life cycle. Not even the high accuracy of the final mechanical processing cannot prevent the defects due to prior improper processing (forging and thermal processing).

5. REFERENCES

[1] Аверченков В. И. Технологическая наследственность в машиностроении. Минск: Наука и техника, 1997 – p 276 с. (в соавторстве),

[2] Мухин В. С. Технологические методы повышения эксплуатационных свойств изделий: Учеб. пособие. Уфа: УАИ, 1982. p 56,

[3] Records from internal researches, conducted in ZO,

[4] SNO specifications.

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Simonovic, S.

DESIGNING PRODUCTS AND EQUIPMENT WITH RESPECT TO REDUCTION OF SETUP TIMES

Abstract: *Reduction of setup times is in the very base of effective flexible production. Standardisation of dimensions, concurrent design of master part and appropriate production equipment that enables swift changeover within the family of parts are a way to this aim. Natural consequences are non stock production, effective applying of CAD/CAM, CIM and expert systems.*
Key words: *flexibility, swift changeover, standardisation, master part*

1. INTRODUCTION - PROBLEMS WITH DURABLE SETUP TIMES ARE DEEPLY ROOTED IN THE DESIGN OF PRODUCT AND ACCESORIES

There is a deep rooted opinion that, as mass production goes, making a changes is main enemy of production. Reason is considerable duration of setup times and consequently lowering of productivity. But can setup times be reduced? If you ask shop flor people the answer would be mainly negativ. And reasons are: Inappropriate shape and dimensions of parts, excesive number of different parts, inappropriate machines, tools and appliances, inappropriate shop layout.
If enumerated reasons are analysed it can be concluded that what prevent flexible production is in domain of planning, mainly: planning of product, planning of processes, planning of plant layout, planning of appliances… And when mentioned planning is done, for flexible production is too late.

So, the planners are right persons to answer posed question, and above all these are the product designers because the product design is first step in the realisation of product and cornerstone that influence all subsequent steps. [2,7,8,10]

2. COST BEHAVIOUR WITH CHANGES IN PRODUCTION VOLUME AND NUMBER OF DIMENSIONS (VARIETIES) OF PRODUCT UNDER SUPPOSITION OF TIME CONSUMING CHANGEOVER

Figure 1 shows that variable cost diagram don`t change with decreased or increased number of dimendions (ND!, ND2). This is because those costs are in relation to cost of material, cost of energy, cost of tooling, cost of direct labour, etc.

On the other hand fixed costs are costs associated with the idleness of machines due to long setup times, cost of space necessary to hold inventories man hours necessary to setup machines, cost of making jigs, fixtures, tool holders etc. This type of cost is very sensitive to duration of setup times.

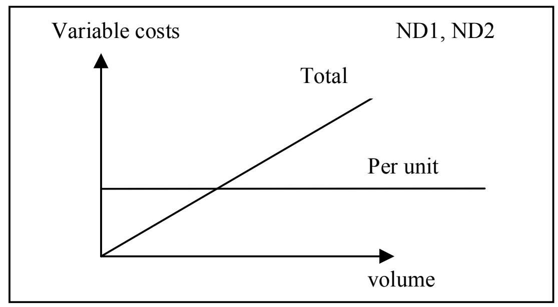

Fig. 1. Total and per unit variable cost don`t change with raising the number of dimensions

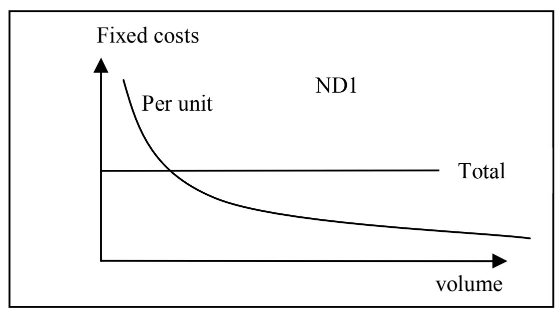

Fig. 2. Fixed total and per unit costs with lower number of dinensions (ND1)

For example product designers may be prone to optimize consumption of material and introduce a great number of dimensions in production process (greater variety of product). So, previous number of dimensions ND1 has changed to greater value ND2. That means more setups, more jigs, more fixtures, so previous fixed costs as shown at figure 2 has increased as shown at figure 3.

