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Editorial

The ***Journal of Production Engineering*** *dates back to 1984, when the first issue of the* ***Proceedings of the Institute of Production Engineering*** *was published in order to present its accomplishments. In 1994, after a decade of successful publication, the Proceedings changed the name into Production Engineering, with a basic idea of becoming a Yugoslav journal which publishes original scientific papers in this area.*

In 2009 year, our Journal finally acquires its present title - ***Journal of Production Engineering****. To meet the Ministry requirements for becoming an international journal, a new international editorial board was formed of renowned domestic and foreign scientists, refereeing is now international, while the papers are published exclusively in English. The Journal is distributed to a large number of recipients home and abroad, and is also open to foreign authors. In this way we wanted to heighten the quality of papers and at the same time alleviate the lack of reputable international and domestic journals in this area.*

In this journal number are published, reviewed papers from 33^{rd} *Conference on Production Engineering of Serbia with foreign participants and new papers as well.*

Editor in Chief

Professor Pavel Kovač, PhD,

Journal of Production Engineering
Vol.15 No.1

Contents

PRELIMINARY NOTE

Journal of Production Engineering
Vol.15 No.1

Review Paper

Kovač, P., Rodić, D., Pucovski, V., Mankova, I., Savkovic, B., Gostimirović, M.

A REVIEW OF ARTIFICIAL INTELIGENCE APPROACHES APPLIED IN INTELIGENT PROCESSES

Received: 01 December 2011 / Accepted: 07 January 2012

Abstract: *In the paper presented are issues involved in the development of intelligent machining processes. Artificial Inteligence techniques can be successfully applied in monitoring of machining processes, the experimental data set for the machining process modeling, the previous knowledge of the machining process etc. The most often used techniques are artificial neural networks, fuzzy logic, adaptive neuro fuzzy interference systems, genetic algorithms, and others. In the paper is given recommended application of each Artificial Inteligence techniques with drawbacks and advantages of application.*
Key words: *artificial intelligence, manufacturing,*

Pregled pristupa primene veštačke inteligencije pri inteligentnim procesima. *U radu su predstavljeni problemi koji su uključeni u razvoj inteligentnih obradnih procesa. Tehnike veštačke iteligencije mogu se uspešno primeniti u praćenju procesa obrade , modeliranje procesa na osnovu eksperimentalnih podataka, prethodnog znanja o procesu obrade itd. Najčešće korišćene tehnike su veštačke neuronske mreže , fazi logika , adaptivni neuro fazi sistemi, genetski algoritmi i drugi. U radu je data preporuka primene za pojedine tehnike veštačke inteligencije sa manama i prednostima primene.*
Ključne reči: *veštačka inteligencija, proizvodnja,*

1. INTRODUCTION

Machining of materials (turning, milling, drilling, etc.) is an empirical science. The decision-making activities in machining operations depend on the numerical data acquired from various machining experiments. The acquired machining data is not directly used in the decision- making activities. It is required to find structures (i.e., knowledge) in a given set of data to make it more useful for making decisions. Most of the times the extracted knowledge is represented by algebraic expressions (empirical equations) or by logical expressions (a trained neural network, ''if . . . then . . . '' rules, decision trees) [1].

In this paper, application of major AI techniques to various machining processes is discussed. AI tools can be used for prediction of the performance parameters of machining as well as for the optimization of the process. For example, in turning processes, cutting speed, feed and radial depth of cut of the tool are the process parameters. These parameters may be optimized and predicted for obtaining the minimum cost of machining and minimum production time.

2. SELECTION OF AI APPLICATION

This paper reviews research work on the application techniques of artificial intelligence (AI) in modeling and optimization of machining processes. The following AI techniques: neural network (NN), fuzzy logic (FL), genetic algorithm (GA). Soft computing is an approach to computing which parallels the remarkable ability of the human mind to reason and learn in an environment of uncertainty and imprecision. In an attempt to find out reasonably useful solutions, soft computing-based methods acknowledge the presence of imprecision and uncertainty present in machining [2].

2.1 Neural network

Artificial neural networks (ANN) are one of the most popular techniques of artificial intelligence which came into force in solving problems related to the production began in the late 80-ies. Since then has been published many papers related to the application of ANN covering a wide range of manufacturing processes, operations and activities. The area of ANN in the production is surprisingly large and covers various areas: design of production systems and processes to the management of production systems and processes. ANN have been recognized as an indispensable tool whose implementation can be achieved by: improving product quality, increase productivity, reducing system response time, increase reliability and so on.

ANN are simplified mathematical models of human brain function, artificial neural network is attempted imitation of biological neural networks. With a view of the structure, neural networks are divided into static (or feedforward) and dynamic (or feedback), depending on the model of neurons from which they were built, and by way of signal propagation through the network. Given the number of layers in which neurons are arranged, different single and multi-layer artificial neural networks. For networks with more layers, each layer typically receives inputs from the previous layer, and its output is sent the next layer. The first layer is called the input, the final is called output, other layers are usually called hidden layers. One of the most common neural network architecture is a network with three layers Fig. 1. The first layer (input) is the only layer that receives signals from the environment. The first layer transmits signals to the next layer (hidden layer) which processes this data and extracts the characteristics and patterns of the received signal. The data are considered important to indicate the output layer, the last layer of the network. At the output neurons of the third layer are obtained by processing the final results. Complex neural network can have multiple hidden layers, feedback loops and time delay elements, which are designed to enable more efficient separation of important characteristics or patterns of input levels. It is generally taught and applied multilayer neural networks in addition to input and output layers containing neurons in the middle (hidden) layers.

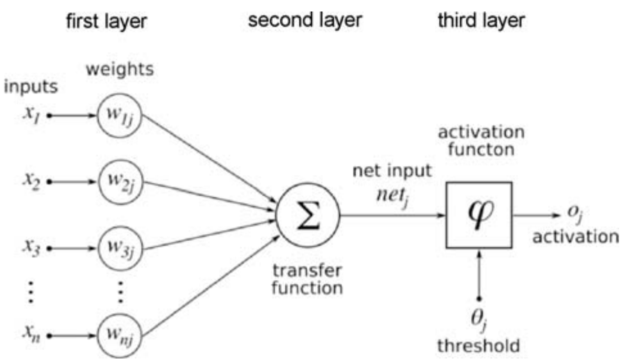

Fig. 1. Model of artificial neuron

Learning the basic and essential feature of neural networks. Neural networks learn from examples. Examples should be more in order to use the network at a later acted as precisely as possible. The essence of the learning process is that it leads to the adjustment of synaptic weights. When the input data that are brought online no longer lead to changes in these ratios, it is considered that the network is trained to solve a problem. Training can be done in several ways, but regardless of the learning algorithm used, the processes are essentially very similar and consist of the following steps:

1. network is presented a set of input data
2. network processes the result and to remember (this is a passage in advance)
3. calculated error value, so that the output from consuming than expected
4. for each node counts the new synaptic weight (this was back passage)
5. changing the synaptic weights, or to leave the old values and new ones are remembered.

An early work for the prediction of machining performance using neural networks is by Rangwala and Dornfeld [3]. The authors utilized a feedforward network model to predict the cutting performance in turning process. Recently, some initial investigations in applying the basic artificial intelligence approach to model machining processes, have appeared in the literature [4,5], concludes that the modeling of surface quality in machining processes has mainly used ANN. Balic and Korosec [6] predicted average mean roughness, Ra using neural network (NN). Surface roughness and surface finish have been considered in [7,8]. Khorasani et al [9] used both Taguchi's design of experiment and artificial neural networks for tool life prediction in face milling. Lin and Ting [10] predicted drill wear using neural network and regression models. Average thrust force and torque, spindle speed, feed rate, and drill diameter were used as input parameters and average flank wear was the only output parameter of the neural network. The authors found that the neural networks with two hidden layers learn faster and can more accurately estimate tool wear than the networks with one hidden layer. Aykut et al. [11] used artificial neural network to predict cutting forces and studied machinability in face milling process. Cutting speed, feed rate, and depth of cut were used as input parameters of the network to predict three cutting forces and they found the estimated force within an error of 10%.

2.2 Fuzzy logic (FL)

The fuzzy logic and fuzzy inference system (FIS) is an effective technique for the identification and control of complex non-linear systems. For prediction, fuzzy logic is used. The theory of fuzzy logics, initiated by Zadeh [12] has proved to be useful for dealing with uncertain and vague information. Fuzzy logic is particularly attractive due to its ability to solve problems in the absence of accurate mathematical models. This theory has proved to be an effective means for dealing with objectives that are linguistically specified. Linguistic terms, such as 'low,' 'medium' and 'high' may be defined by fuzzy sets [13]. Design of fuzzy inference system is showed on Fig.2.

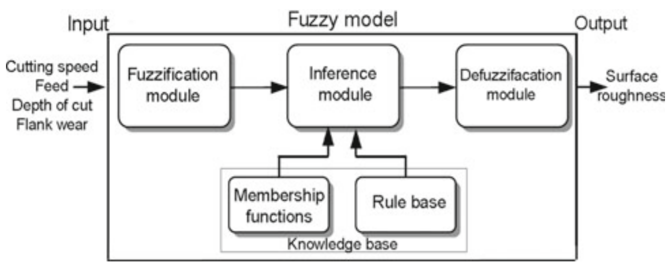

Fig. 2. Fuzzy Inference system

The process of fuzzy inference involves membership functions, fuzzy logic operators, and if-then rules. The basic structure of a FIS consists of three conceptual components: a rule base, which contains a selection of fuzzy rules; a database which defines the membership functions (MF) used in the fuzzy rules; and a reasoning mechanism, which performs the inference procedure upon the rules to derive an output.

The parameters of the if-then rules (referred to as antecedents or premises in fuzzy modeling) define a fuzzy region of the input space, and the output parameters (also is used as consequents in fuzzy modeling) specify the corresponding output.

There are three types of fuzzy inference systems in wide use: Mamdani-type, Sugeno and Tsukamoto-type. These three types of inference systems vary somewhat in the way outputs are determined. The output of the Mamdani FIS is generally defuzzified. Resulting fuzzy sets are combined using aggregation operator from the consequent of each rule of the input. Fuzzy knowledge base system can be formed on the basis of expert knowledge or automatic generation of rules based on previously measured data. Irrespective of the manner of formation, the knowledge base has generally the same form. The system with multiple inputs and one output, knowledge base *R* contains *n* rules in form:

$$R = \{R_1, R_2, \ldots, R_n\} \quad (2)$$

where each *n*-th rule has the form:

IF "X" is A, THEN "Y" is B (3)

or in a mathematical form;

$$\{IF\ (premise_i)\ THEN\ (consequent_i)\}_{i=1}^{n} \quad (4)$$

Where, A and B are linguistic values defined by fuzzy sets on the ranges; X and Y, respectively. The if-part of the rule "X is A" is called the antecedent or premise, while the then-part of the rule "Y is B" is called the consequent or conclusion. The input to an if-then rule is the current value for the input variable and the output is generally defuzzified. Resulting fuzzy sets are combined using aggregation operator from the consequent of each rule of input. Depending on the system, it may not be necessary to evaluate every possible input combination since some may rarely, or never, occur. By making this type of evaluation which is usually done by an experienced operator, fewer rules can be evaluated, thus simplifying the processing logic and perhaps even improving the fuzzy logic system performance.

Design of fuzzy logic system is divided into three phases:

1. define a fuzzy variable
2. set of all fuzzy subsets of variables with appropriate membership functions
3. form fuzzy rules

Fuzzy logic which is recognizing and identifying systems, has been developed and used widely [14,15] have shown many practical applications of fuzzy logic systems in machine monitoring and diagnostics. Lee et al. [16] presented fuzzy nonlinear programming model to optimize cutting conditions for a turning process. Rajasekaran et al [17] researched the influence of machining parameters combination so as to obtain a good surface finish in turning and to predict the surface roughness values using fuzzy modeling.

Several researchers have compared the effectiveness of the fuzzy model with statistical regression models. Kovac et al [18] used FL to predict the surface roughness and compare with regression analysis in face milling process. Cutting speed, feed rate, depth of cut and flank wear were considered as input parameters. The FL was modeled using gausian membership functions. Although fuzzy model is a bit complicated to develop than regression model (need of experience and knowledge). The adequacy of the model is checked and is found to be adequate at 94% confidence level and the model can be used for predicting the surface roughness in machining of carbon steel.

2.3 Adaptive Neuro-Fuzzy Inference System (ANFIS)

The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. Using a given input/output data set, the toolbox function anfis constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method. This adjustment allows your fuzzy systems to learn from the data they are modeling.

A network-type structure similar to that of a neural network. The entire system architecture consists of five layer, namely, the fuzzy layer and total output layer. Five network layers are used by ANFIS to perform the following fuzzy inference steps: (i) input fuzzification, (ii) fuzzy set database construction, (iii) fuzzy rule base construction, (iv) decision making, and (v) output defuzzification. ANFIS is more powerful than the simple fuzzy logic algorithm and neural networks.

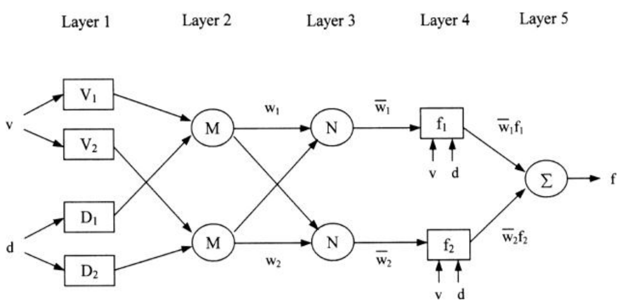

Fig. 3. Basic ANFIS architecture [19]

A number of authors have used the combination of two AI techniques as an effective strategy for the prediction parameters. Sekulic et al. [20] used a neurofuzzy approach for the simulation cutting forces. For this model, main parameters for the experiments are angle φ (input data set) and cutting forces Fx, Fy and Fz (output data set). The error of the force values predicted by ANFIS than 2,21% for Fx, 4,93% for Fy and 1,06% for Fz force component. Nandi and Pratihar [21] employed a fuzzy basis function network for predicting the surface roughness in ultraprecision turning. The parameters of the network were optimized with a genetic algorithm code. Lo [22] used ANFIS to predict the surface roughness in end milling process. Spindle speed, feed rate, and depth of cut were considered as input parameters. The ANFIS was modeled using triangular and trapezoidal membership functions. The average error of prediction of surface roughness for triangular membership function was found lower, around 4%.

2.4 Genetic algorithms (GA)

GA mimics the process of natural evolution by incorporating the “survival of the fittest” philosophy. In GA, a point in search space (binary or decimal numbers) known as chromosome. A set of chromosomes is called population.A population is operated by three fundamental operations:

1. reproduction (to replace the population with large number of good strings having high fitness values)
2. crossover (for producing new chromosomes by combining the various pairs of chromosomes in the population),
3. mutation (for slight random modification of chromosomes).

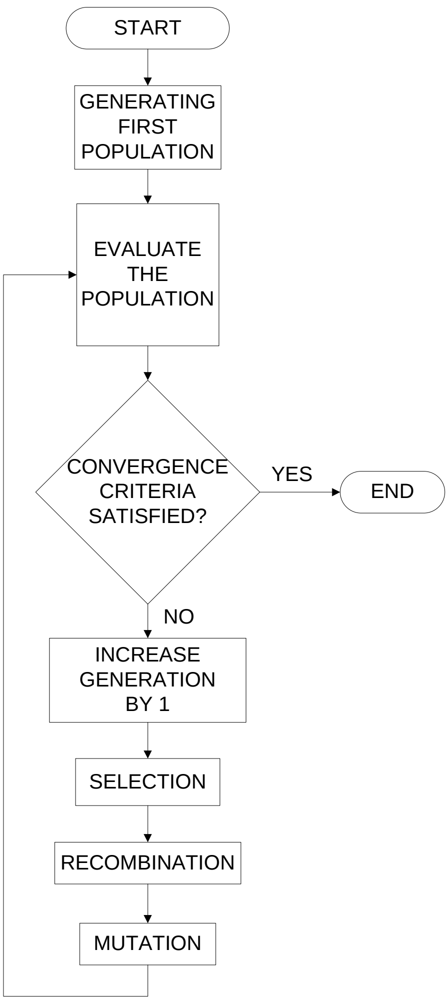

Fig. 4. Structure of genetic algorithm

A sequence of these operations constitute one generation. The process repeats till the system converges to the required accuracy after many generations. The genetic algorithms have been found very powerful in finding out the global minima. Further, these algorithms do not require the derivatives of the objectives and constraints functions.

Through time many scientist manage to successfully implement GA (genetic algorithm) as a problem solving technique. Čuš & Balič [23] were using GA to optimize cutting parameters in process of milling with the use of classical binary encoding. Srikanth & Kamala [24] used real coded GA to optimize parameters in turning. Ficko et al. [25] reported positive experiences in using GA in forming a flexible manufacturing system. Regarding tool life in face milling, statistical approach by the use of response surface method have been covered by Kadirgama et al [26]. Genetic–simulated annealing (GSA) algorithm, which is a hybrid of GA and SA, is used by Wang et al. [27] to determine optimal machining parameters for plain milling process. Gopal and Rao [28] developed a GA-based optimization procedure to optimize grinding conditions, viz., depth of cut, work speed, grit size, density, using a multi-objective function model.GA was used for optimizing the cutting conditions, viz., cutting speed, feed rate, depth of cut and flank wear to obtain desired tool life and temperature in face milling process [29]. Reddy and Rao [30] used genetic algorithm to optimize tool geometry, viz., radial rake angle and nose radius and cutting conditions, viz., cutting speed and feed rate to obtain desired surface quality in dry end milling process.

3. CONCLUSION

In this paper, a review of application of artificial techniques in machining performance prediction and optimization has been presented.

NNs have become an indispensable tool in the solving of tasks related to production processes. The diversity and nature of problems encountered in solving the tasks of production have created favorable conditions for the application of NN. NNs have proven to be very successful in terms of: quality control, production planning, management, simulation, modeling and many other activities. Neural network models have been effectively employed for modeling machining processes, like that the modeling of surface quality; for prediction of machining performance, like for tool life, average mean roughness or cutting forces prediction in machining.

NN require more training data and provide slightly inferior accuracy. However, it is only an experimental observation and in the context of machining, no mathematical proof has been provided to support this observation.

The effectiveness of the fuzzy models is only within the range and factors studies. The model adequacy can be further improved by considering more variables and ranges of parameters. It is necessary to define the membership function for each set of rules which form and combination appear with too many solution. Implementation of fuzzy logic for this purpose can be applied successfully.

Fuzzy sets combination of fuzzy sets and neural networkshave been used for predicting parameters in turning, milling, and grinding. Fuzzy setbased methods are especially advantageous when the expert knowledge is available.

Genetic algorithms have become an indispensable tool for solving tasks related to production processes. GA have been used in machining area for two purposes first for optimizing the internal parameters of neural networks, fuzzy sets, and neurofuzzy systems and second for machining optimization. Mastering and modeling mchining process can contribute to optimal process management which will have a positive influence on cutting down expenses of production.

The best strategy is to use a combination of fuzzy and neural network for performance prediction and optimization tool like GA for optimization.

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Original Scientific Paper

Gostimirović, M., Kovač, P., Sekulić, M., Savković, B.

A STUDY OF DISCHARGE PULSE ENERGY IN ELECTRICAL DISCHARGE MACHINING

Received: 01 November 2011 / Accepted: 17 December 2011

Abstract: *In electrical discharge machining (EDM) material is removed through periodical electrical discharges between the tool and workpiece. Characteristics of discharge pulse energy define the performances of EDM. Therefore, the discharge pulse energy which in the discharge zone is transformed into heat is of key importance in EDM process. Because, characteristics of discharge energy parameters are analyzed in this paper and their influence on material removal rate and machining quality. Researches conducted in this paper allow efficient identification of relevant discharge energy parameters for the selection of optimal EDM machining conditions.*
Key words: *electrical discharge machining, discharge pulse energy, productivity, machining quality*

Prilog istraživanju impulsne energije pražnjenja kod elektroerozivne obrade. *Kod elektroerozivne obrade skidanje materijala ostvaruje se putem periodičnog pražnjenja između alata i obratka. Karakteristike impulsa energije pražnjenja definišu EDM performanse. S toga, energija pražnjenja koja se u zoni obrade transformiše u toplotu predstavlja ključni problem pri EDM obradi. Zbog toga su u radu analizirane karakteristike energije pražnjenja i njihov uticaj na proizvodnost i kvalitet obrade. Sprovedena istraživanja u ovom radu omogućuju efikasnu identifikaciju relevantnih parametara energije pražnjenja za izbor optimalnih EDM režima obrade.*
Ključne reči: *elektroerozivna obrada, impulsna energija pražnjenja, proizvodnost, kvalitet obrade*

1. INTRODUCTION

Electrical Discharge Machining (EDM) is one of the most important non-conventional machining processes. It is primarily used for machining difficult-to-machine materials and complex geometry parts for which traditional techniques are not applicable. Moreover, this process is only available for machining metals (hardened alloy steel, high speed steel, cemented carbide) and materials that offer a minimum electrical conductivity.