Figure 4 shows as total setup time rises as number of dimension introduced increase (ND2 > ND1), but that is only under assumption of long setup times which is a matter of prejudice that setup times must be long..

Taking supposition that each setup consumes considerable time it can be concluded that productivity will decrease and so making change in production is an evil. [7,8]

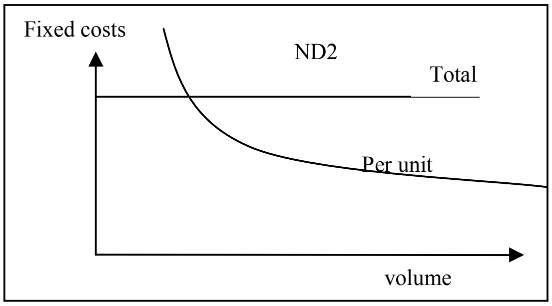

Fig. 3. Fixed total and per unit costs with higher number of dinensions (ND2)

Figure 5 is summary of figures 1 2 and 3. Variable cost per unit + fixed cost per unit 1 corresponds to ND1 and variable cost + fixed cost for unit 2 corresponds to ND2. Points M and N denote minimal economical volumes that correspond to ND1 and ND2 respectively.

We can see that with long setup times much longer production run (point N) is needed to ensure economical production.

So, under supposition of long setup times, products should be as simple as possible with minimal different dimensions if we want reliable return on capital. Setups should be as rare as is possible but that means huge in process inventories, huge production areas, huge transport machines long throughput times, consequently huge inventories of final products, huge operating supplies inventory and huge direct material inventory.

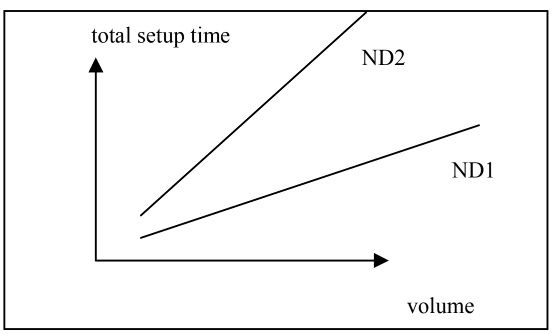

Fig. 4. Total setup time rizes with number of dimension (ND) ND2 > ND1

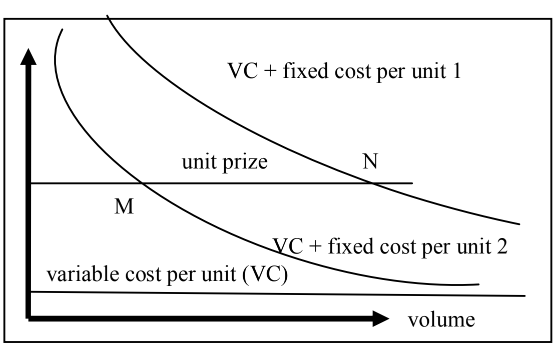

Fig. 5. Minimal economical volumes (points M, N) rize with rising of number of dimension (ND)

3. COST BEHAVIOUR WITH CHANGES IN PRODUCTION VOLUME AND NUMBER OF DIMENSIONS (VARIETIES) OF PRODUCT UNDER SUPPOSITION OF SWIFT CHANGEOVER

First, it must be considered to be possible that Machines setup times can be under ten minutes, even for most complex setups. Let us suppose it is the case.

Figure 6 shows insignificant influence of number of dimension introduced on total setup time, under supposition of low setup times.

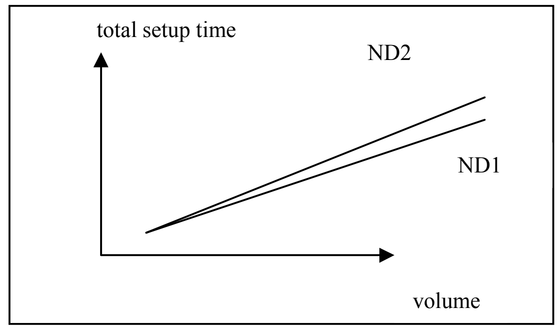

Fig. 6. Under low setup times total setup time rizes insifignicantlu with rising of number of dimension (ND) ND1 > ND2

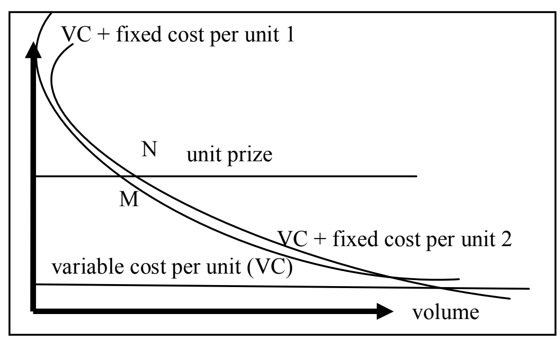

Fig. 7. Under low setup times minimal economical volumes (points M, N) are almost identifal with rising of number of dimension (ND)

It means, although therae are considerable variations of products in the proces, smachines are not idle due to fast swichovers. Figure 7 shows that, under supposition of low setup times, considerable varieties of parts can be introduced into same production line and in the same time production bachs can be small. [7,8]

4. PRINCIPLES OF DESIGN OF PARTS AND EQUIPMENT FOR LOW SETUP TIMES

A basis for the low setup time performance is appropriate and coordinated (concurrent) design of:

- part families
- jigs
- dies
- tools

- tools holders
- fixtures.
- stoppers

Jigs, dies, tools, tools holders, figtures, stoppers must be designed for particular part family and in reverse. These appliances must enable :

- its swift positioning and fixation onto machines
- simple, swift and natural positioning and fixation of family parts into an appliance
- elimination of machine settings

Above mentioned is to be achieved above all by standardisation of dimension of parts and appliances.by way of standardisation of the dimension of the most complex representative part of the family- master part. [2,3,4,6,7,9,10]