In EDM, material is removed through periodical electrical discharges between the tool and workpiece [1]. EDM requires the tool and workpiece to be submerged in a liquid dielectric at a small distance, and they are connected through an electronic switch to a DC power source. Upon establishing the voltage, a strong magnetic field is established between the tool and workpiece. Due to attractive force of the magnetic field, at the shortest local distance between the tool and workpiece there is a build-up of particles from the machining process which float in the dielectric fluid. This forms the plasma channel and the electrons begin to move towards the positively charged electrode. On their way, the accelerated electrons collide with the neutral particles from the machining process and the dielectric liquid. There is a chain reaction in which a large number of negative and positive ions are generated. The ionization initiates creation of electro-conductive zone between the workpiece and tool, thus causing electrical discharge.

Disruption of current supply annihilates the discharge zone, causing abrupt cooling which results in an explosive flushing of melted matter and solid particles off the workpiece surface. A series of discharges results in a number of small craters which increase surface roughness. Between the periodical discharges there is a deionization of dielectric liquid and the products of machining are evacuated from the work zone. This process provides stability of pulse discharge by preventing the continuous current flow and generation of electric arc or a short circuit. Shown in Fig. 1 is principle of EDM process, input parameters (workpiece, tool, machine and dielectric) and output technological performances (material removal rate, machining accuracy and surface integrity).

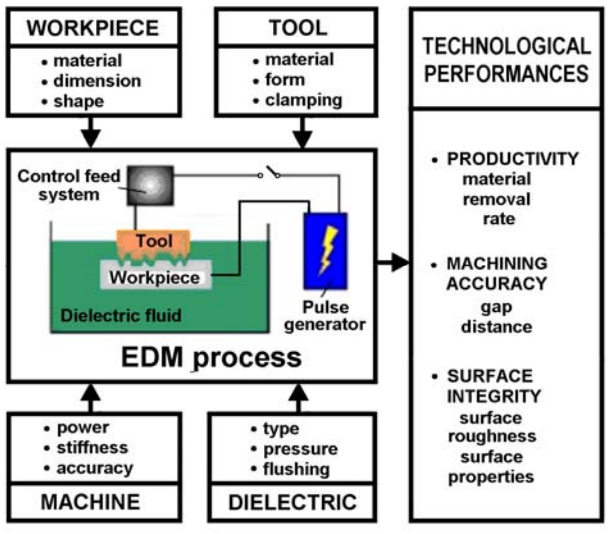

Fig.1. Electrical Discharge Machining

Based on the previously mentioned, efficiency of EDM directly depends on the discharge energy which is transformed into heat in the machining zone [2]. The generated thermal energy leads to high temperatures which result in local melting and evaporation of workpiece material. However, the high temperature also impacts various physical and chemical properties of tool and workpiece. This is why research of discharge energy is of key importance in EDM process.

2. DISCHARGE ENERGY

The discharge energy is the mean value of electric parameter which is transformed into heat during discharge, and can be expressed by a following equation:

$$E_e = \int_0^{t_e} u_e(t) \cdot i_e(t) \cdot dt \cong U_e \cdot I_e \cdot t_e \qquad (1)$$

where $\boldsymbol{U_e}$ is the discharge voltage, $\boldsymbol{I_e}$ is the discharge current and $\boldsymbol{t_e}$ is the discharge duration.

As can be seen from Eq. (1), the discharge energy is directly influenced by the characteristics of electric pulses. Their influences are interconnected and depend on the rest of the machining parameters [3].

The discharge voltage depends on the paired electrode materials and machining conditions. It ranges between 15 and 30 V. It can be indirectly influenced by the choice of tool material. Inherent to the tool material are thermal properties and the speed of deionization of machining are, so that for every tool/workpiece material combination there is a corresponding discharge voltage. Practically all kinds of electro-conductive materials can be used for tools. Generally, most popular are materials with low electrical resistivity and high melting point, among which are copper, graphite, wolfram, and their alloys.

The discharge current directly impacts the discharge energy. However, the impact of discharge current is limited by the tool surface area which is interfacing the workpiece, i.e. the current density. In case when the current density oversteps the limit for the given machining conditions (approximately 10 A/cm^2), the removed material per unit area is such that it cannot be efficiently evacuated by circulation of dielectric liquid. This deteriorates the process of deionization of machining are, thus reducing the efficiency of EDM.

The discharge duration is another parameter which allows direct control of discharge energy. However, here too the independent regulation of process parameters is limited. It is known from experience that discharge duration must be limited for a particular discharge current. Otherwise, a DC arcing occurs which damages the surfaces of tool and workpiece.

The material removal process in EDM is associated with the erosive effects which occur as a result of an extremely high temperature due to the high intensity of discharge energy through the plasma channel, Fig. 2. The material removal rate and the surface integrity correspond to the adjusted crater profile that is defined by a through the radius. For that reason, the material removal models were mainly based on the electro-thermal mechanism.

Therefore, several simplifying assumptions are used for the modeling of the material removal EDM process [4,5]. The material of the workpiece is homogeneous and isotropic. Flushing efficiency is considered to be ideal. The molten of the workpiece material in the discharge zone is removed completely. Only one crater occurs per electrical discharge. The crater radius is assumed to be a function of discharge energy.

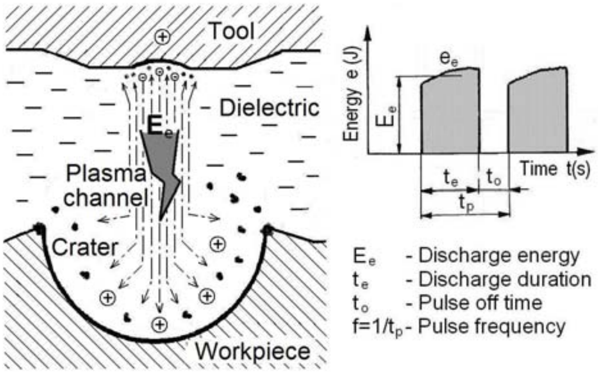

Fig.2. Model of material removal process in EDM

Based on the previous discussion, now it can be logically assumed that the material removed volume of a single electric pulse would be proportional to the discharge energy:

$$V_e = C_V \cdot E_e \qquad (2)$$

where $\boldsymbol{C_V}$ is the constant that depends on the workpiece material.

The material removal rate represents the average volume of material removed over the machining time. By using Eq. (2), as well as Eq. (1), there follows the expression for material removal rate:

$$V_w = V_e \cdot f = C_V \cdot U_e \cdot I_e \frac{t_e}{t_e + t_o} \qquad (3)$$

where $\boldsymbol{f}$ is the pulse frequency and $\boldsymbol{t_o}$ is the pulse off time.

On the other hand, the material removal in a single pulse discharge is determined by computing the volume of the crater supposed to be hemispherical with a radius equal to $\boldsymbol{R_{max}}$:

$$V_e = \frac{2}{3}\pi \cdot R_{\max}^3 \qquad (4)$$

In Eq (4), $\boldsymbol{R_{max}}$ is defined as the maximum surface roughness observed over maximum height of irregularities.

From the Eq. (4) also using Eq. (2) and (1), one derives expression for maximum height of irregularities:

$$R_{\max} = \left(\frac{3}{2\pi} C_V \cdot U_e \cdot I_e \cdot t_e \right)^{1/3} \qquad (5)$$

In practical, the surface quality is defined over the surface roughness $\boldsymbol{R_a} \cong R_{max}/4$. The surface roughness is defined as the arithmetic average deviation of the assessed profile (ISO 4287).

Theoretical, dependence of the gap distance on the discharge energy is given by equation:

$$a_e = C_a \cdot E_e^m \qquad (6)$$

where C_a and m are the constants that depend on the machining conditions.

3. EXPERIMENTAL PROCEDURES

Experimental investigation was conducted on EDM machine tool ″FUMEC – CNC 21″ of South Korea (I_e=0÷100 A, t_e=0÷1000 µs and t_o=0÷100 µs). The material used in the experiment was manganese-vanadium tool steel, DIN 90MnV8 (0,9% C, 2% Mn, and 0,2% V), hardness 62 HRC. The tool was made of electrolytic copper with 99,9 % purity, 20×10 mm cross-section. The dielectric was petroleum. Due to small eroding surface and depth, natural flushing was used.

The machining conditions included variable discharge current and discharge duration. The rest of the parameters were held constant, according to manufacturer's recommendations.

The experiments were conducted according to the specified experiment plan. Input parameters were varied and the resulting machining parameters of EDM process were monitored and recorded. Measured parameters were material removal rate V_w, gap distance a, and surface roughness R_a.

Material removal rate (ratio of removed material volume and the effective machining time) was measured indirectly, by monitoring the machining time for the set eroding depth. The depth and time of eroding were monitored using the machine tool CNC control unit. Gap distance was calculated as the half of difference between the tool and workpiece contour dimensions. Measurements were conducted using electronic callipers (precision: 0,001 mm). Surface integrity was assesed by measuring surface roughness and research of the surface layer properties. ″PERTHOMETER S5P″ of Mahr, Germany was used to measure the surface roughness.

4. RESULTS AND ANALYSIS

Figure 3 shows the results of experimental investigation for the selected machining conditions. For various discharge currents and discharge durations, following process parameters are shown: material removal rate, gap distance and surface roughness.

The analytical considerations presented in this paper confirm that the increase of discharge current increases the material removal rate (Eq. 3), and optimal influence of discharge durations on material removal rate. In real conditions, lengthy pulses cause enormous concentration of removed material, as well as the increase of gas bubbles in the machining area. Due to impaired evacuation of machining products, a portion of the discharge energy is spent on re-melting and evaporation of solidified metal particles. The remaining, larger, portion of discharge energy takes place in a gaseous environment, thus being lost irreversibly. Such impaired process stability affects the EDM productivity.

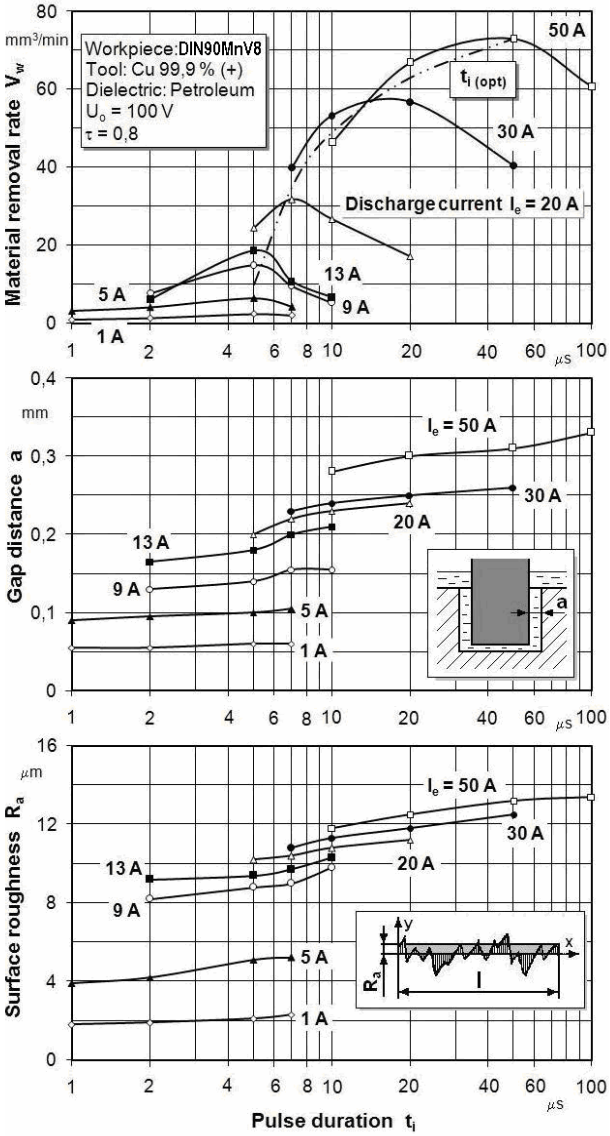

Fig. 3. Dependence of the process quality on the discharge currents and discharge durations

Figure 4 shows the influence of discharge energy on the material removal rate.

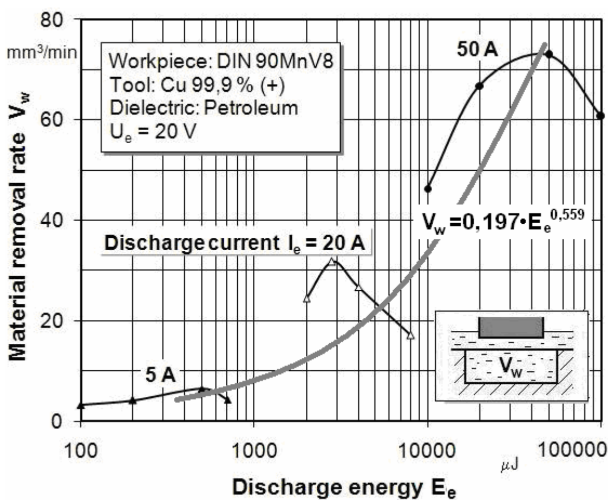

Fig.4. Dependence of the material removal rate on the discharge energy

Shown are comparative results for low, medium, and high discharge current, for copper tool electrode. The diagram shows that the increase of discharge current results in increased discharge energy, which ultimately leads to higher material removal rate. However, for every discharge current there is an optimal value of discharge energy which results in maximum material removal rate. This efficiently precludes us from unambiguous determination of the influence of discharge energy on material removal rate.

Shown in Fig. 5 is the dependence of gap distance on the discharge energy. Somewhat, the increases of discharge current and discharge duration values results in a uniform increase of gap distance. It is evident that the gap distance follows the discharge energy in order to maintain stability of EDM. Otherwise, the deionization of machining are would be affected, which could result in lower productivity. The experimental results confirm the analytical assumptions.

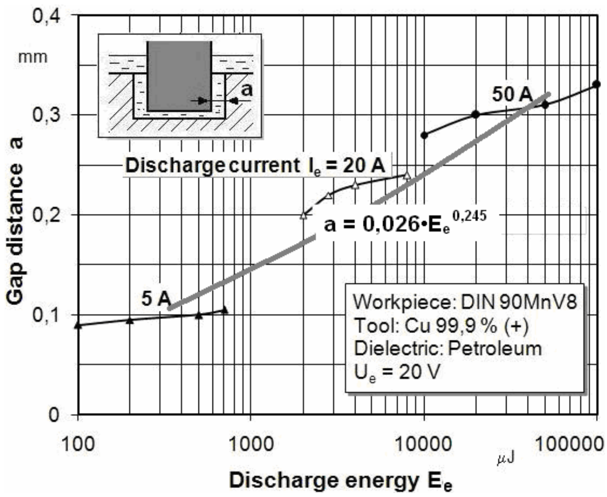

Fig.5. Dependence of the gap distance on the discharge energy

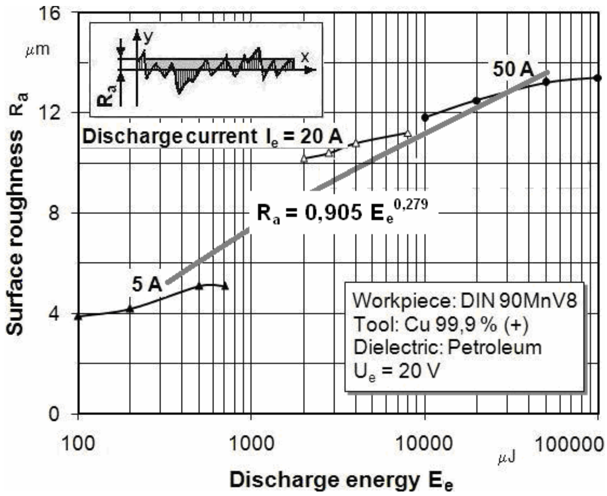

Fig.6. Dependence of the surface roughness on the discharge energy

The relationship between the surface roughness and discharge energy, for various parameters of discharge energy, is shown in Fig. 6. As the discharge energy increases, so do the heat concentration and workpiece surface temperature, which results in larger craters, i.e. greater surface roughness. Moreover, is a slight increase of surface roughness with the discharge duration, while the discharge current has a more pronounced influence on the surface roughness. The machined surface consists of a number of craters of various dimensions, while the roughness is even in all directions.

5. CONCLUSION

The discharge energy is the most important parameter of EDM process. The discharge energy directly depends on the discharge current and the discharge duration. Characteristics of the discharge energy define the technological performances of EDM.

The results of experimental investigation show that, there is an optimal discharge energy which yields maximum material removal rate. The material removal rate increases with the increase of discharge current for an optimal discharge duration. The discharge energy causes uniform increase of gap distance. When the discharge energy is increased the gap distance exerts greater influence on accuracy of EDM. Surface roughness directly depends on the discharge energy. Moreover, the discharge current is more significant than the discharge duration.

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INFLUENCE OF TOOL BALANCING ON MACHINED SURFACE QUALITY IN HIGH SPEED MACHINING

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Abstract: *High speed machining has some differences according to conventional milling. The main difference is higher rotational speed of the spindle (40 000min-1 and higher). During high speed spindle rotations more dynamic forces are rising, which are affecting bearings, frame and the whole machine. The forces are efforting vibrations furthermore causes worse quality of machined surface and may damage the spindle. Minimization of these forces is essential. According to that, the tool balancing machines are used. Tool balancing should provide better mass set out around the tool axis. Two identical tools were balanced according to ISO 1940-1 standard at two different levels. Aluminum plate was used as an experimental part. Both milled surfaces were scanned with3D microscope and surface roughness was evaluated. Results showed High speed machining with balanced tool provided better surface quality than conventional milling as well as worse balanced tool.*
Key words: *Tool balancing, unbalance, high-speed machining,3D microscope, surface quality*

Uticaj balansa alata na kvalitet površine pri visokobrzinskoj obradi. *Visokobrzinska obrada ima nekoliko razlika u odnosu na konvencijalno glodanje. Glavna razlika je visoka rotaciona brzina vretena (40 000 min^{-1} i više). Pri visokom broju obrtaja vretena dinamičke sile rastu, koje utiču na ležajeve, noseću konstrukciju i sam rad mašine. Vibracije nastale podsredstvom dinamičkih sila prouzrokuju lošiji kvalitet obrade i mogu oštetiti vreteno mašine. Minimiziranje sila rezanja je bitno. U tu svrhu koristi se balansiranje alata. Balans alata treba da obezbedi što bolji raspored mase oko definisane ose alata. Dva identična alata izbalansirani su u skladu sa standardnom ISO 1940-1 na dva različita nivoa. Kao obradak koristi se aluminijumska ploča. Dve obrađene površine skenirane su na 3D mikroskopu i merena je hrapavost površine. Rezultati pokazuju da sa izbalansiranim alatima pri visokobrzinskoj obradi obezbeđuju bolji kvalitet površine od konvenialne obrade kao i od lošije izbalansiranog alata.*
Ključne reči: *balans alata, debalans, visokobrzinska obrada, 3D mikroskop, kvalitet površine*

1. INTRODUCTION

The key-stone in high-speed milling is to reach higher surface quality and removal rate with high cutting speed and in the same way reach lower tool wear a lower cutting forces. Large amount of heat generated at the cutting edge is minimally transferred to a material and tool at high-speed milling. In order to reach high surface quality, adequate chip removing rate is an important parameter [1]. By high-speed milling it is possible to achieve surface roughness at level Ra 0, 2 µm [2]. Important parameter affecting achieved surface roughness is run out, caused by unbalance of the tool, tool holder and the spindle. Importance of run out is rising with frequency of spindle rotation, furthermore with rising of centrifugal forces affecting tool in high-speed milling. To verify theoretical knowledge, an experiment was realized.

2. OUT - OF - BALANCE

Unbalance of a rotational part comes from its geometric shape depending on its functionality. Unbalance of parts symmetrical by axe like tools and tool holders are, is caused by inaccuracy of shape and size, non-homogeneity of material, nonsymmetrical parts e.g. clamping screw in some types of tool holders, clamping slot on some tool shanks and run out of a tool holder. Unbalanced tool arrangement can be explained as a rotational part, where momentum central axis is not identical with axis of rotation (Fig.1) [3]. Balancing is a process of mass correction around the central momentum axis by loading or unloading of mass. The aim is to reach identical position of momentum and rotational axis of the tool arrangement as well as it is possible. That preserves dynamic forces

G–level of balancing (*G1,0; G2,5; G6,3*) [ms^{-1}],

m– Tool arrangement weight [kg],

and vibrations in bearings in allowed limits when required rotations are reached [4].

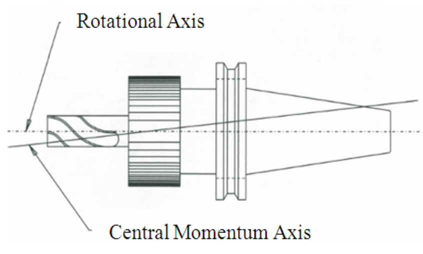

Fig.1. Central momentum axis and rotational axis [5]

2.1 Calculation of unbalance

In High Speed Cutting, the maximum unbalance is characterized in ISO 1940-1 standard. This standard presents levels of G for certain rotational frequencies and rotational parts. For rotational tool arrangements, G level should be at least *2,5 ms*$^{-1}$at maximum spindle rotational speed. According to unbalance G level, rotational speed and tool arrangement weight, maximum allowed unbalance can be calculated as [6]:

$$U_{zv} = \frac{G.9549.m}{n} \quad \text{[gmm]} \quad (1)$$

Where: U_{zv} is remaining unbalance [gmm],
n– Rotational speed [min^{-1}],
9549 – Constant [-].