5. EXAMPLE

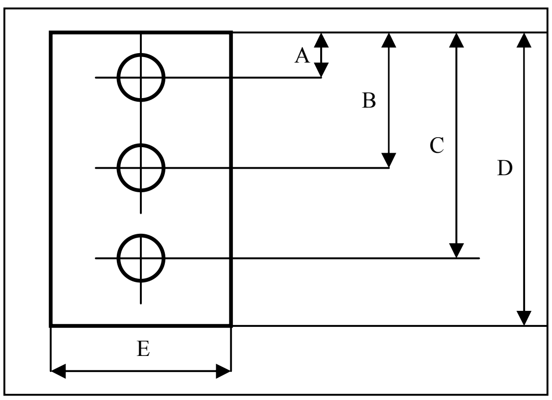

Fig. 8 Master part

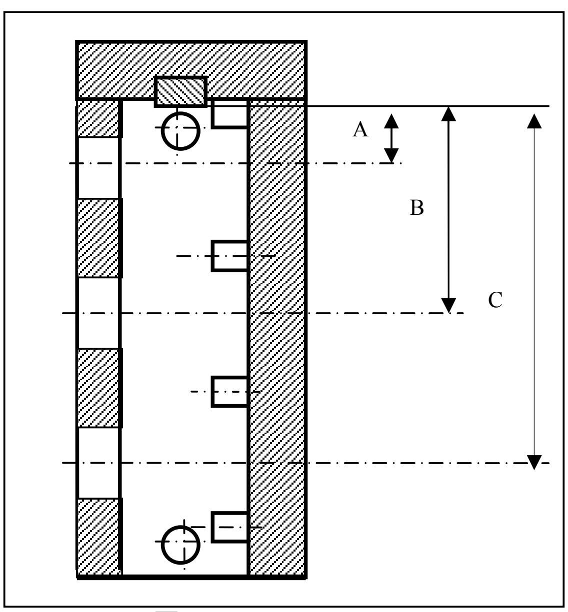

Fig. 9 Jig designed according to master part

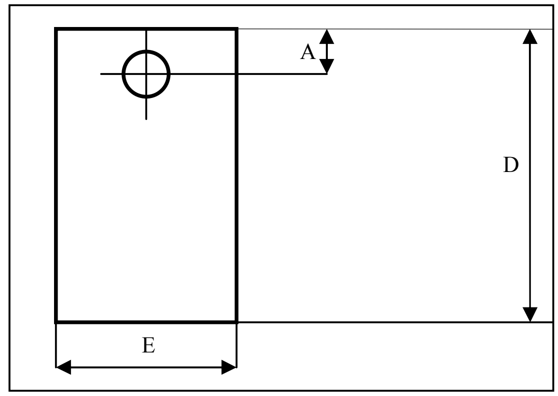

Fig. 10 The family part

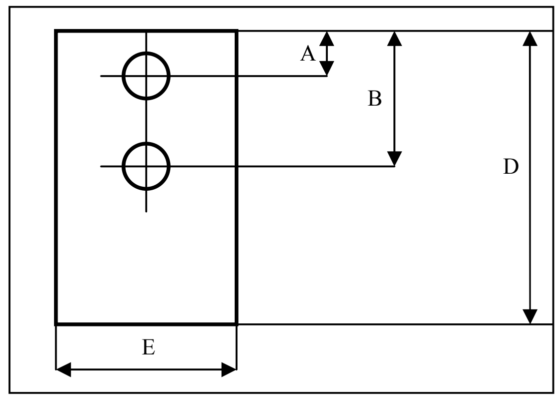

Fig. 11 The family part

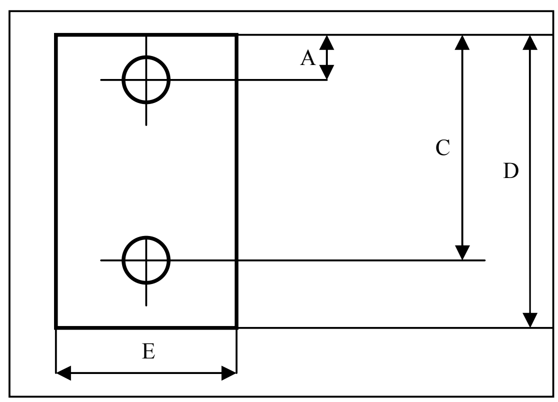

Fig. 12 The family part

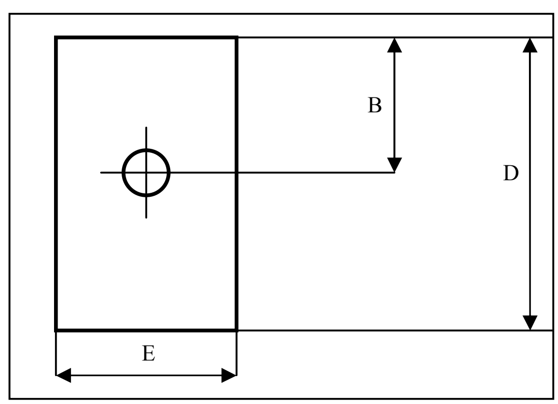

Fig. 13 The family part

The shapes of parts that have to be produced are shown at figures 8, 10, 11, 12, 13.

Diameters of holes and dimensions A,B,C,D,E are standardised.

Master part (figure 8) is designed according to standardised dimensions.

Jig shown at figure 9 is designed according to master part at figure 8 in order to produce family parts at figures 8, 10, 11, 12, 13.

6. IMPACT ON AUTOMATISATION

Low setup times enable one piece flow of parts through introduction of U lines. Because of its simplicity and transparency ,U- lines are easy for computerisation e. g. can be treated as 'islands of automatisation' . Because of its standardised nature more 'islands of automatisation' can easily and naturaly trasformed into CIM.

Because of highly structured and standardised nature of design of parts CAD/CAM sofrvare can be very effective and expert rules are easy to develop. [1,2,3,4,5,6,7,9,10]

7. CONCLUSION

Aims:

- single minute exchange of dies
- single minute exchange of fixtures
- single minute exchange of tools

Means:

- standardisation of dimensions
- design of master part
- standardisation of tools
- standardisation of jigs
- standardisation of fixtures
- multipurpose jigs
- multipurpose dies
- multipurpose tools holders

Results:

- non stock production
- one piece flow
- low throughput time
- U - production lines that are easy for computerisation and central computer control, leading to CIM
- easy for applying CAD/CAM software with predeterminated families of parts, jigs, fixtures, tools and exper rules

6. REFERENCES

[1] Helling, J.: *Världs mästarna*, Sellin & Partner Förlag AB, Stocholm, 1990.

[2] Robinson, A.: *Modern Approaches to Manufacturing Improvement: The Shingo System*, Productivity Press, Portland, Oregon, 1990.

[3] Mitrofanov, S. P.: *Scientific Principles of Group Technology* , Mashinostroyenie, Moscow, 1970.