2.2 Ways of tool arrangement balancing

Ways of tool arrangement balancing can be divided as following:

1. Balancing in one balancing level: static and rotational unbalance.
2. Balancing in two balancing levels: momentum and dynamic unbalance.

Balancing in one balancing level is used when gravity center is out of rotational axis (Fig.2). The aim is to move the gravity center of tool arrangement into rotational axis. When rotational balancing is employed, centrifugal force perpendicular to axis is raising. Rotational unbalance is eliminated in one level; balancing level position is irrelevant in this case. In practice, balancing in one level is enough. It can be said, this is valid for rotational parts, where the ratio of length to diameter is smaller than 0.2 [4].

After balancing in one level, momentum unbalance may remain. In momentum unbalance center of gravity is identic with rotational axis and two unbalances are rotated 180° degrees to each other (Fig.3). This caused vibrations characterized by swinging movement. In order to eliminate the unbalance it is necessary to use momentum with contradictory direction and balancing in two levels.

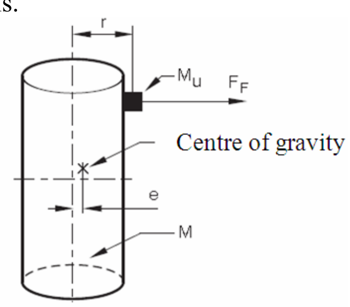

Fig.2. Balancing in one level

M_u unbalance rate [gmm]; r distance of unbalanced mass from rotational axis [mm]; M weight of rotating mass [g];
e distance of gravity center of mass from rotational axis[mm], $C_e$ntrifugal force [N][1]

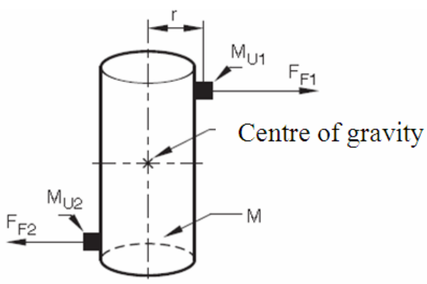

Fig. 3. Balancing in two levels

M_{u1}, M_{u2}unbalance rate [gmm]; r distance of unbalanced mass from rotational axis [mm]; M weight of rotating mass [g]; e distance of gravity centre of mass from rotational axis[mm], F_{F1}, F_{F2} centrifugal force[N]; M_{u1}= M_{u2} ; F_{F1}=F_{F2} [7]

Dynamic unbalance is caused by two unbalances with different angle position. Dynamic unbalance can be divided into static and moment unbalance.

3. EXPERIMENTAL

Experimental part is a plate made of aluminum according to standard EN6061 with dimensions 80 x80 10 mm divided into 3 areas, as is figured out in Fig.4. For experiments DMG Sauer Ultrasonic 20 linear machine tool was used and Seco JV 40 HEMI carbide monolith cutting tools with diameter 8mm. Both tools were clamped into shrink fit holders and the arrangement were balanced by Haimer Tool Dynamic 2009 with G levels according to Table 1.

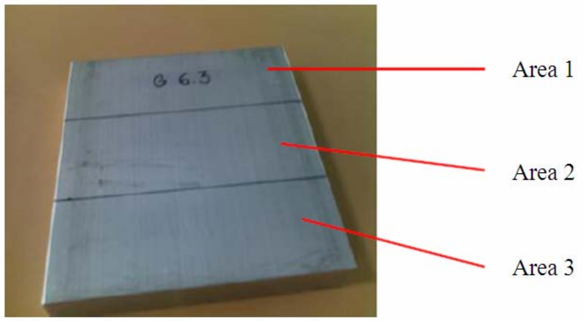

Fig. 4. Experimental part

3.1 Cutting conditions

Stability of cutting process was one of the most important conditions in cutting conditions setup. Feed *fz* was considered as a constant and rotations were selected based upon balance level G and cutting parameters were obtained through analytical calculation (for cutting speed and feed). Selected values for feed velocity and rotations are in Table 2. According to selected cutting parameters and tool diameter, standard ISO 1940-1 were selected for tool balancing. At nowadays machine tools and tool shanks producers start using standard DIN 69888 especially for small diameters and weights of tools, where ISO 1940 -1 standard is not adequate.

Fig. 5. Cutting process on DMG Ultrasonic 20 linear machine tool with balanced tool arrangement by eccentric balancing rings on shrink fit tool holder with HSK 32 adaptor for high-speed milling.

3.2 Experiment realization

Surface of experimental part were divided into three areas, where each of them were machined under different cutting conditions (different rotations and feed velocity) according to a Table 1 with a tool arrangement balanced to a G level of 1.6. The other side of a part was machined under different cutting conditions with tool arrangement balanced to a G level of 6.3. Surface quality of machined surface was analyzed by confocal microscope LSM 700 with ZEISS optics. Results are shown in Table 3; the cutting process is in Fig.5; the output from 3D microscope is shown in Fig. 6.

G 1,6		G 6,3	
Rotations *(min^{-1})*	***Feed vf*** *($mm.\ min^{-1}$)*	***Rotations*** *(min^{-1})*	***Feed vf*** *($mm.min^{-1}$)*
18 000	2016	6 000	672
24 000	2688	12 000	1344
30 000	3360	18 000	2016
Cutting depth ap = 0,5 mm			

Table 1. Cutting conditions

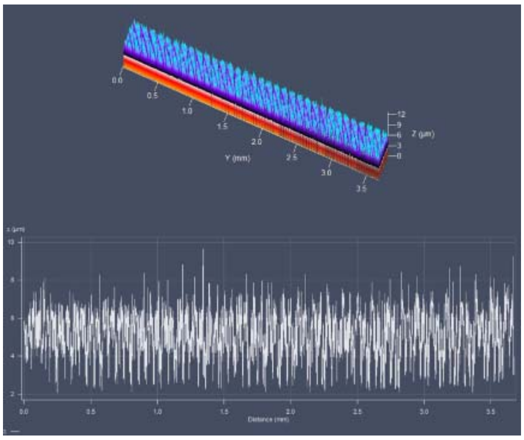

Fig.6. 3D profile map of milled surface with rotations of 18 000 min^{-1}

Surface area		Ra [µm]
G1,6	Area 1. (18 000 min-1)	1,031
	Area 2. (24 000 min-1)	0,945
	Area 3. (30 000 min-1)	0,76
G6,3	Area 4. (6 000 min-1)	0,882
	Area 5. (12 000 min-1)	1,03
	Area 6. (18 000 min-1)	0,979

Table 2. Measured Ra values

4. CONCLUSION

Based upon measured values, shown in Table 2 following charts (Chart 1, Chart 2.) were created for better imagination according to equations written below. For both charts creation, method of ordinary least squares was used. The calculation for experiment with tool arrangement balanced to a G level of 6.3 is as following.

Meas. N.	zi [min-1]	xi	xi2	wi [µm]	yi	xi, yi
1.	*6 000*	*3, 778*	*14, 273*	*0, 882*	*-0, 054*	*-0,204*
2.	*12 000*	*4, 079*	*16, 638*	*1, 031*	*0, 012*	*0, 048*
3.	*18 000*	*4, 255*	*18, 105*	*0, 979*	*-0, 009*	*-0, 038*
Σn = 3	***Σzi = 36000***	***Σxi = 12,11***	***Σxi2 = 49, 016***		***Σyi = -0,051***	***Σ xi . yi = -0,194***

Table 3. Ordinary Least Squares input values for G 6,3

$(\Sigma xi)^2 = 12,1122 = 146,7$; $xi = \log zi$; $yi = \log wi$

Regression coefficients:

$$b_0 = \frac{\Sigma yi.\Sigma xi2 - \Sigma xi.\ \Sigma xi.yi}{n.\ \Sigma xi2 - (\Sigma xi)2} =$$

$$\frac{-0{,}051.49{,}016 - 12{,}112.(-0{,}194)}{3{,}49{,}016 - 146{,}7} = -\ \underline{0,43.}$$

$$b_1 = \frac{n.\ \Sigma xi.yi - \Sigma xi.\ \Sigma yi}{n.\ \Sigma xi2 - (\Sigma xi)2} =$$

$$\frac{3.(-0{,}194) - 12{,}112.(-0{,}051)}{3.49{,}016 - 146{,}7} = \underline{0,101.}$$

$b_0 = \log c \rightarrow$	$c = 10^{b_0}$	$w = c.\ z^k$
	$c = 10^{-0,43}$	$k = b_1$
	$c = 0,37$	$k = 0,101$

Then Ra calculation is as following:

$$w\ (Ra) = c.\ z\ (n)^{0,101} \qquad (2)$$

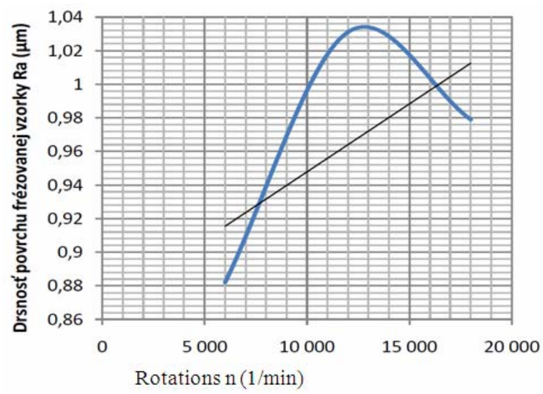

Chart 1. Surface roughness flow on a surface machined with tool balanced to a G level of 6,3

Chart 1 shows relation between surface roughness characterized by Ra and rotations where the G level of balanced tool was 6.3. The chart may be explained as following: surface roughness, represented by Ra was rising until the rotations reached approximately 13 000min^{-1}, since that we can see decreasing of roughness. This effect may be caused by the transformation of cutting conditions from conventional to high speed milling conditions. According to tool manufacturer's recommendations, rotations for selected tool should reach a value of 19890min^{-1}.

The calculation for experiment with tool arrangement balanced to a G level of 1.6 is as following:

Meas. N.	zi [min-1]	xi	xi2	wi [µm]	yi	xi, yi
1.	*18 000*	*4, 255*	*18, 105*	*1, 031*	*0, 013*	*0, 055*
2.	*24 000*	*4, 380*	*19, 184*	*0, 945*	*-0, 024*	*-0, 105*
3.	*30 000*	*4, 477*	*20, 043*	*0, 760*	*-0, 119*	*-0, 532*
Σn = 3	***Σzi = 72 000***	***Σxi = 13, 082***	***Σxi2 = 57, 332***	______	***Σyi = -0 13***	***Σ xi . yi = -0,582***

Table 4. Ordinary Least squares input values for G 1.6

$(\Sigma xi)^2 = 13,0822 = 171,13$; $xi = \log zi$; $yi = \log wi$

Regression coefficients:

$$b_0 = \frac{\Sigma yi.\Sigma xi2 - \Sigma xi.\ \Sigma xi.yi}{n.\ \Sigma xi2 - (\Sigma xi)2} =$$

$$\frac{-0,13.57,332 - 13,082.(-0,582)}{3.57,332 - 171,13} = \underline{0,18}$$

$$b_1 = \frac{n.\ \Sigma xi.yi - \Sigma xi.\ \Sigma yi}{n.\ \Sigma xi2 - (\Sigma xi)2} =$$

$$\frac{3.(-0,582) - 13,082.(-0,13)}{3.57,332 - 171,13} = \underline{-0,05}$$

$b_0 = \log c \rightarrow$ $c = 10^{b_0}$ $w = c.\ z^k$

$c = 10^{0,18}$ $k = b^1$

$c = 1,51$ $k = -0,05$

Then Ra calculation is as following:

$$w\ (Ra) = c.\ z\ (n)^{-0,05} \qquad (3)$$

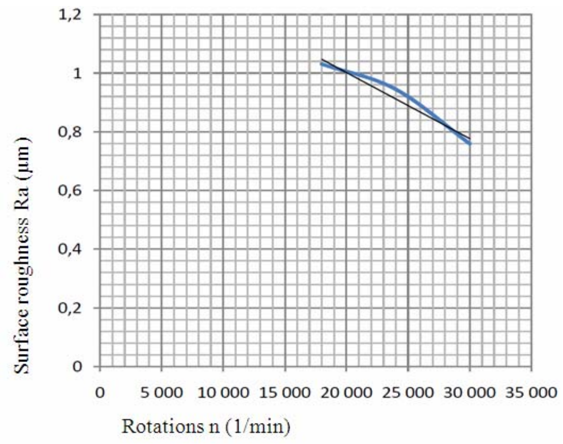

Chart 2. Surface roughness flow on a surface machined with tool balanced to a G level of 1,6

Chart 2 Shows surface roughness flow in High speed milling with tool balanced to a G level of 1.6. Explanation of chart is as following: decreasing of surface roughness is caused by cutting speed rising, where in high speed machining, cutting conditions are changing. In High speed machining various changes are raising especially heat transfer and chip removing, which caused surface roughness declination. Surface quality is one of the most important benefits of high-speed machining.

The influence of tool balancing in possible to evaluate according to a surface roughness characterized by Ra and its relation to rotations at level of 18 000. This rotation speed was used both for G level of 6.3 and G level of 1,6. From Charts 1 and 2 or Table 2 it is clear that better G level provided better surface quality, however the difference at this rotation speed level is not very high. We can assume that the difference of surface roughness will rise with rotation speed. According to a ISO 1940 -1 standard it is not possible to use tool arrangement with balance level G of 6.3 for higher rotational speed like it was used, it will produce high centrifugal and dynamic forces and may cause breakage of spindle bearings or the whole spindle. Due to we can only suppose that surface quality decreasing in relation with rotational speed raising is valid.

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SURFACE ROUGHNESS OF GLASS PARTS WHEN ENGRAVING WITH ABRASIVE AIR JET

Received: 16 March 2011 / Accepted: 17 July 2011

Abstract: *The abrasive jet engraving is based on the effects generated during impact of abrasive particles transported by means of a compressed air jet with surface layer of the machined part. The paper includes some considerations concerning the phenomena able to affect the surface roughness parameters during abrasive jet engraving. An experimental research was developed in order to establish empirical models for the evolution of surface roughness parameters by considering some experimental work conditions (average dimension of the abrasive particles, distance between nozzle and test piece flat surface, angle between the direction of abrasive jet and test piece flat surface).*
Key words: *abrasive jet engraving, surface roughness, empirical model, influence*

Hrapavost površine staklenih delova kada se gravira abrazivnim vazdušnim mlazom. *Graviranje abrazivnim mlazom se zasniva na efektima koji su proizvedeni dejstvom abrazivnih čestica ubrzanih mlazom komprimovanog vazduha na površinski sloj obratka. Rad obuhvata razmatranja fenomena koji utiču na parametre hrapavosti površine tokom graviranja abrazivnim mlazom. Eksperimentalno istraživanje je sprovedeno u cilju uspostavljanja empirijskih modela za razvoj parametara hrapavosti površine, uzimajući u obzir uslove izvođenja eksperimenta (srednja veličina abrazivnih čestica, rastojanje između mlaznice i površine obratka, ugao između pravca abrazivnog mlaza i površine obratka).*
Ključne reči: *graviranje abrazivnim mlazom, hrapavost površine, empirijski model, uticaj*

1. INTRODUCTION

The glass is an amorphous material characterized by a high mechanical resistance and hardness, by brittleness, transparency and low dilatation coefficient. The common glass contains 75% silica (SiO2), Na2O, CaO and several minor additives. For long time, the glass was used especially in windows and drinking vessels; nowadays, the glass is used also in various industrial fields [1,2,3]. The main machining processes applied to glass workpieces are cutting, drilling, and engraving [2,3,4,5]. The engraving could be defined as a machining method which allows the transfer of inscriptions and drawings on parts surfaces. There are many types of engraving methods applied to the glass workpieces, but they could be included in two main groups: chemical methods and cutting methods. The chemical engraving methods use chemical reactions developed on the surfaces which are not protected between the chemical active substances and the glass.

The cutting methods could be materialized by means of solid tools (abrasive wheels or drills, small diamond tipped burrs) or abrasive particles; these last methods could be considered as abrasive jet machining methods.

The abrasive jet engraving uses the effects generated at the contact of the abrasive particles with the workpiece surface layer: if in the case of metallic workpieces this machining method supposes the changing of the surface aspect as result of plastic deformation, microcracking and microcutting effects, in the case of the glass workpiece it is expected that the machined surface aspect changes especially due to the material removal by microcracking effects. Glass engraving is a form of decorative glasswork that involves engraving a glass surface or object.

Adjouadi et al. studied the phenomena of light scattering in the case of glass test pieces eroded by sandblasting; during the experiments, they varied the projected sand mass, the opening of the light beam and the distance sample-receptor [2]. A decrease of the optical transmission from 91.6 to 13 % and an increase of the surface roughness from 0.035 up to 2.27 μm as consequence of the sandblasting process were highlighted. Ismail et al. investigated the erosion phenomenon in glass by experimental research and simulations by finite element method; they highlighted the influence exerted by the particle size and velocity on the material removal in the sandblasting process [3]. The material removal in the case of a single impact was determined by means of a profilometer; the authors appreciated that there is a good correspondence between the results obtained by simulation and by experimental research about the craters sizes.

2. SURFACE ROUGHNESS AT ENGRAVING

It is known that the surface roughness is one of the parameters (together with the shape errors and the waviness) used to define the geometry of a machined surface; there is a convention to consider as roughness the assembly of asperities characterized by a ratio between the wave length and height lower than 50. Many factors exert influence on the roughness parameters of the machined surface; chemical composition and mechanical properties of the workpiece material, sizes of the machining parameters, geometry of cutting tool active part, rigidity of the machining system, presence and type of the cooling liquids etc. On the other hand, nowadays there are many parameters used to characterize the surface roughness of the machined surface; in accordance with the actual standards, some groups of the profile parameters are the following: amplitude parameters which take into consideration the prominences and gaps, amplitude parameters which consider the average ordinate, pitch parameters and hybrid parameters. Each of these parameters could be useful for a certain destination of the machined surface.

When the glass workpieces are sandblasted or engraved by means of the abrasive jet, a certain roughness will characterize the obtained surface and some parts properties (transparency, friction coefficient etc.) will depend on the surfaces roughness; for this reason, it is important to know which is the influence exerted by various factors on the roughness parameters of to the surfaces machined by means of the abrasive jet.

Initially, the abrasive particles directed to the workpiece surface have a kinetic energy W_i:

$$W = \frac{m_p v_i^2}{2}, \quad (1)$$

where m_p is the abrasive particle mass and v_i – the initial speed of the abrasive particle, before the impact.

During the impact of the abrasive particle with the workpiece surface layer, a part of their kinetic energy is transferred to this layer, and transformed in other types of energy. After the impact, the abrasive particle may continue its motion, but with a diminished speed vf. The difference ΔW between the initial kinetic energy and the kinetic energy of the abrasive particle after impact represents the energy which contributed to the development of some specific phenomena in the workpiece surface layer:

$$\Delta W = \frac{m_p \left(v_i - v_f\right)^2}{2}, \quad (2)$$

v_f being the final speed of the abrasive particle.

Generally, as consequence of the abrasive particle impact with the workpiece surface layer, effects of elastic deformation, plastic deformation, microcraking and microcutting could be highlighted.

Due to the high brittleness of the glass, it is expected that the material removal and the changing of the blasted surfaces aspect in comparison with the initial one develop especially as result of the microcracking (fig. 1); if some close microcracks join or the pressure exerted by the abrasive particles is high enough, small particles from the glass workpiece could be removed. The machined surface could be considered as a concatenation of the microcavities resulted by material detaching or of deformed small zones; at the same time, this surface is the result of the statistic distribution of the impact phenomena on the workpiece surface.

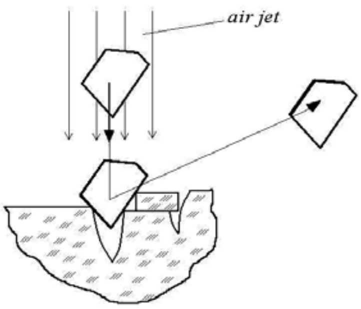

Fig. 1. Phenomena of microcracking and material detaching as result of the engraving process

3. EXPERIMENTAL RESEARCH

In order to verify the validity of the above mentioned hypothesises and to obtain more information concerning the influence exerted by various factors on the roughness of the surface affected by the action of the abrasive jet, some experimental research were designed and developed.

With this aim in view, a common blasting gun (type 650R, Prodif Air comprimé - France) was connected by adequate tubes to a usual compressor (p=0.588 MPa) and to the recipient containing the abrasive particles (sand). In order to determine empirical models able to highlight the influence of some operating parameters on the sizes of the surface roughness parameters, a factorial experiment with three variables at two levels was designed and materialized. A schematical representation of the sandblasting equipement is included in figure 2. Essentially, the sand is absorbed from a recipient by the depression generated in the blasting gun by the circulation of the compressed air. The abrasive particles are directed to the workpiece surface by means of a nozzle. After their impact with the workpiece surface, the abrasive particles arrive in a conical zone of the sandblasting precinct, from which they could be periodically removed.