[4] Boothroyd, G., Dewhurst,P., Knight, W.: *Product Design for Manufacturing*, Marcel Dekker, New York, 1994

[5] Harrington, J.: *Understanding the Manufacturing Process Key to Successful CAD/CAM Implementation*, Marcel Dekker, New York, 1984.

[6] Edwards, G. A. B.: *Readings in Group technology,* Machinery Publishing Company, London, 1971.

[7] Salvendy, G;: *Handbook of Industrial Engineering,* John Wiley & Sons, 1982

[8] Sveriges Rationaliseringsförbund: *Kapitalrationalisering,* Stockholm, 1992.

[9] Burbidge,J. L: *The Introduction of Gropup Tecnology,* John Wiley & Sons, New York, 1975

[10] Browne, J., Harhen, J., Shivnan, J.: *Production Management Systems - An Integrated Perspective*, Addison - Wesley Publishers Ltd, 1996

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10th INTERNATIONAL SCIENTIFIC CONFERENCE
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COST ANALYSIS BASED ON MODERN FORGING TECHNOLOGY PLANNING

Abstract: *Analysis of cost structure in manufacture of forges is performed in this paper to allow cost reduction and quality enhancement, as prerequisites for increased profits and productivity. Underpinning modern approaches to forging technology planning are the information technologies which allow design process automation and numerical simulation of processes. Of special interest here is the software for simulation of forging process, which allows reduction of costs of manufacture of trial tools, shortens the lead time, extends tool life, reduces material, labour and energy costs, while design process automation contributes to substantial reduction of time required for process planning and tool design.*
Key words: *forging technology, costs, numerical process simulation, design process automation.*

1. INTRODUCTION

Process planning for a forge, or any other part, in todays competetive market has to result in low market price and high quality.

Conventional product costing is based on calculating total costs (T_u), and adding up the planned profit margin. This approach is currently undergoing important revisions due to the fact that market price is more and more often limited by market in advance, especially when it comes to manufacture of mass produced car parts, kitchen appliances, consumer electronics, etc. In this case, the economic calculations boil down to profit margin as the main goal of every kind of production:

$$\text{Profit} = \text{Market price} - T_u \quad (1)$$

Achievement of highest possible profit margin, and competitive edge, calls for constant development aimed at higher quality and reduced total costs. In order to single out segments in which there exist real possibilities for improvement, one needs to revise the cost structuring process.

Total costs (T_u), which are included in the market price of a product, can be related to manufacturing (T_{pa}) and non-manufacturing activities (T_{na}):

$$T_u = T_{pa}+T_{na} \quad (2)$$

Non-manufacturing activities include management, marketing, administration and auxilliary tasks. Cost optimization in this area deals with the minimum number and optimal structure of workers in this sector. These costs are not considered in this paper because they are not technology-related.

Manufacturing activities include introduction of novel technology, manufacturing tasks and other tasks which are related to manufacturing. With this in mind, the structure of costs of manufacturing activities (T_{pa}) is:

$$T_{pa} = T_{ot} + T_p + T_{ost} \quad (3)$$

where:

T_{ot} – are the costs of introduction of novel technology,

T_p – are the costs of manufacturing,

T_{ost} – other costs.

The costs of introduction of novel technology for a forged part (T_{ot}) can be broken down in four components which comprise activities from early process planning stage to launch of production:

$$T_{ot} = T_{pt} + T_{ka} + T_{ia} + T_{up} \quad (4)$$

where:

T_{pt} – are the costs of process planning,

T_{ka} – are the costs of tool design,

T_{ia} – are the costs of tool manufacture,

T_{up} – are the costs of production launch.

The costs of manufacturing (T_p) consist of five items:

$$T_p = T_m + T_r + T_{oa} + T_e + T_{am} \quad (5)$$

where:

T_m – are the costs of material,

T_r – are labour costs,

T_{oa} – are tool maintenance costs,

T_e – are energy costs,

T_{am} – are machine amortization costs.

Presented costs structure is applicable to all manufacturing technologies, as well as the forging technology.

Possibilities for improvement of quality of forged parts and increase of profits lies in the application of modern approaches to process planning. For a large-batch production this should allow reduction of costs in all segments of manufacturing activities.

2. COST-RELATED ANALYSIS OF EXISTING TECHNOLOGY

According to the proposed plan, in association with a domestic factory of forged parts, analysis of exisitng tecnology was conducted which included process planning as well as a review of present production program, based on detailed examination of technological documentation available for particular forged parts.

Numerous examples indicate that the dominant manufacturing technology is the open-die forging in combination with free-form forging of preforms. The basic elements of this technology are:

- selection of technological variant,
- definition of shapes and dimensions for a finished part and blank,
- definition of forming stages (preparatory, preform and finished),
- tool design, manufacture and testing.

Selection of technological variant is guided by the batch size and available equipment, in this case – conventional forging presses and hammers. Preforms are shaped using only two technological variants:

- simple variant – which employs only free-form forging in the preparatory phase,
- more complex variant - which includes additional preform die forging.

Most often, preparatory forging**,** including the stages up to the finishing, are done entirely by free-form forging, which is accounted by small-batch production. Mass ballance is usually defined based on experience, with additional corrections on a trial basis. In the case of more complex parts, when the finishing die is not filled correctly, simple solution is to increase the volume of blank. This method very often inflates the gross material expenditure much above the average.

Preform die is used in cases when complex geometry parts are forged in large batches, which increases life of finish die and reduces material expenditure, but also drives up costs of introduction of novel technology.

Die design is based on predefined forming stages and machine tool characteristics. Once the dies have been manufactured in factory tool shop, they are tested for technological defficiencies (on a trial and error basis) after which they are ready to enter production process.

Basic traits of the technology described above are:

- short planning time, due to designers experience, as well as intrinsic simplicity and repetitiveness of technological solutions,
- large portion of free-form forging due to small-batch production,
- long manufacturing time,
- increased material and energy costs,
- increased costs of introduction of novel technology for complex-geometry workpieces,
- medium quality of workpieces,
- low level accumulation (low profit margin).

2.1 An example of presently used technology

As an illustrative example of the use of present technology a relatively complex fork-shaped workpiece will be used (Fig.1).

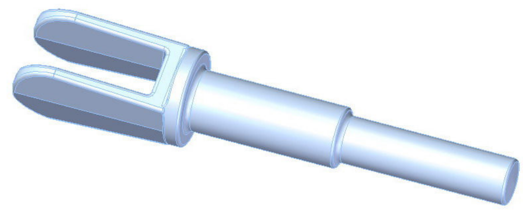

Fig. 1 Forged part in the shape of fork

Basic data from technological documentation for this workpiece are:

- batch size: 16 000 pcs,
- net workpiece mass: 1,95 kg,
- workpiece dimensions: 55x55x136 mm,
- blank mass: 3,23 kg,
- manufacture time of forging operations: 1,5 min/pc,
- no. of pieces per hour: 40 pcs/h,
- gross cost of labour on forging press: 3 260 din/h ≈ 35 €/h, that is: 0.875 €/pc,
- workpiece material cost: ~ 0,75 €/kg,
- new tool cost: ~ 5 000 €,
- single tool regenration cost: ~ 600 €,
- tool life per single generation: ~ 2 000 pcs.
- number of generations: 7,
- tool regeneration cost: 4 200 €/batch

Listed data yield following conclusions:

- substantial difference between blank mass and net workpiece mass (1.28 kg, i.e. ~65%, which tops industry average by 35%, in case of simple geometry parts),
- long manufacture time for forging operations,
- short tool life,
- relatively high gross machine labour costs.

It should be noted that, beside machine operator labour costs, the gross machine labour costs also include all other costs, from design costs, to non-manufacturing activities costs (overhead expenses), to energy and amortization costs. Such representation of machine labour cost is suitable for rapid calculation of unit forge cost, which is crucial for short - term estimation of business proposals and bidding.

Previous data lead to conclusion that cutting down machine time (i.e. time of manufacture for forging operations) can lead to significant reduction of total costs.

The above described technology - which involves free-form forging of complete preform, followed by substantial material wastage and slow manufacture - is mostly used due to relatively small batch, and low labour cost used for those operations.

In case of large batches of more complex but similar parts, which are to be expected in the near future, beside large expenses which are intrinsic to the described technology, there is also an important question of production capacity of the present equipment. The solution is primarily to be found in a more modern approach to process planning of forging, and, during subsequent stage, in acquisition of modern equipment.

3. POSSIBILITIES FOR COST REDUCTION

Modern approaches to process planning are based on computers which, in terms of forging, bring following advantages:

- automation of process planning and
- numerical simulation of forging process.