The average size g of the abrasive particles, the distance h between the nozzle of the sandblasting gun and the flat surface of the workpiece, and the angle α of inclination between the abrasive jet axis and the workpiece flat surface were considered as independent variables. The sizes of the surface roughness parameters were measured by means of a surface roughness meter type Mitutoyo, which allowed the measurement of arithmetic mean deviation of the profile *Ra*, maximum height of the profile *Ry* (determined as sum of height *Yp* of the highest peak from the mean line and depth *Yv* of the deepest valley from the mean line), ten-point height of irregularities *Rz* and root-mean-square deviation of the profile *Rq*. The sizes of the parameters which define the experimental conditions and the experimental results were inscribed in table 1. In the columns 2, 3 and 4 of the table 1, the sizes of the input parameters corresponding to each experiement were included; three sizes of each surface roughness used parameter (*Ra*, *Ry*, *Rz*, *Rq*) were measured. In distinct columns, the average sizes of the surface roughness parameters were mentioned.

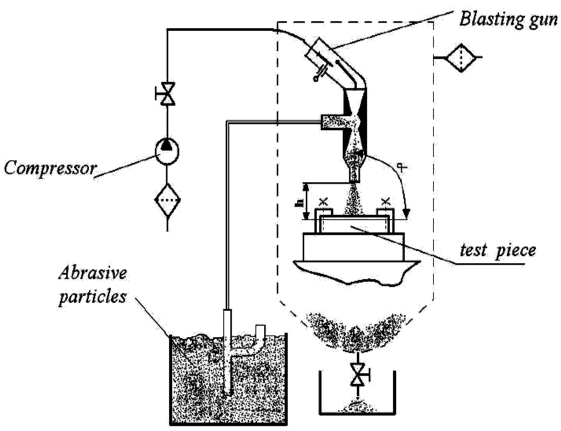

Fig. 2. Schematic representation of the equipment for abrasive jet engraving

The experimental results were matematically processed by means of software based on the method of the last squares [6] and taking into consideration only the average dimensions of the sizes corresponding to each surface roughness parameter. The software allowed establishing the most adequate mathematical relation for the determined experimental data, on the basis of the Gauss's criterion. However, accepting the hypothesis that the considered factors (the average dimension g of the abrasive particles, the distance h and the inclination angle α) exert a monotonous influence (without maximum and minimum points) on the output factors, functions type power were preferred, because these functions offer a direct image on the significance of the influence exerted by each considered factor.

In the above mentioned conditions, the following empirical models were determined:

$$Ra = 3.554 g^{0.392} h^{-0.00473} \alpha^{0.124} \quad (3)$$

$$Ry = 30.884 g^{0.309} h^{0.00217} \alpha^{-0.0559} \quad (4)$$

$$Rz = 21.927 g^{0.334} h^{-0.00809} \alpha^{0.0939} \quad (5)$$

$$Rq = 4.459 g^{0.390} h^{-0.00498} \alpha^{0.120} \quad (6)$$

By examining the empirical models, one may notice that the most important influence exerted on the studied surface roughness parameters corresponds to the average dimension g of the abrasive particles, because the exponents attached to this size have the highest sizes in the empirical models. The second factor able to influence the surface roughness parameters is the angle α of inclination between the axis of the abrasive jet and the flat surface of the workpiece, but this influence is significant only in the cases of the parameters *Ra* and *Rq*. For the other situations, the sizes of the exponents are very low and this fact shows that the considered parameters practically do not exert influence on the surface roughness parameters; this is the situation of the angle α in the case of roughness parameters *Ry* and *Rz* and of the distance h for all four considered surface roughness parameters.

The graphical representation from figure 3 shows the influence exerted by the average dimension g on the surface roughness parameters *Ra*, *Ry*, *Rz* and *Rq*, on

Exp. no.	Input parameters			Surface roughness parameter *Ra*, μm				Surface roughness parameter *Ry*, μm			
	g, mm	*h*, mm	*α*, degrees	Ra_1	Ra_2	Ra_3	Average value for *Ra*, μm	Ry_1	Ry_2	Ry_3	Average value for *Ry*, μm
1	2	3	4	5	6	7	8	9	10	11	12
1	0.35	10	15	3.37	3.93	3.71	3.67	27.05	31.79	28.52	29.120
2	0.35	10	90	4.48	3.83	3.98	4.10	37.87	29.7	29.67	32.413
3	0.35	40	15	2.94	2.91	3	2.95	21.18	27.05	24.54	24.257
4	0.35	40	90	4.2	4.05	3.61	3.95	23.7	24.9	22.43	23.677
5	1.6	10	15	5.59	7.17	4.54	5.77	33.55	44.91	37.87	38.777
6	1.6	10	90	5.81	7.53	7.62	6.99	40.03	40.6	38.04	39.557
7	1.6	40	15	5.86	6.14	5	5.67	38.96	51.99	30.95	40.633
8	1.6	40	90	6.59	8.96	8.44	8.00	55.24	55.45	56.87	55.853
Exp. no.	Input parameters			Surface roughness parameter *Rz*, μm				Surface roughness parameter *Rq*, μm			
	g, mm	*h*, mm	*α*, grade	Rz_1	Rz_2	Rz_3	Average value for *Rz*, μm	Rq_1	Rq_2	Rq_3	Average value for *Rq*, μm
1				21.06	22.42	22.92	22.13	4.31	4.79	4.74	4.61
2	0.35	10	15	24.64	23.42	24.2	24.09	5.44	4.86	4.96	5.09
3	0.35	10	90	17.68	18.73	17.62	18.01	3.68	3.68	3.74	3.70
4	0.35	40	15	20.99	22.5	18.82	20.77	5.05	4.9	4.31	4.75
5	0.35	40	90	29.6	36.32	25.61	30.51	6.82	8.55	5.6	6.99
6	1.6	10	15	36.41	37.96	35.43	36.60	7.94	9.26	9.14	8.78
7	1.6	10	90	31.89	33.74	24.56	30.06	7.28	7.79	5.98	7.02
8	1.6	40	15	40.21	43.32	42.98	42.17	8.54	10.62	10.27	9.81

Table 1. Experimental conditions and results

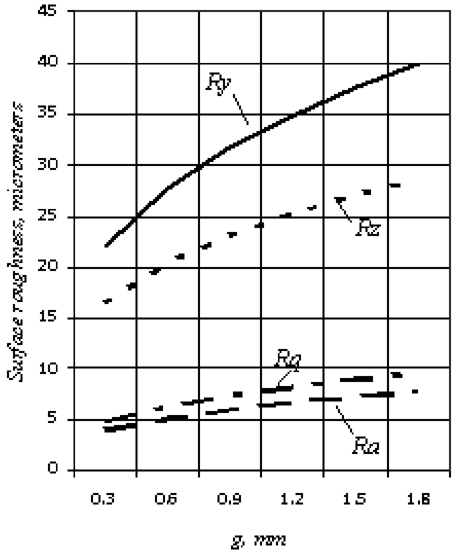

Fig. 3. Influence exerted by the average dimension of the abrasive particles on the sizes of the surface roughness parameters

taking into consideration the empirical relations (3), (4), (5) and (6).

To better highlight the change of the surface profile as consequence of the sandblasting process, the profilogram from the figure 4 can be used; in this profilogram, the left zone correspond to the blasted surface, while the right zone represents the surface which was not affected by the blasting process.

4. CONCLUSIONS

The study of glass parts sandblasting could highlight either the resistance of the glass parts at erosion process or the change of the optical properties of these parts. Essentially, during the process of glass sandblasting, the material removing develops as consequence of microcracking phenomena. The roughness of the surfaces affected by sandblasting process depends essentially on the abrasive particles and workpiece material properties, on the operating parameters, on the parameters which characterize the compressed air circulation. Some theoretical considerations were formulated about the developing of the glass sandblasting process. A factorial experiment with three variables at two levels allowed the establishing of some empirical relations type power which show the influence exerted by the average dimension of the abrasive particles, the distance between the nozzle of the sandblasting gun and the flat surface of the test piece and by the angle of inclination between the abrasive jet axis and the same flat surface of the workpiece on the surface roughness parameters *Ra*, *Rz*, *Ry* and *Rq*. In the future, there is the intention to extend the investigation of the influence exerted also by other factors on the parts surface layers properties as result of applying the sandblasting process.

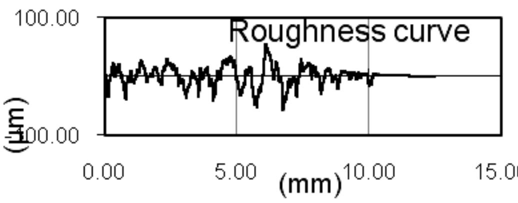

Fig. 4. Roughness profile for the initial surface (right) and the sandblasted surface (left) of the glass part

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FRICTIONAL WORK IN ORTHOGONAL CUTTING - RELATIONS OF FRICTIONAL WORK BETWEEN THE CONTACT SURFACES OF CUTTING TOOL AND CHIP AND MACHINED SURFACES

Received: 23 October 2011 / Accepted: 17 January 2012

Abstract: *This paper presents the approach to determine the relation of frictional work on the contact surfaces, face surface – chip and flank surface – machined surface, and the necessarily work which caused the formation of chip. The frictional work on the contact between cutting tool and chip and machined surface in relation to work performed formation of chip points out very important role of friction in the total balance of energy consumed in the cutting process and that the frictional work on the flank and machined surface is considerable and cannot be ignored.*
Key words: *orthogonal cutting, face surface, flank surface, machined surface, frictional work*

Rad trenja pri ortogonalnom rezanju – odnosi radova trenja na kontaktnim površinama reznog alata i strugotine i obrađene površine. *U ovom radu je prikazan pristup određivanja zavisnosti trenja između dodirnih površina, grudne površine alata – strugotine kao i leđne površine alata – obrađene površine obratka, i neophodnih procesa koji dovode do formiranja strugotine. Tribološki procesi između reznog alata, strugotine i obrađene površine u zavisnosti od izvedenog rada, formiranje strugotine naglašava veoma važnu ulogu trenja u ukupnom balansu utrošene energije tokom procesa rezanja kao i činjenicu da su tribološki procesi između leđne površine alata i obrađene površine obratka pozamašni i ne mogu se zanemarivati.*
Ključne reči: *ortogonalno rezanje, grudna površina, leđna površina, obrađena površina, rad trenja*

1. INTRODUCTION

The total mechanical work which is invested in the cutting process can be approximatly expressed as a sum [1]

$$A = A_p + A_e + A_t + A_d \tag{1}$$

where A_p is a work necesary for plastic deformation, A_e work necesary for elaslc deformation, A_t, work spent for friction and A_d dispersion work.

When machining the plastic materials dispersion and elastic deformation works can be neglected, so that we will consider the total work to be

$$A = A_p + A_t;\ A_e = 0;\ \ A_d = 0 \tag{2}$$

From Fig. 1 follow [1, 2, 3, 4, 5]

$$F_1' = F_R' \cos(\rho - \gamma) \tag{3}$$

and

$$F_N' = F_R' \cos \rho \tag{4}$$

the normal component F_N', in function of tangential components F_1' can be determined by elimination of result force F_R' from (5) and (6)

$$F_N = F_1' \frac{\cos \rho}{\cos(\rho - \gamma)} \tag{5}$$

In order to determine the values of particular adenda in (2) we will start with the total cuttlng work and the frictional work.

The frictional work is expresed as a sum

$$A_t = A_t' + A_t'' \tag{6}$$

where A_t' is the frictional work on the contact between face and chip and A_t'' is the frictional work on the contact between flank and machined surfaces [6].

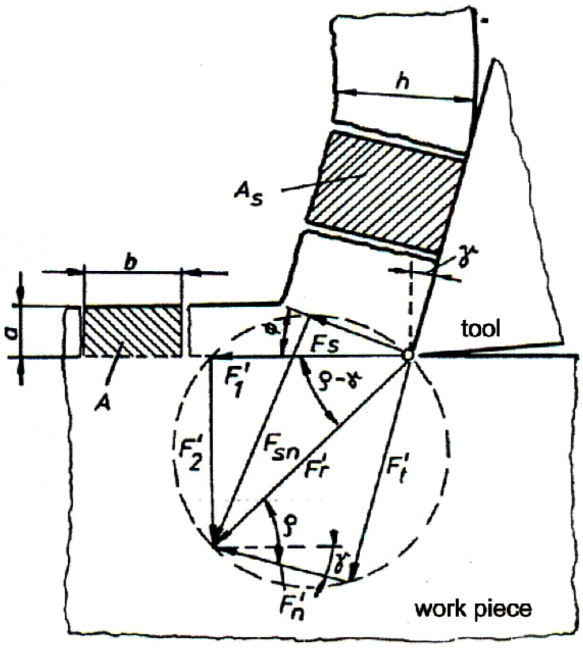

Fig. 1. Normal and tangential forces during process of cutting

2. FRICTIONAL WORK ON THE CONTACT BETWEEN FACE AND CHIP

If we neglect, as a first approximation, the frictional work on the contact between flank and machined surfaces, the total frictional work will be equal to the frictional work on the face, e.g.

$$A_t = A_t' + A_t'' \tag{7}$$

Frictional work on the face is [1, 3, 4, 7]

$$A_t = \mu F_N \cdot v_{st} \tag{8}$$

the chip compression factor can be presented by ratio

$$\lambda = \frac{v}{v_{st}} \tag{9}$$

and supstitution (7) and (9) for frictional work we have

$$A_t' = \mu \cdot F_1' \cdot \frac{\cos\rho}{\cos(\rho-\gamma)} \tag{10}$$

The value of the coefficent of friction μ can be determined from the K r o n e n b e r ' s dynamic equation [5, 8, 9]

$$\lambda = \exp\cdot \mu \cdot \left(\frac{\pi}{2} - \gamma\right) \tag{11}$$

i.e

$$tg\rho = \mu = \frac{\ln\lambda}{\frac{\pi}{2} - \gamma} \tag{12}$$

so that friction angle

$$\rho = arctg\frac{\ln\lambda}{\frac{\pi}{2} - \gamma} \tag{13}$$

The work needed for the formation of chip is

$$A' = F_t' \, v \tag{14}$$

and, referring to (5), (6) and (8) we obtain the ratio between the frictional work on the contact between the face and the chip and the work needed for the formation of chip as

$$\frac{A_t'}{A'} = \frac{\mu}{\lambda} \cdot \frac{\cos\rho}{\cos(\rho-\gamma)} = f(\lambda,\gamma) \tag{15}$$

Consequently, for certain values of the chip compression factor λ and the rake angle λ the ratio A_t/A_t' can be giving the frictional work on the contact between the face and chip expressed as the percentage of the work needed for the formation of chip

$$A_t' = \frac{A_t'}{A'} \cdot 100\% \tag{16}$$

The values of friction f(λ, γ), for real values of chip compresion factor λ and rake angle γ, in table 1, are given.

For easily analysis of relationship (15), the graphics

$$\frac{A_t'}{A'} = F_1(\lambda);\ \gamma_i = const.$$

and

$$\frac{A_t'}{A'} = F_2(\lambda);\ \gamma_i = const.$$

were drawn and presented on Fig. 2 and Fig. 3.

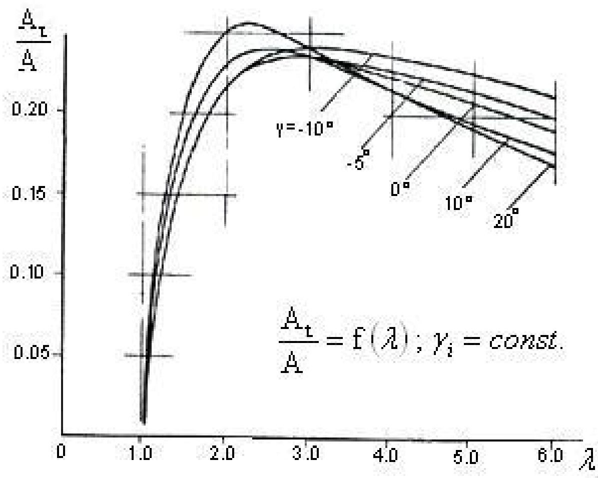

Fig. 2 Correlation of A_t', A' and F (λ)

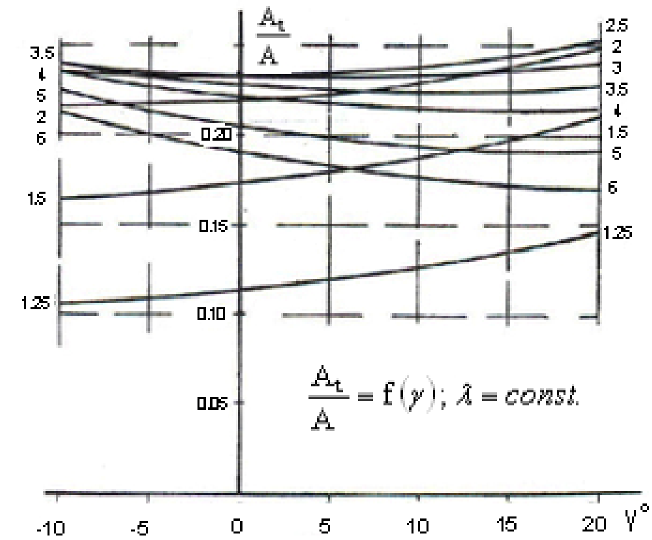

Fig. 3. Correlation of A_t', A' and F (γ)

On the bases of formula (9) the conclusion can be drown that the value of the chip compression factor λ and the rake angle γ have a considerable impact on the ratio of the frictoonal work on the contact between the face and chip and the work needed for the formation of chip.

3. THE FRICTIONAL WORK ON THE CONTACT BETWEEN THE FLANK AND MACHINED SURFACES

The frictional force between the flank and machined surfaces is determined by using the formula [10, 11, 12, 13]

$F_t'' = \tau_{sr}\, b\, \Delta$ (17)

where τ_{sr} mean tangential stress on contacts area between flank and machined surface, b active cutting edge lenght and Δ contact lenght on flank area.

How, on the research basis, distribution of tangential stress on the contact area of flank and machined surface can be described by triangle distribuion (Fig.4) in form [10, 12]

λ	γ^0						
$\frac{A_t'}{A'} = \frac{\mu}{\lambda}\cdot\frac{\cos\rho}{\cos(\rho-\gamma)} = f(\lambda,\gamma)$	-10	-5	0	5	10	15	20
1,01	0,00574	0,00597	0,00627	0,00666	0,00716	0,00778	0,00856
1,25	0,10625	0,10936	0,11365	0,11922	0,12627	0,13502	0,14580
1,50	0,16398	0,16723	0,17208	0,17863	0,18701	0,19740	0,21008
2,00	0,21682	0,21779	0,22064	0,22530	0,23176	0,24004	0,25021
2,50	0,23499	0,23317	0,23333	0,23529	0,23890	0,24409	0,25079
3,00	0,23966	0,23525	0,23313	0,23271	0,23387	0,23645	0,24032
3,50	0,23842	0,23204	0,22787	0,22553	0,22475	0,22531	0,22704
4,00	0,23447	0,22638	0,22064	0,21678	0,21449	0,21351	0,21365
5,00	0,22364	0,21296	0,20492	0,19892	0,19455	0,19149	0,18951
6,00	0,21214	0,19967	0,19011	0,18275	0,17710	0,17280	0,16959

Table 1. The values of friction f (λ, γ), for real values of chip compresion factor λ and rake angle γ

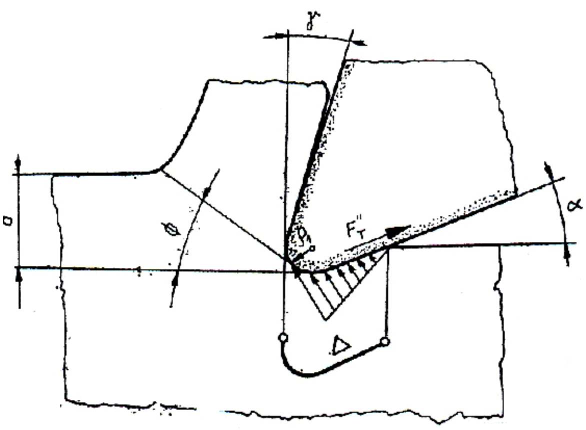

Fig. 4. Triangle distribution of tangential stress on the contact area of flank and machined surface

$$\tau = \tau_p \cdot \left(1 - \frac{x}{\Delta}\right) \quad (18)$$

the mean value of tangential stress contact area between flank and machined surface is

$\tau_{sr} = 0{,}5\ \tau_p$ (19)

here τ_p is material resistance by plastic shear. The contact lenght on flank area can be determined by formula (14)

$$\Delta \cong 1.25\cdot\rho_1\cdot\sqrt{\frac{1}{ctg\phi\cdot\sin\alpha}} \quad (20)$$

where ρ_1 round radius of cutting edge and α clereanse angle of cutting tool [14].