Process planning automation allows substantial reduction of time required for process planning and tool design, as well as linking with CNC machines for rapid tooling (CAD/CAPP/CAM) [8].

Acquisition of software for process planning automation can be cost effective in cases when there are a number of technological tasks to be solved which are repeated on identical or similar shapes of various dimensions. This particular topic is of interest in the near future.

Application of software for simulation of forging processes is possible in all particular cases of process planning optimization. However, in cases of complex-geometry workpieces it is a must.

Introduction of numerical simulation into process planning in forging contributes to following:

- reduction of time and costs involved with development of technology, since it eliminates the tool (die) trial and error phase,
- reduction of material wastage by defining optimal mass balance, i.e. the preform,
- significant reduction of manufacturing time through elimination or minimization of open-die preparatory forging, which also reduces labour and amortization costs,
- reduction and better load distribution on forging dies, i.e. prolonged die life and reduced costs of regeneration,
- reduction of energy costs due to lower mass of material.

3.1 Results of forging process simulation

To illustrate the benefits of numerical simulation in forging process planning, an example of a relatively complex part is used (Fig.1).

Presented here are just the core data, necessary for assessment of economic effects of the proposed process planning. Complete analysis can be found in [10].

Essential improvement of process planning method is the introduction of die prefinish forging together with definition of optimal shapes through forming stages. All this contributed to good filling of die and a more even laod distribution in prefinishing and finishing dies.

Optimal solutions were reached through an iterative procedure of performing complete simulations with several shape variants (no physical experiments were necessary).

Shown in Fig. 2 is the optimal preform shape which is produced by free-form forging with a minimum number of strokes, using simple dies with mild radii [10].

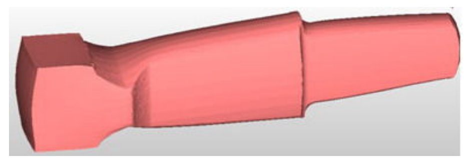

Fig. 2 Optimal preform shape produced by free-form forging

The preform forge shown above proved its value in simulation of die forging process of the preform shape, shown in Fig.3 with stress distribution. Majority of forge area is covered with lower contact pressure zones (lighter shades - right), with a mild increase in the zone of larger deformations (top left).

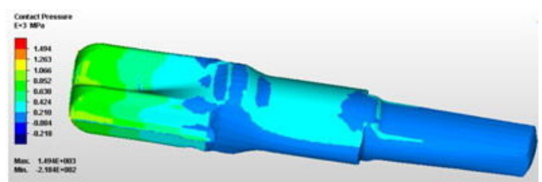

Fig. 3 Optimal preform shape produced by die forging [10]

In Fig. 4 is shown correct final shape of fork-shaped forge with flesh and plate, and contact stress distribution. There is a visible balance of stress distribution, with acceptable mean values. Slight increase is visible in the area of plate and the cylindrical section of workpiece, but those do not impact die life significantly.

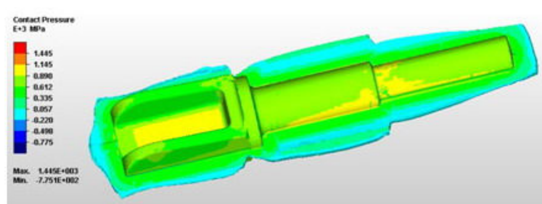

Fig. 4 Final forge shape [10]

Based on comparison of the shown stress state with the results of simulation of forging process according to the presently used technology (without the preform die forging), where much higher stresses were obtained [10], one can conclude that the novel technology prolongs die life for approx. 50%, while the lead manufacture time is reduced for about 40%.

At the same time, due to higher complexity, one can expect increased cost of die, as well as increased cost of a single regeneration, for approximately 30%. However, this should not affect total costs of regeneration since the prolonged die life.

3.2 Economic effects of the novel process planning procedure

Finally, in order to assess economic effects of the proposed technology innovation, basic parameters of the novel process plan are listed:

- blank dimensions: 50x40x170 mm,
- blank mass: 2,67 kg,
- manufacturing time for forging operations: 0,90 min/pc,
- number of pieces per hour: 66 pcs/h,
- gross labour costs (forging press): 0,53 €/kom,
- cost of new die: ~ 6500 €,
- cost of a single die regeneration: ~ 780 €,
- die life per generation: ~ 3000 kom,
- numbers of die regeneration: 4,
- cost: 3 120 €/ser.

Parameters, such as batch size, net forge mass, gross labour costs, and forge material cost, remain unchanged.

Economic effects as the result of application of novel tehnology, are:

- material savings: 0,56 kg/pc, that is: 0,42 €/pc, or per batch: 6720 €/batch,
- machine labour savings: 0,345 €/pc, per batch: 5520 €/batch,
- increased costs of new die: 1500 €/batch,
- savings on die regenartion: 1080 €/batch.

By subtracting savings from costs, one derives a substantial sum of 11820 €/batch of saving, which represents the total economic effect of introduction of novel technology for the batch of 16000 forges, or 0,738 €/pc per forge.

The results support economic viability of the proposed changes in process plan.

Introduction of innovative technology is followed by additional expenditures on licenced software, but this can be compensated by an increased number of complex forges and larger batches, which are to be expected in the future period.

4. CONCLUSION

Modern approaches to process planning are based on extensive use of IT technologies, primarily in the domain of computer-aided design and process planning, and numerical simulation of forging processes.

Design automation enables shorter process planning time, and die design.

Application of software for numerical simulation allows cost reduction and shorter periods required for introduction of novel technology, prolongs die life, and significantly reduces material, labour and energy costs.

5. LITERATURA

[1] Biba, N., Stebounov, S., Lishiny, A.: *Cost effective Implementacion of forging simulation,* Journal of Materials Processing Technology, vol. 113, pp. 34-39, 2001.

[2] Tomov, B. I., Gagov, V. I., Radev, R. H.: *Numerical simulations of hot die forging processes using finite element method,* Journal of Materials Processing Technology, vol. 153-154, pp. 352-358, 2004.

[3] Sedighi, M., Tokmechi, S.: *A new approach to preform design in forging process of complex parts,* Journal of Materials Processing Technology, vol. 197, pp 314–324, 2008.

[4] Behrens, B. A.: *Finite element analysis of die Wear in hot forging processes,* CIRP Annals – Manufacturing Technology, vol. 57, pp. 305 – 308, 2008.

[5] Caporalli, A., Gileno, L.A., Tonini Button, S.: *Expert system for hot forging design,* Journal of Materials Processing Technology, vol. 80-81, pp. 131-135, 1998.

[6] Vujović, V.: *Technology of plasticity in Mechanical engineering, Faculty of technical science,* Novi Sad, 1990.

[7] Mandić, V.: *Optimizacija prethodnog oblika u višepozicionom toplom kovanju primenom FE simulacije,* 30. SPM SCG, str. 145 - 150, Vrnjačka Banja, 2005.

[8] Trbojević, I., Vilotić, D., Lužanin, O., Movrin, D.: *Razmatranje mogućnosti automatizacije u projektovanju tehnologije kovanja,* 32. SPM SCG, str. 195-198, Novi Sad, 2008.

[9] Trbojević, I., Lužanin, O., Milutinović, M.: *Softver za automatsko projektovanje faza oblikovanja pripremka u procesu toplog valjanja prstena složenog preseka,* 31. SPM SCG, str. 498 – 501, Kragujevac, 2006.

[10] Movrin, D., Vilotić, D., Milutinović, M., Plančak, M., Lužanin, O.: *Design of forging tools for yoke - like elements based on numerical simulation, MMA 2009,* 10. International scientific conference, 2009.

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O nama

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Tehnologija ›

Kvalitet ›

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Zahvaljujući vrlo atraktivnim kamatnim stopama na oročenu deviznu štednju, Banka beleži njen stalan porast. Poseban kvalitet se ogleda u činjenici da ulozi oročeni na 12 i više meseci, u odnosu na prethodnu godinu, beleže rast od 397,50 indexnih poena , te da je njihovo učešće u strukturi svih deviznih uloga udvostručeno.

Ove godine, Banka obeležava petnaest godina svoga postojanja a poslovanje kroz mrežu koju čine 53 poslovne jedinice u 38 mesta širom Srbije (prema zvaničnim podacima NBS **METALS-BANKA** je druga banka po rangu po obimu ekspanzije poslovne mreže u 2005. godini), sa 416 zaposlenih, svedoči o njenom uspešnom razvoju i likvidnom i profesionalnom poslovanju.

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