After supstitution (18), (19) and (20) in (17), from frictional force between flank and machined surface we have

$$F_t'' \cong 0.625\cdot\tau_p\cdot\rho_1\cdot b\cdot\sqrt{\frac{1}{ctg\phi\cdot\sin\alpha}} \quad (21)$$

The frictional work on the contact between the flank and machined surfaces is

$A_t'' = F_t'' \cos\alpha\, v$ (22)

with the respect of equation (21)

$$A_t'' \cong 0.625\cdot\tau_p\cdot\rho_1\cdot b\cdot\sqrt{\frac{1}{ctg\phi\cdot\sin\alpha}}\cdot\cos\alpha\cdot v \quad (23)$$

The ratio of the frictional work on the contact between the flank and machined surfaces and the frictional work on the face can be expressed as

$$\frac{A_t''}{A_t'} = \frac{A_t''}{\left(\frac{A_t''}{A'}\right)\cdot A''} \quad (24)$$

e.g. after substituting (12) and (9) into (13) we obtain

$$\frac{A_t''}{A_t'} = \frac{0.625\cdot\tau_p\cdot\rho_1\cdot b\cdot\sqrt{\frac{1}{ctg\phi\cdot\sin\alpha}}\cdot\cos\alpha\cdot v}{\frac{\mu}{\lambda}\cdot\frac{\cos\rho}{\cos(\rho-\gamma)}\cdot F_1'} \quad (25)$$

How is from Fig. 1

$F_S = F_R' \cos(\Phi + \rho - \gamma)$ (26)

and

$F_1' = F_R' \cos(\rho - \gamma)$ (27)

By elimination F_R' from (26) and (27) we have

$$F_1' = F_s\cdot\frac{\cos(\rho-\gamma)}{\cos(\phi+\rho-\gamma)} \quad (28)$$

By respect of

$F_S = \tau_p\, A_s$ (29)

and shear area

$$A_s = \frac{ab}{\sin\phi} \quad (30)$$

taken in respect previously formulas (28) and (29) we have

$$F_1 = a \cdot b \cdot \frac{\tau_p}{\sin\phi} \cdot \frac{\cos(\rho-\gamma)}{\cos(\phi+\rho-\gamma)} \quad (31)$$

By substituting (15) into (14) we obtain the formula for the ratio of frictional work on the flank and face

$$\frac{A_t^{''}}{A_t^{'}} = \frac{0.625 \cdot \rho_1 \cdot \cos\alpha \cdot \sin\phi \cdot \cos(\phi+\rho-\gamma) \cdot \lambda}{a \cdot \mu \cdot \cos\rho\sqrt{ctg\phi \cdot \sin\alpha}} \quad (32)$$

The value of the shear angle Φ can be determined from the formula for the chip comoression factor [1, 2, 3, 4, 5, 9, 12, 13]

$$\lambda = \frac{\cos(\phi - \gamma)}{\sin\phi} \quad (33)$$

from which after development *cos*(Φ – γ) for shear angle we have

$$\phi = arc\,ctg\frac{\lambda - \sin\gamma}{\cos\gamma} \quad (34)$$

and the value of the friction angle ρ is calculated by using the formula (7).

The ratio between the fractional work on the contact of flank and machined surfaces and the frictional work across the face is. according to (7) and (18)

$$\frac{A_t^{''}}{A_t^{'}} = \varphi(\gamma, \alpha, \rho_1, a, \lambda) \quad (35)$$

For in advance adapted values clereance angle α round radius ρ_1 and depth of cut a, favourable is the elements of relationship (32) group in three parts

$$\frac{A_t^{''}}{A_t^{'}} = \frac{\rho_1}{a} \cdot \frac{\sin\phi \cdot \cos(\phi+\rho-\gamma) \cdot \lambda}{\mu \cdot \cos\rho\sqrt{ctg\phi}} \cdot \frac{0.625 \cdot \cos\alpha}{\sqrt{\sin\alpha}} \quad (36)$$

i.e

$$\frac{A_t^{''}}{A_t^{'}} = \frac{\rho_1}{a} \cdot \varphi_1(\gamma, \lambda) \cdot \varphi_2(\alpha) \quad (37)$$

$$\varphi_1(\lambda, \gamma) = \frac{\sin\phi \cdot \cos(\phi+\rho-\gamma) \cdot \lambda}{a \cdot \mu \cdot \cos\rho\sqrt{ctg\phi}}$$

λ	γ°						
	-10	-5	0	5	10	15	20
1,01	66,31420	72,71804	78,82412	84,52360	89,71000	94,28006	98,13424
1,05	13,46382	14,75934	15,98801	17,12605	18,14991	19,03639	19,76264
1,10	6,85248	7,50957	8,12897	8,69764	9,20261	9,63096	9,96987
1,20	3,53925	3,87729	4,19261	4,47774	4,72521	4,92761	5,07759
1,25	2,87389	3,14816	3,40285	3,63166	3,82828	3,98649	4,10015
1,50	1,53198	1,67890	1,81303	1,93055	2,02772	2,10095	2,14687
2,00	0,84094	0,92431	0,99910	1,06293	1,11356	1,14897	1,16738
2,50	0,59919	0,66128	0,71658	0,76327	0,79966	0,82430	0,83596
3,00	0,47288	0,52417	0,56974	0,60806	0,63773	0,65758	0,66666
3,50	0,39408	0,43876	0,47844	0,51178	0,53756	0,55478	0,56264
4,00	0,33973	0,37988	0,41557	0,44558	0,46882	0,48439	0,49159
5,00	0,26889	0,30315	0,33369	0,35946	0,37953	0,39313	0,39971
6,00	0,22425	0,25475	0,28203	0,30515	0,32328	0,33574	0,34202

Table 2. Function values of φ_1 (γ, λ) for diferent values of rake angles and chip compression factor

$$\varphi_2(\alpha) = \frac{0.625 \cdot \cos\alpha}{\sqrt{\sin\alpha}}$$

α°	2	6	10	14	18
φ_2	3,346	1,933	1,500	1,271	1,124

Table 3. Function values of φ_2 (α) for diferent values of rake angles and clereance angles

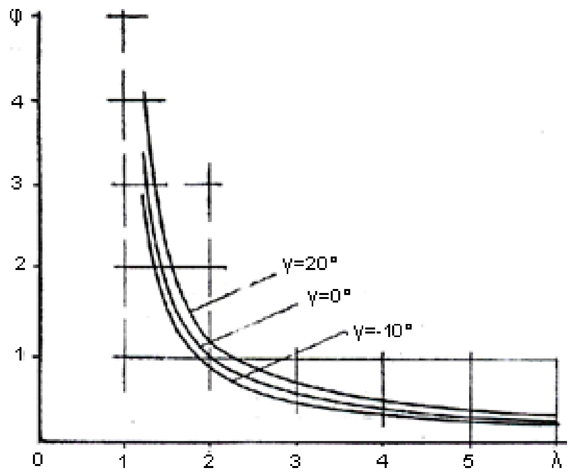

Fig. 5. Diagram for $[\varphi_1(\gamma,\lambda)] = \psi_1(\lambda)$; $\gamma_i = const$

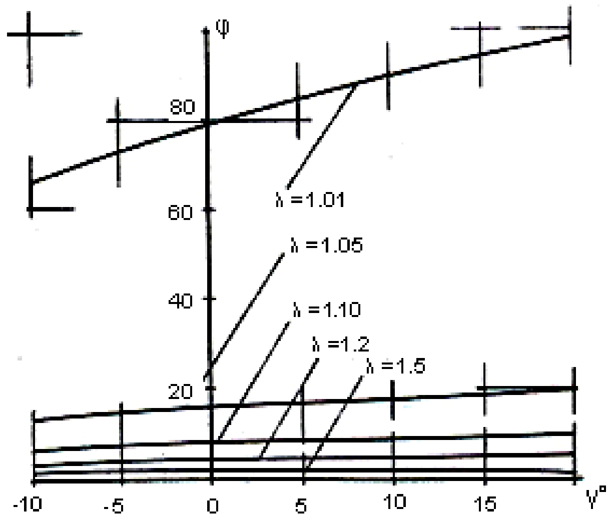

Fig. 6. $[\varphi_1(\gamma,\lambda)] = \psi_2(\lambda)$; $\lambda_i = const$

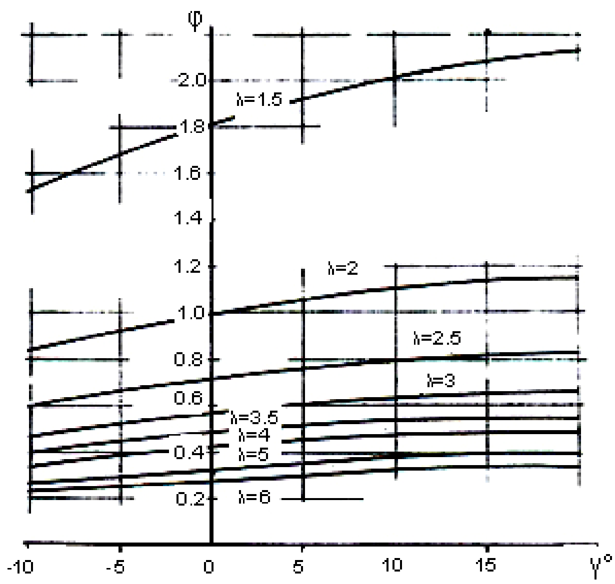

Fig. 7. $[\varphi_1(\gamma,\lambda)] = \psi_2(\lambda)$; $\lambda_i = const$

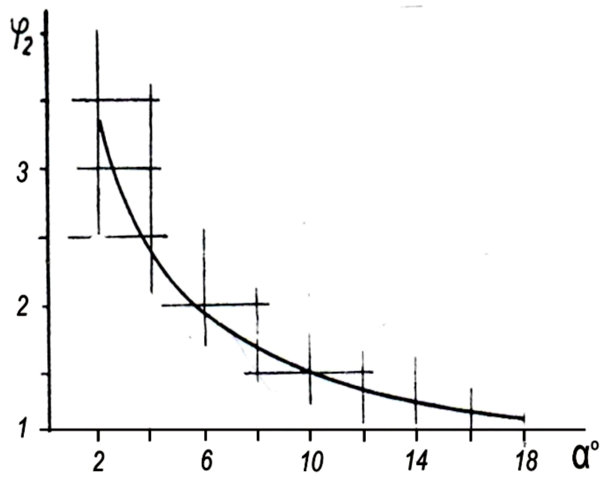

Fig. 8. Diagram for $\varphi_{2} = \psi_3(\alpha)$

Function values of $\varphi_1(\gamma,\lambda)$ and $\varphi_2(\alpha)$ for diferent values of rake angles, chip compression factor and clereance angles in tables 2 and 3 are given. In aim og lighter analysis relationship (37) the graphics

$$[\varphi_1(\gamma,\lambda)] = \psi_1(\lambda)\ ;\ \gamma_i = const$$

and

$$[\varphi_1(\gamma,\lambda)] = \psi_2(\lambda)\ ;\ \lambda_i = const$$

are drawn, presented on Fig. 5, 6 and 7, and diagrams $\varphi_{2} = \psi_3(\alpha)$ on Fig. 8.

Thus, ratio frictional work between clearance and machined surface and frictional work on face area, on the basis of relationship (37), for adapted values, on the basis of dates from corresponding tables and diagrams can be determined.

4. THE FRICTIONAL WORK ON FACE AND FLANK AREAS

The frictional work on the contact surfaces across the face and flank surfaces is easily determined on the basis of before mentioned, as a sum

$$A_t = A_t' + A_t'' \tag{38}$$

Dividing both sides of the above equation by the value of the work needed for the formation of chip A' gives to

$$\frac{A_t}{A'} = \frac{A_t'}{A'} + \frac{A_t''}{A'}$$

After multiplying the second term of the right side by $A_t'/A_t' = 1$ we obtain

$$\frac{A_t}{A'} = \frac{A_t'}{A'} + \frac{A_t''}{A'} \cdot \frac{A_t'}{A_t'}$$

so

$$\frac{A_t}{A_t'} = \frac{A_t'}{A_t'} \cdot \left(1 + \frac{A_t''}{A_t'}\right) \tag{39}$$

The term in brackets on the right side of the equation (20) describes the increase of the ratio of the friction work across the face and the work needed for the formation of chip becouse of the existence of friction on the contact surfaces between the flank end machined surfaces.

Since the ratios, A_t'/A and A_t''/A_t are known, ths ratio of the frictlonal work between the flank and machined surfaces A_t'' and the work needed for chip formation A' can be easily determined, because

$$\frac{A_t''}{A_t'} = \frac{A_t''}{A'} \cdot \frac{A_t'}{A_t'} = \frac{A_t''}{A_t'} \cdot \frac{A_t''}{A'} \qquad (40)$$

Example: For the depth of.cut a = 0,5 mm, the cuttlng tool with rake and clearance angles respectively $\gamma = 5°$ and $\alpha = 6°$, as well as the radius of roundness of the cutting edge $\rho_1 = 0{,}02$ mm and the chip compression factor $\lambda = 2{,}5$.

Based on the formulas (6) and (7) we have

$\mu = tg\ \rho = \ln \cdot \lambda / (\pi/2 - \gamma) = \ln 2{,}5/(\pi/2 - 5/57{,}3) = 0{,}61764$

e.g.

$$\rho = arc\ tg\ \mu = arc\ tg\ 0{,}61764 = 31°\ 42'$$

and from the equation (9)

$$A_t'/A' = 0{,}23529$$

From the formula (18) is

$$\Phi = arc\ ctg\ (2{,}5 - \sin 5°) / \cos 5° = 22°\ 26'$$

so that from expresion (16) it follows that

$$A_t''/A_t' = 0{,}059016$$

And formulas (20) and (21) give

$$A_t/A' = 0{,}23529\ (1 + 0{,}059016) = 0{,}249176$$

$$A_t''/A' = 0{,}059016 \cdot 0{,}23529 = 0{,}013865$$

so we conclude that in the above example the total frictional work is 24,9 % the frictional work on the contact across the face and chip 23,5 % the frictional work across flank and machined surfaces 1,4 %, of the work needed for the chip formation, e.g. 5,92 of the work which is spent for friction between chip and face surfaces

5. CONCLUSIONS

On the basis of before mentioned the following conclusions can be drawn:

- the methodology developed enables determining the ratios of friction work on the contact surfaces on the flank and face surfaces and the ratio between the friction work across the face and flank surfaces and the work needed for the chip formation,
- the friction work on the contact surfaces is considerable compared with the friction work between the face and the chip and cannot be neglected,
- the friction work on the contact surfaces across the face and flank surfaces and the work needed for the formation of chip points to the considerable inpact of friction in the total energy balance in the cutting process and,the ratio of the friction work on the flank and face surfaces is proportional to the ratio of the roundness radius of the cutting edge and the depth of cut.

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THE ADEQUATE TYPE OF FUNCTION FOR MODELING TOOL LIFE SELECTION BY THE USE OF GENETIC ALGORITHMS

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Abstract: *In this paper comparison between three types of functions for predicting tool life modeling is presented. Genetic algorithms as a means for optimizing those functions are used. Most accurate results obtained were when power function was used. Although it was most time consuming, it still is justified because obtained results are far more precise.*
Key words: *tool life, genetic algorithms, power function*

Određivanje adekvatne funkcije za modeliranje postojanosti alata pomoću genetskih algoritama *U ovom radu je prikazano poređenje tri tipa funkcija predviđanja postojanosti reznog alata. Genetski algoritmi su korišćeni prilikom optimizacija tih funkcija. Najtačniji rezultati su bili generisani korišćenjem stepene funkcije. Iako je vremenski najzahtevnija, ipak bi trebala biti izbor broj jedan zbog neuporedivo veće tačnosti.*
Ključne reči: *postojanost alata, genetski algoritmi, stepena funkcija*

1. INTRODUCTION

Industry is making huge leaps forward on daily basis. Increasing demands putted are on precision, productivity and economy of process. Competition on market is unforgiving and sometimes not fair. Not only competition is putting pressure on producing companies but also so are buyers. To an average buyer, everything counts design, functionality, accuracy, time of delivery and most of all prices. If a company wants to meet all this requirements, it has to rationalize on every step during technological process. Extra expenses cannot be tolerated because it could turn out to be devastating regarding companies business. Cutting corners is present almost in every company on every step. Some of these made in right direction, for example learning to think on long runs or decreasing production times, but unfortunately, some of them made in wrong direction. Few of these examples could be: employing under qualified staff, buying materials that does not meet standards or basing working environment on non-human conditions. This article presents one use of artificial intelligence for cutting tool life prediction. Comparison of results presented for three types of modeling tool life. By being able to predict precisely tool life one can optimize cutting parameters and in that way increase efficiency of production, which will consequently lead to more competitive final product.

2. PREVIOUS WORK

Various scientists manage to implement successfully genetic algorithms in a problem solving area as modeling of tool life technique in milling process [1]. Čuš & Balić [2] used genetic algorithms for optimization of cutting parameters in milling process by classical binary encoding. Real coded genetic algorithms for optimization of parameters in turning process used [3]. By the use of genetic algorithms [4] build a flexible manufacturing system. With statistical approach, by the use of response surface method, [5] modeled tool life in face milling. Taguchi’s design of experiment and artificial neural networks used to for tool life prediction in face milling and reported positive experience with both techniques [6]. In addition, a review paper [7] presents the use of artificial intelligence in tool monitoring systems.

3. MODELING FUNCTION

In the paper genetic algorithms used to, as a means for modeling tool life. Genetic algorithms present a powerful tool for space search. They are well known for theirs ability to find a global minimum for functions that otherwise would be impossible. They belong to a group of evolutionary algorithms. All these have one thing in common and that is that all they inspired by nature. Because of that, most expressions and terms were taken from biology as a science.

3.1 Genetic algorithms

Genetic algorithms were widely spread after popularization by a scientist John Holland in seventies, last century. Since they inspired by nature, way of finding minimum for given function is very simple; take two individuals with high fitness, mate them and most probably that you will produce an offspring with same or higher fitness. Almost like every principle found in nature, is simple yet surprisingly effective. This is the reason why this type of artificial intelligence selected. For purpose reviewed in this article, it doesn’t require much computational power nor time. It could easily were implemented in production sphere where it could save considerate amount of resources.

3.2 Tool life

For modeling of tool life, three different four factorial functions used:

$$T = C \cdot e^{x_1 \cdot v + x_2 \cdot f_t + x_3 \cdot a + x_4 \cdot VB} \quad (1)$$

$$T = C + x_1 \cdot v + x_2 \cdot f_t + x_3 \cdot a + x_4 \cdot VB \quad (2)$$

and

$$T = C \cdot v^{x_1} \cdot f_t^{x_2} \cdot a^{x_3} \cdot VB^{x_4} \quad (3)$$

In further text, function (1) is known as exponential, function (2) as linear and function (3) as power function.

Process of tool life modeling consist of finding coefficients C, x_1, x_2, x_3, and x_4 for which modeled tool life will be as close as possible to experimentally obtained values. In other words, every individual will consist of these five, real numbered values.

3.3. Fitness function

In order to be able to simulate "survival of the fittest" one must have a quantitative measure of every individual's success rate. This quantitative measure provided by fitness function. In this case, it was defined as a sum of absolute deviations for modeled values and experimentally measured values of tool life. Mathematical presentation of fitness function is:

$$\Delta(j) = \sum_{i=1}^{25} \left| 1 - \frac{M(i,j)}{P(i)} \right| \times 100\% \quad (4)$$

where M(i,j) is modeled value of tool life for i-th parameters combination and j-th individual, and P(i) is experimentally measured tool life for same parameters combination.

4. EXPERIMENT

Experiment was performed on a 14-kW vertical milling machine without cooling fluid. Milling cutter of 125 mm diameter, and a single carbide P 25 insert SPAN 12 03 ER was used as a tool. The working material was a block of 100x120x600 mm of steel AISI 1060 and was fixed on milling machine table [8]. In experiment, following parameters were varied: cutting speed *v* [m/s], respectively number of revolution on machine *n* [^{o}/min], feed per tooth f_t [mm/t], respectively corresponding feed rate *f* [mm/min], depth of cut *a* [mm] and width of flank wear *VB* [mm]. For each variation of mentioned parameters, tool life *T* [min] was obtained. Results of experiment are shown in Table 1.

No.	*v* [m/s]	f_t [mm/t]	*a* [mm]	*VB* [mm]	*T* [min]
1	2.32	0.178	1	0.12	8
2	3.67	0.178	1	0.12	6
3	2.32	0.28	1	0.12	9
4	3.67	0.28	1	0.12	2
5	2.32	0.178	2.25	0.12	8
6	3.67	0.178	2.25	0.12	5.2
7	2.32	0.28	2.25	0.12	7
8	3.67	0.28	2.25	0.12	4
9	2.32	0.178	1	0.28	42
10	3.67	0.178	1	0.28	16.6
11	2.32	0.28	1	0.28	30
12	3.67	0.28	1	0.28	9.2
13	2.32	0.178	2.25	0.28	43.5
14	3.67	0.178	2.25	0.28	18.5
15	2.32	0.28	2.25	0.28	32
16	3.67	0.28	2.25	0.28	6.5
17	2.95	0.223	1.5	0.18	13.3
18	1.83	0.223	1.5	0.18	20
19	4.65	0.223	1.5	0.18	3.2
20	2.95	0.142	1.5	0.18	13
21	2.95	0.351	1.5	0.18	7
22	2.95	0.223	0.67	0.18	14
23	2.95	0.223	3.37	0.18	13
24	2.95	0.223	1.5	0.08	2
25	2.95	0.223	1.5	0.4	28

Table 1. Experimentally gathered data

5. PRACTICAL REALIZATION

For practical realization of problem, software Matlab was used.

In first generation 50 individuals, with their values between 0 and 1, were randomly created. Afterwards they were ranked from highest to lowest by fitness value, and with roulette wheel method selected in the mating pool. Two of highest ranked individuals were automatically moved to next generation. This act is called elitism and it enables preservation of best genetic material. By crossover of two parents in the mating pool, 43 off springs are created. Heuristic crossover with rate of 1.6 was used because it was the only method which would yield successful results. Remaining 5 individuals, were created by mutating same amount of theirs predecessors. Uniform mutation was selected with slightly high rate of 0.2. This means that chances of mutating specific gene are 20 %. After 200 generations results were gathered in form of best individual which had these attributes:

$C = 3.3011$
$x_1 = -0.6294$
$x_2 = -4.6464$
$x_3 = 0.1804$
$x_4 = 8.3884$

Implementing these into exponential type of function, average absolute deviation for all 25 experiments was E = 43.30 %. Graphical comparison between simulated and experimentally gathered results is shown in Fig. 1.

Using the same settings linear function (2) was analyzed. Results were as follows:

$C = 13.9865$
$x_1 = -3.5294$
$x_2 = -28.6429$
$x_3 = 0.2226$
$x_4 = 73.0316$

Mentioned coefficients will produce an average absolute deviation of E = 27.56 % which is a noticeable improvement compared to exponential type of function. Graphical presentation of these results can be found in Fig. 2.

At the end power function was analyzed (3). Same settings used with only difference that number of generation had to be increased to 500. Following coefficients generated:

$C = 701.407$
$x_1 = -2.2661$
$x_2 = -0.8211$
$x_3 = 0.0865$
$x_4 = 1.8512$

and graphical comparison between experimental and simulated data can be seen in Fig. 3.

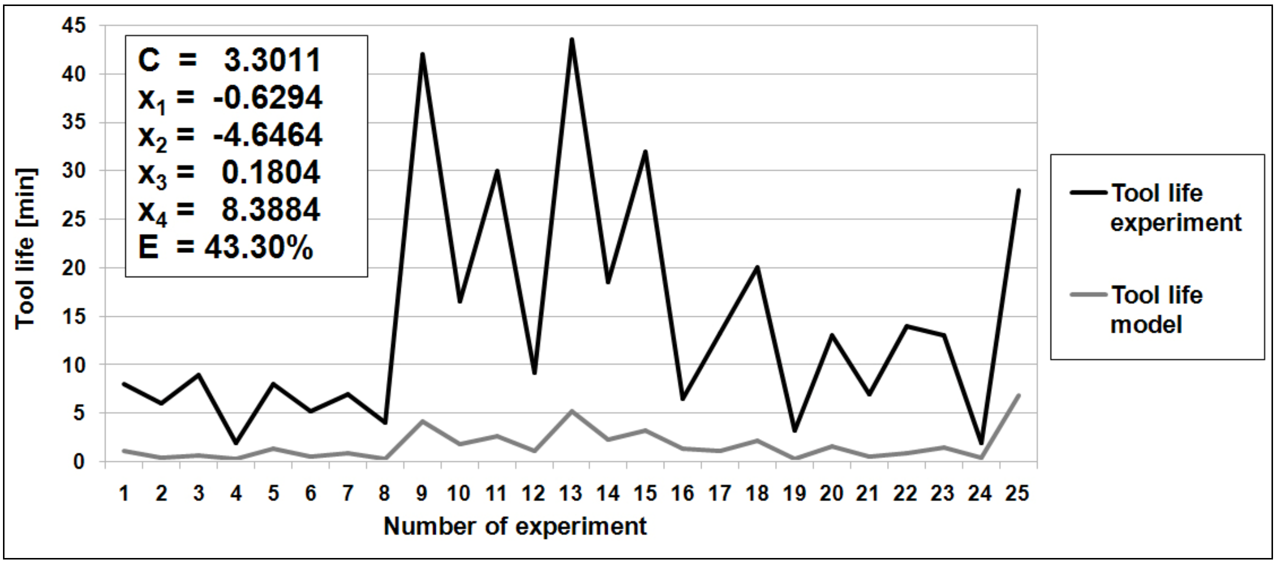

Fig. 1. Graphical presentation of results for exponential type of function (1)

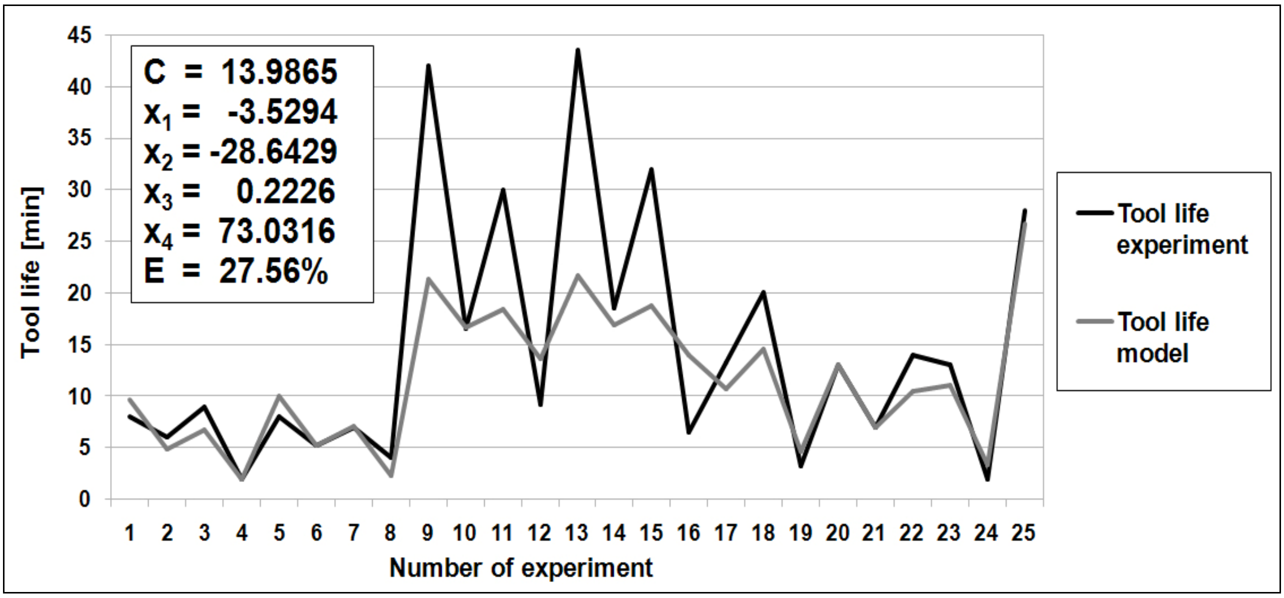

Fig. 2. Graphical presentation of results for linear type of function (2)

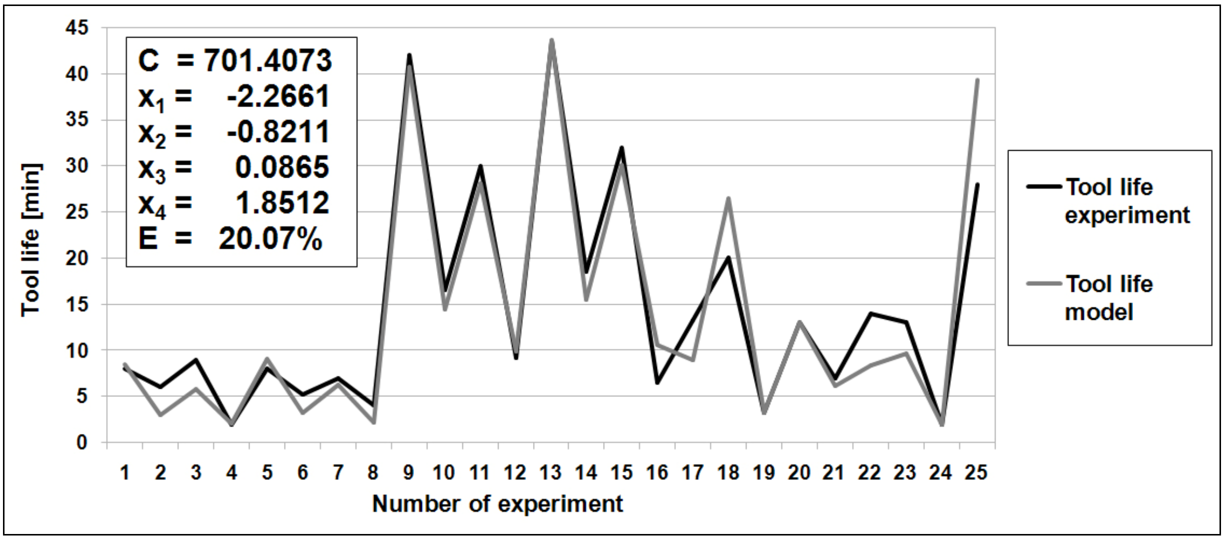

Fig. 3. Graphical presentation of results for power function (3)

6. CONCLUSION

As it can be seen form Fig. 1, Fig. 2 and Fig. 3, power function is most precise in tool life modeling. Although it takes 300 generations more to yield the best solution, this amount of time, measured in seconds, can be overlooked because result are far more better than the other types of functions. So if one would use genetic algorithms for predicting tool life, it is advisable to use power function.

Further research in this area would be to implement more real life factors that have influence on tool life duration. For example various cooling fluids and theirs effect could be observed and alternatively implement theirs effect in modeling function in form of coefficients.

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Original Scientific Paper

Lazarević, D., Madić, M., Janković, P. , Lazarević, A.

SURFACE ROUGHNESS MINIMIZATION OF POLYAMIDE PA-6 TURNING BY TAGUCHI METHOD

Received: 18 March 2011 / Accepted: 15 September 2011

Abstract: *In order to reduce the production costs and achieve the required product quality it is crucial to determine the optimal settings of the cutting parameters. In this paper the Taguchi method was used for minimizing the surface roughness in turning polyamide PA-6. The influence of four cutting parameters: cutting speed, feed rate, depth of cut, and tool nose radius and theirs interactions on average surface roughness (R_a) were analyzed based on the standard L_{27} Taguchi orthogonal array. Based on the analysis of means (ANOM) and the analysis of variance (ANOVA), the optimal cutting parameter settings was determined, as well as the level of importance of the cutting parameters*
Key words: *Optimization, Taguchi method, Turning, Surface Roughness, Polyamide PA-6*

Minimizovanje hrapavosti površine pri strugarskoj obradi poliamida PA-6 primenom Taguči metode. *Da bi se smanjili proizvodni troškovi i postigao zahtevani kvalitet proizvoda utvrđivanje optimalnih parametara rezanja je od sustinske važnosti. U ovom radu je korišćena Taguči metoda za minimizovanje hrapavosti površine poliamida PA-6 pri strugarskoj obradi. Analiziran je uticaj četiri parametra rezanja: brzina rezanja, korak, dubina rezanja i radijus vrha noža i njihov uticaj na vrednost srednjeg aritmetičkog odstupanje profila (R_a) na osnovu standardnih L_{27} Taguči ortogonalnih redova. Na osnovu ANOM i ANOVA, određeni su optimalni parametari rezanja, kao i nivo njihove značajnosti*
Ključne reči: *Optimizacija, Taguči metoda, struganje, hrapavost površine, Poliamid PA-6*

1. INTRODUCTION

Polyamides are thermoplastic polymer composites extensively used in a variety of applications in different fields of engineering, such as aircraft, automobile, robots and machines, due to an excellent property profile, and hence replaced many traditional metallic materials [1]. Even though the polyamides are produced as near net shapes, the machining has to be performed during the final stage of production to get the finalized products [2]. However, there is limited number of papers related to the machining of polyamides in the available literature.

Gaitonde et al. [1] applied Taguchi's quality loss function approach for simultaneous minimization of power and specific cutting force during turning of both PA6 and PA66 GF30 polyamides. Taguchi's optimization was performed for the process parameters such as material, feed rate and cutting speed. Gaitonde et al. [2] developed RSM based second-order mathematical models for analyzing the influence of cutting speed and feed rate on machining force, cutting power, and specific cutting pressure during turning of unreinforced polyamide (PA6), and reinforced polyamide with 30% of glass fibres (PA66 GF30). Eriksen [3] examined the influence of cutting parameters (feed rate, cutting speed and tool nose radius) and the fibre orientation on the surface roughness in turning of short fibre reinforced thermoplastic. The results showed that the roughness of the machined surfaces was highly influenced by feed rate and tool nose radius, whereas the influence of cutting speed was negligible. Marin [4] analyzed the effects of cutting speed, feed rate, and depth of cut on main cutting force in turning of PA 66 polyamide.

In this paper, Taguchi method [5] was applied to optimize cutting parameters in turning of polyamide PA-6 in order to achieve better surface quality.

2. OPTIMIZATION METHOD

The Taguchi technique is a methodology for finding the optimum setting of the control factors to make the product or process insensitive to noise factors [5]. Taguchi's techniques have been used widely in engineering design, and can be applied to many aspects such as optimization, experimental design, sensitivity analysis, parameter estimation, model prediction, etc. The background idea of Taguchi's robust design that differs from the conventional experimental design is that this method allows the simultaneous modelling of both mean and variability [5].

Taguchi based optimization technique represents a unique and powerful optimization discipline that differs from the traditional practices. The traditional experimental design methods are sometimes too complex and time consuming, while Taguchi methodology is a relatively simple to be used.

Traditionally, data from experiments is used to analyze the mean response. However, in Taguchi method the mean and the variance of the response (experimental result) at each setting of parameters in orthogonal array (OA) are combined into a single performance measure known as the signal-to-noise

(S/N) ratio. Depending on the criterion for the quality characteristic to be optimized, different S/N ratios can be chosen: smaller-the-better, larger-the-better, and nominal-the-better. For example, the S/N ratio for smaller-the-better criterion is used when the aim is to make the response as small as possible. This category of the S/N ratio is defined as:

$$\eta_i = S / N = -10\, log\left(\frac{1}{n} \sum_{j=1}^{n} y_{ij}^2 \right) \qquad (1)$$

where η_i is *S/N* ratio in the i-th trial, y_{ij} is the j-th observed value of the response (quality characteristic) in i-th trial, n is the number of individual observations in i-th trial, due to noise factors or repetition of trial. Regardless of the category of the quality characteristic, a higher algebraic value of *S/N* ratio corresponds to better quality characteristic, i.e. to the smaller variance of the output characteristic around the desired (target) value.

A full explanation of the method can be found in many references including [5, 6].

3. EXPERIMENTAL PROCEDURE

3.1. Material and cutting parameters

The material used for cutting was unreinforced polyamide PA-6 (commercially DOCAMID 6E) produced by Quattroplast Ltd. (Hungary). The mechanical properties of the work material are: density = 1.14 g/cm^3, tensile strength = 80 N/mm^2, module of elasticity = 3200 N/mm^2, Charpy impact resistance > 3 KJ/m^2. The test specimens were in the form of bar, 92 mm in diameter and 50 mm in length (Figure 1).

The machine used for the experiments was the universal lathe machine “Potisje PA-C30” with 11 kW power, speed range n = 20÷2000 rpm, and longitudinal feed rate range f = 0.04÷9.16 mm/rev. Cutting tool was SANDVIK Coromant tool holder SVJBR 3225P 16 with inserts VCGX 16 04 04-AL (H10) and VCGX 16 04 08-AL (H10). The tool geometry was: rake angle γ = 7º, clearance angle α = 7º, cutting edge angle χ = 93º, and cutting edge inclination angle λ = 0º.

In the study, the average surface roughness (R_a) was considered. It was measured at three equally distributed positions around the circumference of the workpiece using the profilometer Surftest Mitutoyo SJ-301.

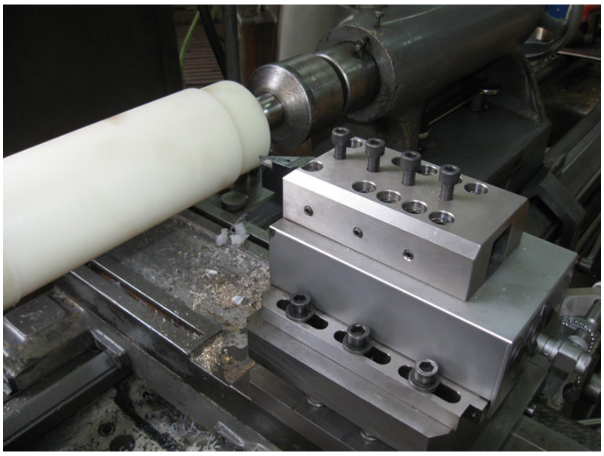

Fig. 1. Experimental setup

Trial no	Designation	Cutting speed V_c, (mm)	Feed rate f, (mm/rev)	Depth of cut a_p, (mm)	Tool nose radius r, (mm)	R_a (µm)		η (dB)
1	$A_1B_1C_1D_1$	65.03	0.049	1	0.4	1	1.07	0.0000
2	$A_1B_1C_2D_2$	65.03	0.049	2	0.8	0.95	0.86	0.8563
3	$A_1B_1C_3D_1$	**65.03**	**0.049**	**4**	**0.4**	1.31	1.42	-1.3292
4	$A_1B_2C_1D_1$	65.03	0.098	1	0.4	1.39	1.51	-3.2348
5	$A_1B_2C_2D_1$	65.03	0.098	2	0.4	2.05	1.4	-4.8873
6	$A_1B_2C_3D_2$	65.03	0.098	4	0.8	2.09	1.67	-5.5370
7	$A_1B_3C_1D_2$	**65.03**	**0.196**	**1**	**0.8**	3.78	3.56	-11.2972
8	$A_1B_3C_2D_1$	65.03	0.196	2	0.4	3.46	3.34	-10.6309
9	$A_1B_3C_3D_1$	65.03	0.196	4	0.4	3.61	3.51	-11.0299
10	$A_2B_1C_1D_2$	**115.61**	**0.049**	**1**	**0.8**	1.04	1.4	-1.8207
11	$A_2B_1C_2D_1$	115.61	0.049	2	0.4	1.04	1.01	-0.2154
12	$A_2B_1C_3D_1$	115.61	0.049	4	0.4	1.22	1.12	-1.3716
13	$A_2B_2C_1D_1$	**115.61**	**0.098**	**1**	**0.4**	1.43	1.29	-2.6823
14	$A_2B_2C_2D_2$	115.61	0.098	2	0.8	1.25	1.44	-2.5961
15	$A_2B_2C_3D_1$	115.61	0.098	4	0.4	1.78	1.63	-4.6429
16	$A_2B_3C_1D_1$	**115.61**	**0.196**	**1**	**0.4**	3.41	3.23	-10.4260
17	$A_2B_3C_2D_1$	115.61	0.196	2	0.4	3.41	3.39	-10.6296
18	$A_2B_3C_3D_2$	115.61	0.196	4	0.8	6.03	5.74	-15.3976
19	$A_3B_1C_1D_1$	**213.88**	**0.049**	**1**	**0.4**	0.85	0.69	2.2236
20	$A_3B_1C_2D_1$	213.88	0.049	2	0.4	1.04	1.16	-0.8408
21	$A_3B_1C_3D_2$	213.88	0.049	4	0.8	1.45	1.36	-2.9580
22	$A_3B_2C_1D_2$	213.88	0.098	1	0.8	1.37	1.59	-3.4292
23	$A_3B_2C_2D_1$	213.88	0.098	2	0.4	1.24	1.45	-2.6008
24	$A_3B_2C_3D_1$	**213.88**	**0.098**	**4**	**0.4**	1.7	1.54	-4.2009
25	$A_3B_3C_1D_1$	213.88	0.196	1	0.4	3.33	3.1	-10.1492
26	$A_3B_3C_2D_2$	213.88	0.196	2	0.8	5.53	4.94	-14.3921
27	$A_3B_3C_3D_1$	213.88	0.196	4	0.4	3.61	3.45	-10.9577

Table 1. Experiment plan, results and S/N ratios for the average surface roughness

3.2. Experimental plan

In the present study, four cutting parameters, namely, cutting speed (V_c), feed rate (f), depth of cut (a_p), and tool nose radius (r) were considered. The cutting parameters ranges were selected based on machining guidelines provided by workpiece and tool manufacturer's recommendations and previous researches [2, 3].

Three levels for cutting speed, feed rate and depth of cut and two levels for tool nose radius were considered (Table 2). The cutting parameters were arranged in standard Taguchi's L_{27} (3^{13}) OA. Cutting parameters V_c, f and a_p were assigned to columns 1, 2 and 5, respectively. Cutting parameter r was assigned to the column 12. As tool nose radius had only two levels, the dummy-level technique [4] was used to reassign level 1 to level 3. The plan of experimental layout to obtain the average surface roughness (R_a) is shown in Table 1. Following the Taguchi's L_{27} (3^{13}) OA, 54 experiment trials were performed at random order to avoid systematic errors.

Cutting parameter	Level		
	1 (low)	2 (medium)	3 (high)
A – V_c (m/min)	65.03	115.61	213.88
B – f (mm/rev)	0.049	0.098	0.196
C – a_p (mm)	1	2	4
D – r (mm)	0.4	0.8	-

Table 2. Cutting parameters and their levels used in experiment

Since the objective of experiment is to optimize the cutting parameters to get better (i.e. low value) of average surface roughness S/N ratio the average S/N ratios for smaller the better for average surface roughness were calculated using the Eq. 1. The S/N ratios are given in Table 1.

4. ANALYSIS OF EXPERIMENTAL DATA

The experimental results were analyzed by the analysis of means (ANOM) and analysis of variance (ANOVA). The analyses have been obtained by using the statistical software application MINITAB. The calculations of ANOM and ANOVA were described in details by Phadke [5].

4.1. Analysis of means

ANOM is a process of estimating the factor effects. Based on the ANOM, one can derive the optimum combination of cutting parameters, with respect to the average surface roughness (R_a). [5] The optimum level for a factor is the level that gives the highest value of S/N ratio in the experimental region.

The results of ANOM are presented in Figure 2. From the Figure 2, it can be observed that the optimal ANN combination of cutting parameter levels is $A_1B_1C_1D_1$. In other words, optimal value of each cutting parameter is (A) cutting speed, 65.03 m/min, (B) feed rate, 0.049 mm/rev, (C) depth of cut, 1 mm, and (D) tool nose radius, 0.4 mm.

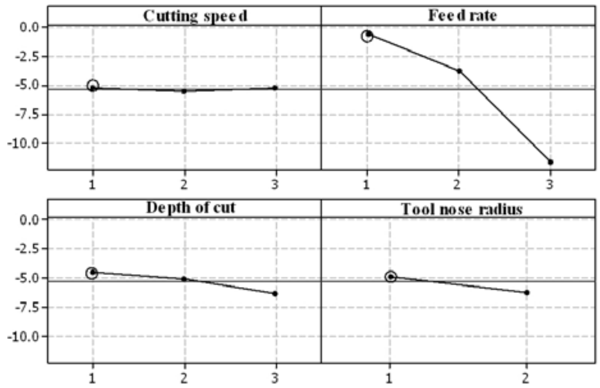

Fig. 2. ANOM diagram

4.2. Analysis of variance

The purpose of ANOVA is to investigate which cutting parameters significantly affect the surface quality characteristics. ANOVA was performed using the *S*/*N* ratios as the response (Table 2). ANOVA was accomplished by separating the total variability of the S/N ratios, which was determined as a sum of squared deviations from the average of the S/N ratio, into contributions by each of the cutting parameters and the error.

In ANOVA, the ratio between the variance of the cutting parameter and the error variance are called Fisher's ratio (F). It was used to determine whether the parameter had a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value ($F_{0.05}$) at the 5% significance level. If the F test value was greater than $F_{0.05}$, the cutting parameter was considered significant. Table 3 shows the results of ANOVA for average surface roughness.

Source	Degrees of freedom	Sum of squares	Mean square	F
Cutting speed	2	0.497	0.249	0.17
Feed rate	2	583.343	291.671	196.41
Depth of cut	2	16.076	8.038	5.41
Tool nose radius	1	12.077	12.077	8.13
Error	19	28.215	1.485	
Total	26	640.208		

Table 3. Analysis of variance (ANOVA) for S/N ratios

From the ANOVA results, it can be observed that cutting parameters, namely feed rate, depth of cut and tool nose radius are statistically significant for affecting average surface roughness (R_a). The change in cutting speed in the range given in Table 1 had insignificant effect on the R_a.

Figure 3 shows the percentage contribution of each cutting parameter to the total variation, indicating their degree of influence on the R_a. Feed rate is the most influential parameter followed by depth of cut and tool nose radius, whereas the influence of cutting speed is negligible.

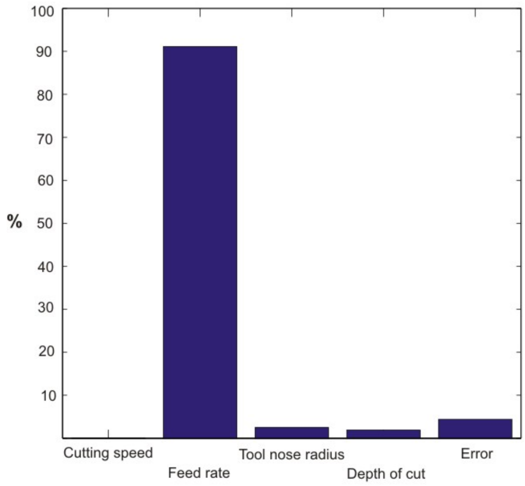

Fig. 3. Cutting parameters percentage contribution

From Figure 3 it can be observed that changing the cutting parameters (feed rate, depth of cut, and tool nose radius) between the chosen parameter levels (Table 1) contributes to 95.59 % of the total variation in the R_a. Furthermore, the small percent contribution of error confirms the absence of significant factor interactions.

4.3. Verification

Confirmation testing is necessary and important step in the Taguchi method. Once the optimal combination of cutting parameters was selected, the final step was to predict and verify the expected response through the confirmation test. There is no need to run the confirmation test if the optimal parameter combination is already included in the OA, as it was in this case. The optimal combination of cutting parameters ($A_1B_1C_1D_1$) corresponds to 1-st trial in Table 1.

Taguchi prediction of S/N ratio under optimum conditions is η_{est} = 0.779205 dB which is higher than obtained in experiment (Table 1).

In order to judge the closeness of the η_{est} and observed value of S/N ratio, the confidence interval (CI) is determined. The CI is given by [6]:

$$CI = \sqrt{\frac{F_{\alpha(1,f_e)} \cdot V_e}{n}} \qquad (2)$$

where $F_{\alpha(1;fe)}$ is the F value from statistic table at a confidence level of (1-α) at degrees of freedom (DoF) =1, and error DoF = 19, V_e is the error variance, and n is defined as:

$$n = \frac{N}{1+\nu} \qquad (3)$$

where N is the total number of experiments and ν is the total DoF of all parameters. At the 95% confidence level, the CI is ± 1.388. Since the prediction error is within CI value, the optimal combination of cutting parameter levels can be validated.

5. CONCLUSIONS

This article has described the application of Taguchi method for optimization of cutting parameter settings for minimizing the average surface roughness in turning of polyamide PA-6. Four cutting parameters, cutting speed, feed rate, depth of cut, and tool nose radius were considered are arranged in the L_{27} OA. From the ANOM and ANOVA results the following conclusions can be done:

– The combination of low levels of cutting parameters was beneficial for minimizing average surface roughness,
– ANOVA results indicated that the feed rate was the most significant parameter, followed by tool nose radius, and depth of cut, whereas the influence of cutting speed was negligible. ANOVA resulted in less than 5% error indicating that the interaction effect of process parameters was negligible.
– Since the cutting speed was not significant, it could be set at the highest level to obtain higher material's removal rate.

The Taguchi method is relatively simple but powerful optimization approach that could be efficiently applied for machining optimization problems.

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Original Scientific Paper

Novák-Marcinčin, J., Janák, M., Nováková-Marcinčinová, Ľ.

DEVELOPMENT OF SPECIAL SOFTWARE FOR COMPUTER AIDED SELECTION OF OPTIMAL CNC MILLING STRATEGY

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Abstract: *The main objective of this paper is to describe manufacturing strategies used in 3D CNC milling and possibilities to simplify the choice of manufacturing strategy, especially for inexperienced user. Main attention is directed to creation of simple software tool for optimization of suitable milling strategy selection, functional principles of this program and conditions related to its creation.*
Key words: *computer support, milling strategies, software application, Delphi*

Razvoj specijalnog softvera za kopmijutersku selekciju optimalne cnc strategije glodanja. *Osnovni cilj ovog rada je da opiše strategija proizvodnje koja se koristi u 3D CNC glodanju i mogućnosti da se pojednostavi izbor proizvodne strategije, posebno za neiskusne korisnike. Glavni pažnja je usmerena na stvaranje jednostavnog softverskog alata za optimizaciju odgovarajuće selekcije strategije glodanja, funkcionalnih principa ovog programa i uslova koji se odnose na njegovo stvaranje .*
Ključne reči: *kompijuterska podrška, strategija glodanja, primena softvera, Delfi*

1. INTRODUCTION

In present time in the field of CAD/CAM systems application there is need of using systems for improvement of production's efficiency, production time shortening, simplification of production, saving of energies and materials and that also in implicated form of better exploitation of production devices and lesser tools consumption. This request of productivity improving concerns all the participants from the field of tool, automobile and aero-industry, producers of moulds and different parts of variable shapes in various usage areas.

Proposal of optimal suitable manufacturing strategy is important matter mainly for new and inexperienced users of CNC technologies, for the acquirement of knowledge about strategies and their importance and utilization of new software tools would present barrier from economical and time aspect. Simple but helpful software product should assist in faster decision about strategy fitness and produce positive impacts of this decision correctness. Further chapters consist briefing of computer aid of manufacturing strategies and creation method of software which mitigates the selection of milling strategy.

2. CNC PROGRAMS CREATION

The area of the numerical control (Numerical Control - NC) is the most worked part of CAM systems. It is technology, where the programs for controlling of the production machines are used; for example for lathes, milling, drilling, sheet bending, grinding, conventional and unconventional cutting machines (laser, plasma, water-jet), but also for mechanical working and pressing machines by their control systems. There exist two primary types of numerical control, which are different by program storage method. In case of CNC (Computer Numerical Control), the control system of production machine is directly connected to local control computer. The second, more modern method is characterized by flexible distributed controlling of several production machines from common centre - DNC (Distributed Numerical Control). For quality form of program realization for milling NC machine is needed to apply of optimal strategy of cutting tool motion.

The first benefit offered by all forms of CNC machine tools is improved automation. The operator intervention related to producing workpieces can be reduced or eliminated. Many CNC machines can run unattended during their entire machining cycle, freeing the operator to do other tasks. This gives the CNC user several side benefits including reduced operator fatigue, fewer mistakes caused by human error, and consistent and predictable machining time for each workpiece. Since the machine will be running under program control, the skill level required of the CNC operator (related to basic machining practice) is also reduced as compared to a machinist producing workpieces with conventional machine tools.

The second major benefit of CNC technology is consistent and accurate workpieces. Today's CNC machines boast almost unbelievable accuracy and repeatability specifications. This means that once a program is verified, two, ten, or one thousand identical workpieces can be easily produced with precision and consistency.

A third benefit offered by most forms of CNC machine tools is flexibility. Since these machines are run from programs, running a different workpiece is almost as easy as loading a different program. Once a program has been verified and executed for one production run, it can be easily recalled the next time the workpiece is to be run. This leads to yet another benefit, fast change-overs.

Since these machines are very easy to set up and run, and since programs can be easily loaded, they allow very short setup time. This is imperative with today's just-in-time production requirements.

Presented here are three methods of developing CNC programs, manual programming, conversational (shop-floor) programming, and CAM system programming. To this point, we have exclusively stressed manual programming techniques at G-code level in order to ensure your understanding of basic CNC features [1, 2].

In this key concept, however, we will explore the various methods of creating CNC programs. We will give applications for each method to determine which is best for a given company. While we do tend to get a little opinionated in this section, you should at least understand the basic criteria for deciding among the programming alternatives. We will discuss three methods of developing CNC programs, manual programming, conversational (shop-floor) programming, and CAM system programming. Keep in mind that no one of these alternatives is right for all companies. Each has its niche in the manufacturing industry.

3. BASIC MANUFACTURING STRATEGIES

There are a huge number of products offering computer aid in different production spheres including manufacturing strategies area. Common effort of these CAM systems is to simplify the work of NC programmer and to ensure the correctness of his decisions or even to substitute his own decision by software process and so to ensure best possible milling efficiency. To most used CAD/CAM systems solving the problems of manufacturing strategies currently belong: EdgeCAM, VisiCAM, Pro/ENGINEER, ProTOOLMAKER, CAM-TOOL, Catia, FeatureCAM, SurfCAM, NX, MasterCAM, PowerMILL, ESPRIT, VX CAD/CAM and other.

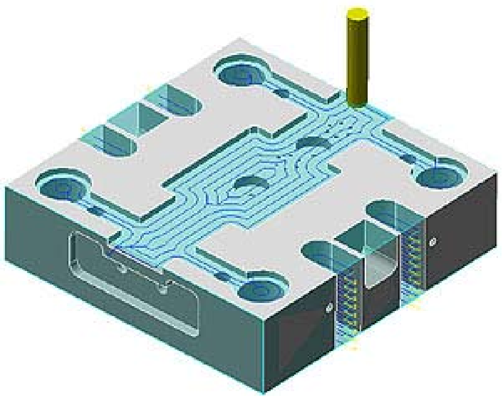

Fig. 1. Milling strategies in CAM system

These software systems concern milling in the scope of 2 – 5 axis machining. They offer section designing for roughing, which is machining with goal of cutting as much material as possible considering additional material for further operations. They also offer finishing, which means the process of removing residual material left on workpiece after some previous technology [3].

To main roughing strategies supported in CAD/CAM systems belongs:

- raster milling – tool path is parallel with coordinate system axis, tool is moving upright with minimal steps,
- contour milling – tool path copies the contour of machined element,
- profiling – tool path copies the contour of machined element while keeps moving with defined steps,
- raster and profiling – combination of two previous strategies.

To finishing strategies offered in CAD/CAM systems usually belongs [4, 5]:

- projection milling – means projection of 2D predefined motion to the model,
- constant Z-hight milling – mill moves in certain hight while copying model’s contours,
- corner milling – for removing the residual material after previous tool or in between two surfaces,
- nib milling – mill moves down the model continuously like a pen,
- rotary milling – tool moves linear, workpiece rotates around its axis.

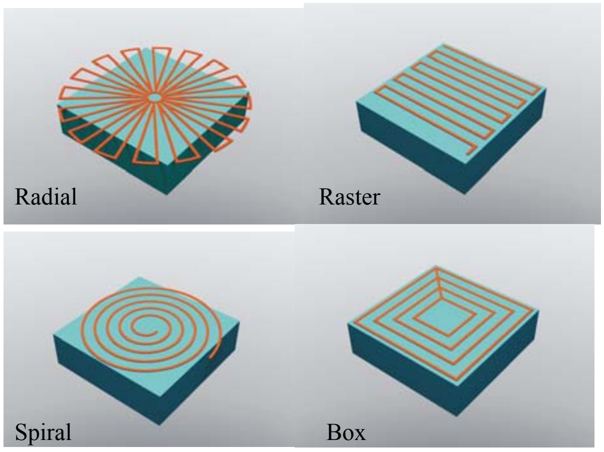

Fig. 2. Projection strategies of finish cutting

In most software concerning manufacturing strategies NC programmer has an option to choose suitable strategy, which would allow surface machining in shortest possible time while preserving requested quality. However only few programs select optimal strategy without choice process of its user.

4. SPECIAL MANUFACTURING STRATEGIES

In optimized system all the components work until the limit of their maximal capacity, though none of them is being overstretched. In order to prevent the tool damage, turn speed and feed should stay in the boundary of maximal load for existing tool path. This way of setting the turn speed and feed leads to the fact, that in the sections with lower load the tool works slower compared to its maximum.

So we try to keep the tool working up to its limit through the whole trajectory, which means that we attempt to reach constant material withdrawal and steady cutting forces. Unstable cutting force may result to tool damage or slow manufacturing [6].

Optimization of material withdrawal during the roughing is the most important step of CAM programming. Cutting depth and tool pitch recommended in tables for tool and material combination assume that we do the constant pitch roughing through the whole trajectory. If the tool path involves entire tool diameter cutting (grooving), or the driving in corners isn't handled, the tool may withdraw more material than expected. One possibility to keep clear of entire tool diameter irruption into the material in CAM systems is trochoid roughing. (Fig.3)

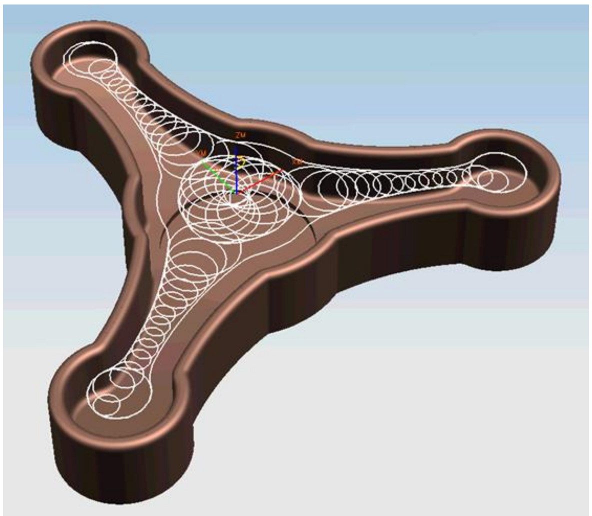

Fig. 3. Trochoidal milling in the CAM system

In most cases finishing of 3D surfaces in Z-layers (also known as "water line" or "constant Z finishing") provides better material breach and more stable withdrawal as finishing with the operations of trajectory projection. In contour strategies with trajectory projection the tool moves up and down according to the geometry, suffering load peaks during axial irruption into the steep surfaces. In order not to cause the tool damage during the load peaks it must work really slow in the sections with lower precipitousness.

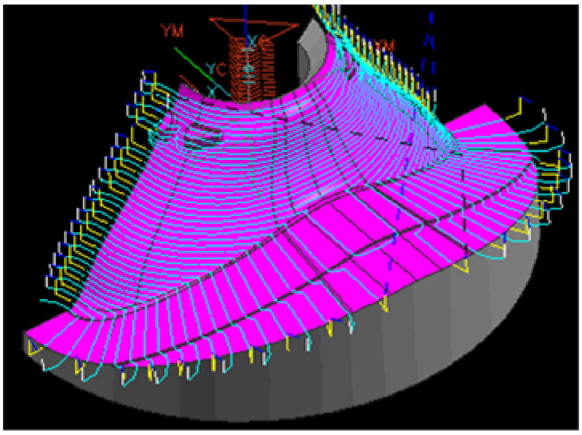

Fig. 4. Classical milling with uniform Z-levels

Besides constant Z-layers milling CAM system enables inserting the trajectories in low-pitched areas so that depth of remaining material is constant and next operations have steady material withdrawal (Fig. 5).

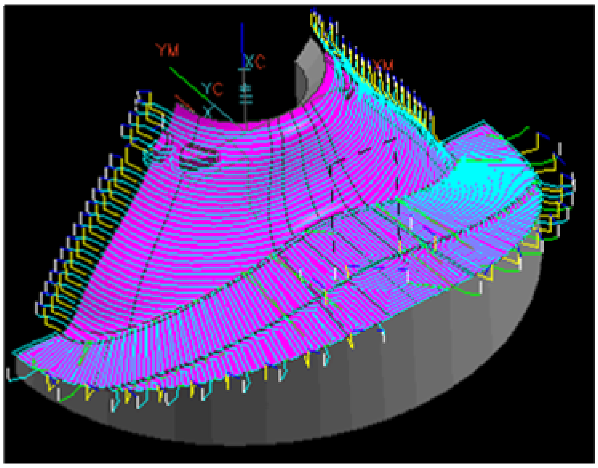

Fig. 5. Z-level milling with added levels on non-steep faces in the CAM system

If there is a need of finishing surfaces by 3-axis contouring instead of Z-layers machining, peak load is dramatically increased by axial irruption into the steep surfaces (for example chamfered sides of moulds).

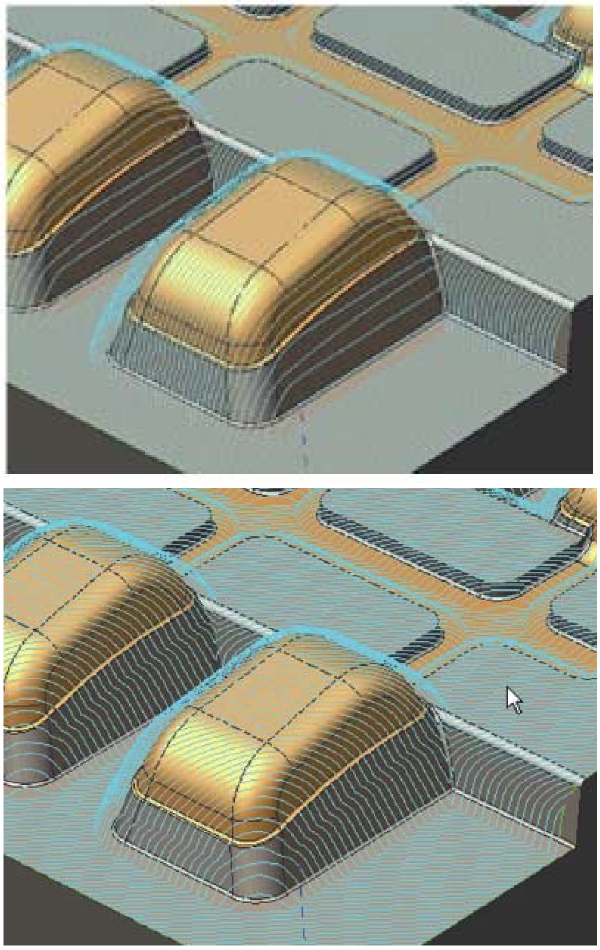

Fig. 6. Steep areas engages with 90° and 45° angle

There are two ways of lowering the peak loads while penetrating steep surfaces. One of them is to modify the angle of overriding so that tool goes through the steep sides under 45°. This decreases real precipitousness of trajectory and overloading of tool. Minor effect of this solution is that the tool doesn't longer remain in lengthwise corners. The other method of avoiding the tool overload on steep surfaces is to use first machining using Z-layers operations.

5. SOFTWARE FOR OPTIMAL CNC MILLING STRATEGY SELECTION

For creation of application we use program language Object Pascal and its visual implementation called Delphi. Every application created in Delphi is based on components. They generate its design and executive kernel. Most of necessary components are implied with an installation pack of Delphi, other can be created by user or downloaded from web [5].

Application should terminate optimal strategy after consideration of certain criteria such as machining time, residual stresses volume and tool wear. To do so it will compare the output values of computations for each strategy (length of absolved trajectory, number of contours, etc). To perform these computations program needs input data given by user corresponding with cutting conditions. That concern tool diameter, feed rate, side motion and sizes of machined surface.

User's environment consists out of 4 main parts:

- Geometry selection section – buttons for choice of machined surface type according to its geometrical characteristics.
- Input information section – space for writing of cutting parameters related to suitable strategy selection.
- Graphical information section – visual information giving user a view of planned strategy and dimensions.
- Output information section – space for quoting the results of computations and final strategy selection. For comparison, numerical values of results are shown for each strategy. Optimal variant will be highlighted.

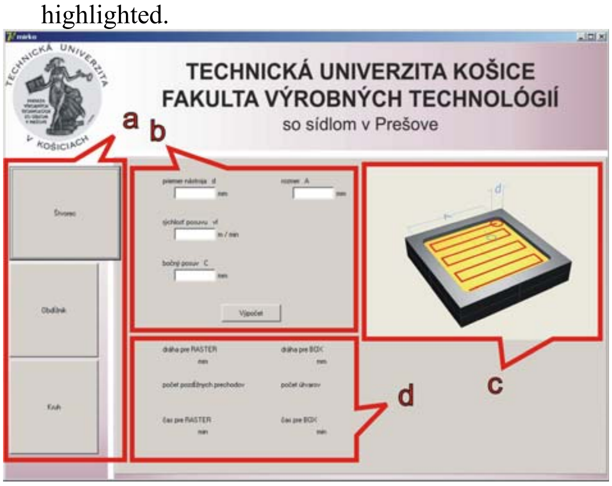

Fig. 7. User's environment of software – a) geometry selection, b) input information, c) graphical information, d) output information section

Program for its computation uses mathematical operations summarizing length of tool trajectory. When entering input data into the editable labels, it assigns them to relevant variables. Numerical dimensions of machined surface and tool diameter serves as limit borders decisive about stopping of tool motion. After pressing the COMPUTATION button program starts the procedures that calculate the length of tool path for each strategy according to input data received from user. Optimal solution presents the variant with lowest value of machining time criteria.

6. CONCLUSION

From programmer point of view, application uses events control of particular visual components – panels, edit fields, labeled edit fields, buttons, images. From the aspect of computation, main part of program code consists of cycles, that ensure computing determination in case of reaching the borders of machined surface. Final border contouring of machined element is added to result in order to make the final faces and edges smooth. Ministry of Education, Science, Research and Sport of SR supported this work, contract VEGA No. 1/0032/12, KEGA No. 002TUKE-4/2012 and ITMS project 26220220125.

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KINEMATIC ANALYSIS OF MACHINE TOOL BASED ON O-X GLIDE HYBRID MECHANISM USING A SYMBOLIC VIRTUAL MODEL

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Abstract: *Designing of modern machine tools is a procedure which requires great effort of the designer and which includes quick and detailed analysis of their kinematics and dynamic characteristics in exploitation. Thus, in recent times, design and analysis of machine tools is performed by using virtual models that describe the kinematic structure of the machine.*
In this paper a way of symbolic designing of machine tool virtual model on the example of machine tools based on the hybrid O-X glide mechanism is presented. Also, on this model, an analysis of kinematic characteristics and workspace of the observed machine is performed.
Results presented in this paper are part of the research conducted at the Faculty of Technical Sciences in Novi Sad in order to develop a new machine tool based on O-X glide hybrid mechanism.
Key words: *Machine tools, O-X glide mechanism, virtual model, kinematic analysis, SimMechanic*

Kinematska analiza mašine alatke bazirane na O-X glide hibridnom mehanizmu primenom simboličkog virtuelnog modela. *Projektovanje savremenih mašina alatki predstavlja proces koji zahteva veliko učešće projektanta i koji podrazumeva brzu i detaljnu analizu kinematskih i dinamičkih karakteristika mašine. Zbog toga se, u novije vreme, projektovanje i analiza mašina alatki vrši primenom virtuelnih modela koji opisuju kinematsku strukturu same mašine.*
U radu je na primeru mašine alatke bazirane na hibridnom mehanizmu O-X glide prikazan način simboličkog definisanja virtuelnog modela mašine alatke. Takođe, na ovom modelu su sprovedene i analize kinematskih karakteristika i radnog prostora posmatrane mašine.
Ispitivanja prikazana u ovom radu predstavljaju deo istraživanja na Fakultetu tehničkih nauka u Novom Sadu u cilju razvoja nove mašine alatke bazirane na O-X glide mehanizmu.
Ključne reči: *Mašina alatka, O-X glide mehanizam, Virtuelni model, Kinematska analiza, SimMechanic*

1. INTRODUCTION

In the conditions imposed by a contemporary market for a long time period, the behaviour estimation of the product in the exploitation creates requirements for its improvement even from the early phases of the development process. In previous periods physical prototypes of a product were maximally utilized for the verification of the theoretical exploitation characteristics, which caused additional production costs. The development of computers and the development of specialized software systems provided the basis for the creation of product virtual prototype, whose implementation significantly reduces the development time of new product [1].

Observing machine tools, the increase in market demands from the aspects of productivity and accuracy of the machining process makes it necessary to employ new methods and tools during their improvement. An efficient way to achieve defined requirements in the shortest time period possible is the solution based on the concept of designing a virtual model, i.e. virtual prototype, a machine tool describing kinematic structure of the machine itself [2].

Figure 1 illustrates the time saving achieved by applying virtual prototypes in the process of machine tool design.

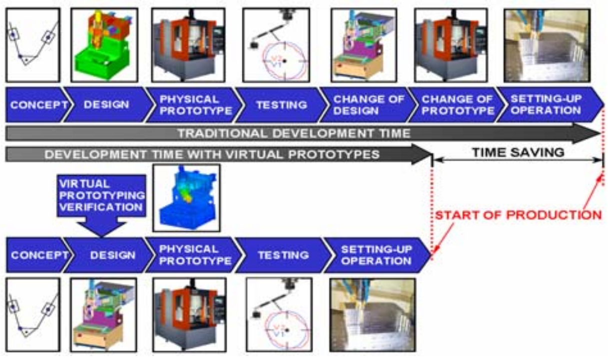

Fig. 1. Shortening the machine tools design process by applying virtual prototypes [2]

The application of a virtual model of a machine tool during design process greatly simplifies the testing of a huge number of proposed design solutions in the early design phase. Likewise, it also enables: fast and detailed analysis of kinematic and dynamic characteristics of a machine; estimations of functionality; safety of a machine tool; basic operator training; or the presentation of the designed machine for marketing purposes. Modelling, testing and alterations of physical prototypes for the above mentioned purposes are very costly and impractical.

A virtual model of a machine tool presents its geometric or symbolic description that can be utilized for the analysis instead of physical model of machine tool, by applying the adequate programme systems. The geometric described virtual model is usually applied for the simplest analysis, while the symbolic described model is applied for the complex analysis and it can be associated with a geometric model [2].

The analysis most often implies the simulation of the behavior of the machine tool elements in exploitation conditions. This simulation is done in the artificial environment created with computer hardware and software, presented to the user in such a way that it appears and feels realistic [3].

This paper describes the procedure for forming a symbolic virtual model of a machine tool based on O-X glide mechanism, by applying a functional module of the programme system *Matlab*, known as *SimMechanic*. Also, in the same software system, analysis of kinematic characteristics and working space of the observed mechanism on his virtual model are conducted .

2. FORMING OF THE MACHINE TOOL VIRTUAL MODEL

As noted above, this paper describes a symbolic manner of forming a virtual model on the example of a machine tool based on hybrid, parallel-serial, kinematic mechanism, O-X glide. O-X glide mechanism was developed at the Faculty of Technical Sciences in Novi Sad, and is composed of four rod that are on the one side connected to the base via sliders, and on the other side with movable platform (Figure 2). The main characteristic of this mechanism is the possibility of the sliders opposite passing. Thereby the mechanism rods can be placed at two characteristic positions, stretched "O" and crossed "X" position [10]. This mechanism type has been chosen due to its specific kinematic structure made of a planar parallel mechanism that is translated along one axis providing a basis for a three-axes machine tool.

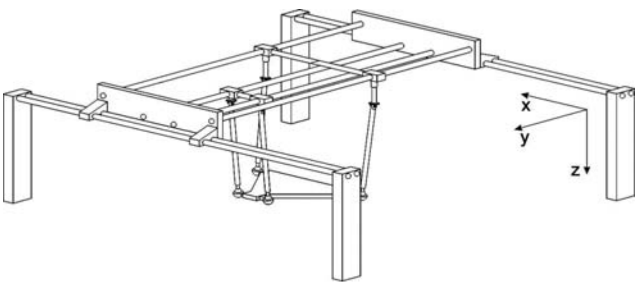

Fig. 2. Hybrid mechanism O-X glides [4]

Since the accent has placed on the virtual model and its analysis it was considered only "O" position of the mechanism rods. Also, because of the specificity of the O-X glide mechanism structure, in the observed position of rods it can be considered that the sliders moving along the same guide.

2.1. Symbolic modeling

Symbolic modeling refers to the description of a physical model by connecting adequate symbolic blocks. Each symbolic block contains information on the following:

- Physical properties of the machine elements (inertia matrices, mass matrices, coordination systems, etc.),
- Connections between elements (joints),
- Environment influences (stimuli), and
- Management – monitoring elements (mutual influences and monitoring elements, feedbacks, etc.)

In order to use a certain block to describe a physical element of a machine tool (platform, rod, guide, etc.), it is necessary to define its: dimensions, physical characteristics, and spatial orientation. Relations between elements are described by connections that, depending on demands, can be of guide, joint and rigid connection types, and with them it is possible, on a virtual model, to present any relations between two elements of a machine tool. It should be noted that individual blocks can be grouped in order to simplify the formed virtual model.

To obtain as authentic results as possible during the process of analysing a virtual model, it is also necessary to define the environment influence on a machine tool, friction and resistance between moveable elements, power engines, as well as segments presenting the obtained results [5].

2.2. Visualization of a virtual model

For a better insight into the movements that the formed model exhibits in space, there is a segment for the model visualization in the programme system Matlab. This visualization can be employed in two manners:

1. By generating the VRML model of the mechanism in the SimMechanic. In this manner, the geometry of individual elements of the kinematic structure of a machine tool is generated, based on information on dimensions and moments inertia input into individual blocks. Hence, a simple VRML model made of fundamental geometric shapes – primitives (cylinder, sphere, slab, etc.) is generated. Figure 3 presents a VRML model of an O-X glide mechanism formed for further analyses in this paper.

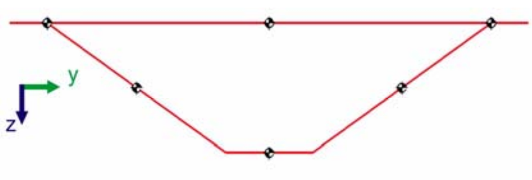

Fig. 3. VRML model of a O-X glide mechanism

2. By linking a detailed geometric mechanism model formed in one of the CAD programme packages with the adequate blocks of the virtual model created in SimMechanic. In such a manner, one obtains a virtual model that is geometrically more similar to the physical model of the machine tool with a more complete and realistic visualization.

The first method of visualization was used below, since the accent was placed on results rather than the appearance of virtual model.

3. DEFINING A VIRTUAL MODEL OF A O-X GLIDE HYBRID MECHANISM

The generation of the virtual model of the O-X glide mechanism is performed in such a manner that all mechanism elements are described by appropriate blocks forming an adequate scheme. This scheme, actually, presents a virtual model of mechanism illustrated in Figure 4.

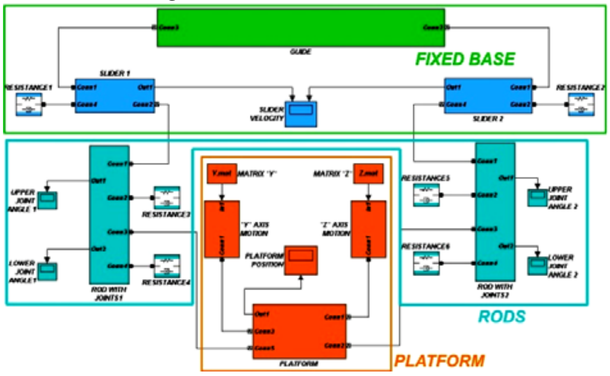

Fig. 4. Virtual model of the O-X glide formed in Matlab SimMechanic

In the figure, one can observe three units that represent individual complex elements of the mechanism. These are the mechanism base made of a guide and sliders, moveable platform and rods connecting the base and the moveable platform. Inside these subunits there are also complex blocks originating from the integration of simpler elements; e.g. rods, beside the rod itself, also have two joints on its ends.

3.1 Realized analyses

As already stated, one can perform several types of analyses on virtual models of machine tools (and mechanisms in general), providing an insight into the behaviour of individual elements, as well as the entire mechanism in exploitation. In this case, the virtual model is used for analysing the following:

- Position and orientation of individual mechanism elements in the entire working space,
- Kinematic characteristics of the primary mechanism moveable elements.

The results obtained in this analysis provide the necessary information which enable selection and design of the machine tools basic elements.

3.1.1 Working space analysis

During the research, one of the main requested goals has been to examine the behaviour of all vital mechanism elements (sliders, joints and rods) in the working space. Dimensions and the shape of the working space of the mechanism were obtained by analytical methods in earlier research phases, and they were subsequently expressed in a discrete form (as an adequate matrix) to simplify further analyses.

Figure 5 shows the entire O-X glide mechanism workspace, where the blue colour indicates the workspace that is created in the "O" rods position and which was used in further analysis.

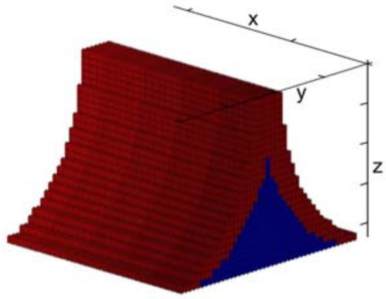

Fig. 5. Theoretical working space of the O-X glides mechanism

The positions of the moveable platform define the working space. They are determined by the direct kinematics chains of mechanism. Figure 6 shows the O-X glide mechanism in the Y-Z plane. Equations (1), (2) and (3) are obtained by direct kinematics analysis and they describe the working space of the mechanism in space, for positions of gliders.

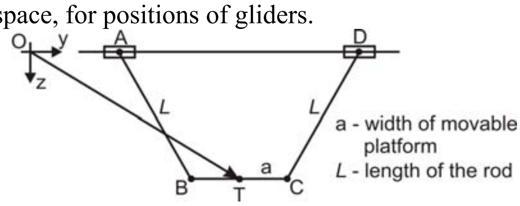

Fig. 6. O-X glide mechanism in the Y-Z plane

$$x_t = x \quad (1)$$

$$y_t = \frac{y_A + y_D}{2} \quad (2)$$

$$z_t = \sqrt{l^2 - \left(\frac{y_D - y_A - a}{2}\right)^2} \quad (3)$$

The analysis of the theoretical working space has enabled the elimination of singular points, inadequate slider and joints positions and the formation of an efficient usable working space of a mechanism.

Furthermore, the analysis of the working space of the virtual model is employed to determine minimal and maximal angles occupied by rods in relation to the base and the moveable platform.

In the specific case, the current values of the angles of mechanism joint at the position of connections between rods and sliders, i.e. rods and moveable platform, have been monitored (Fig. 7), as well as the position of sliders at the mechanism base.

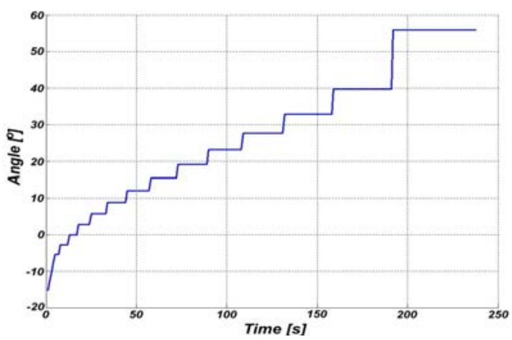

Fig. 7. Alteration in the joint angle between the rod and sliders

From the figure, it can be observed that the values of angles in the mechanism joints during movement alter in the total range of 70°. The determination of these values enables a selection of adequate joints for the mechanism of requested dimensions and characteristics, together with the optimization of individual elements, if necessary.

3.1.2 Kinematic analysis of the mechanism

Apart from the analysis of the working space, to design a certain machine tool it is necessary to perform the analysis of kinematic factors in the process of mechanism movement. In this case, it implies the analysis of the velocities of individual mechanism elements for the maximal values achieved by the moveable platform in the machine tool.

On the other hand, to select guides, sliders, joints, power elements of the machine tool and the like, it is necessary to analyse accelerations appearing on these elements in exploitation conditions, taking in consideration the maximal load of the moveable platform.

The kinematic analysis of the O-X glide mechanism has been conducted by utilizing the inverse kinematic chain, referring to setting the movement of a moveable platform and monitoring the behaviour of all joint mechanism elements. As a result, one can obtain velocities and accelerations of transverse sliders for the movement of the moveable platform across the theoretical working space defined by velocity and acceleration.

In the analysis, the moveable platform was assigned the velocity of 1 m/s and the acceleration of 10 m/s^2 with the definition of friction between sliders and the guide, and friction in joints.

Figures 8 and 9 illustrate functional dependencies between velocities and accelerations of mechanism sliders and time, respectively, originating in linear movement of the moveable platform in various positions, for the defined movement conditions of the moveable platform.

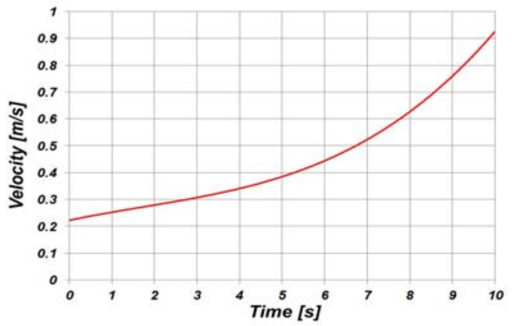

Fig. 8. Velocity of mechanism sliders for the set values of the platform velocity

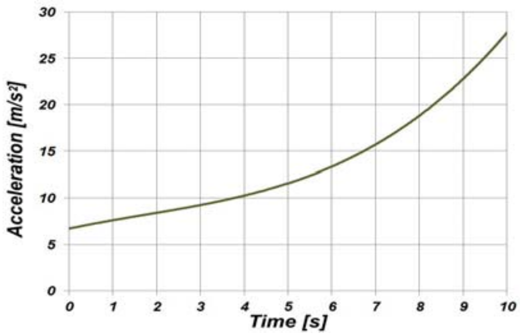

Fig. 9. Acceleration of mechanism sliders for the set values of the platform acceleration

Based on the obtained results, the adequate power engines, guide dimensions and mechanism slider characteristics are adopted, significantly simplifying the design process.

4. FINAL CONSIDERATIONS

As it can be observed from the presented diagrams, the application of virtual models in this phase of the machine tool design process enables a continual monitoring and the analyses of all relevant movements on a machine. In such a manner it enables, on one hand, forming of a conclusion on the possibilities of applying the mechanism itself in machine tools and, hence, determining of the feasibility of further improvements; on the other hand, it enables the realization of individual phases of the design by optimizing dimensions and characteristics of its elements.

The virtual model of O-X glide mechanism and the obtained results of its analyses presented in this paper are a segment of the research being conducted at the Department for Production Engineering, Faculty of Technical Sciences in Novi Sad.

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ANALYSIS OF THE OPERATOR INFLUENCE ON THE ACCURACY OF THE CALIBRATION STYLI RESULTS IN CMM

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Abstract: *The accuracy of the results from coordinate measurements depends on the accuracy of the measuring device, workpiece properties, environmental conditions, and especially operator procedures. As a part the latter, and usually the most important factor, is one of the crucial procedures for measuring accuracy, known as the stylus calibration. Calibration of the styli, in the narrow sense, consists of two basic concepts. It defines the location of the stylus relative to a common source – the position of the calibration sphere, and it defines the stylus size – relative to the known diameter of the calibration sphere. The accuracy of the calibration procedure using the stylus is primarily influenced by the accuracy of the shape and the size of the calibration sphere, the environmental conditions in which the calibration process is taking place, as well as the software of the coordinate measuring machine. In this paper, the influence of the aforementioned factors is neglected, and the calibration results are researched only in dependence on the position and orientation of the reference sphere in the working area of the machine, as well as the initial calibration points. The statistic data processing has been performed and the adequate conclusions have been drawn.*
Key words: *Calibration styli, probe, accuracy, CMM, ANOVA.*

Analiza uticaja operatera na tačnost rezultata kalibracije mernog pipka na KMM. *Tačnost rezultata dobijenih koordinatnim merenjem zavise od mernog uređaja, osobina radnog predmeta, uslova okoline i posebno od procedura operatera. U poslednje, i obično najuticajnije faktore, spada jedna od krucijalnih procedura za tačnost merenja i ona se naziva kalibracija mernog pipka. Kalibracija mernog pipka u užem smislu gledano se sadrži iz dva osnovna koncepta. Definiše položaj mernog pipka u odnosu na poziciju kalibracione sfere i definiše prečnik mernog pipka u odnosu na poznati prečnik kalibracione kugle. Na tačnost kalibracionog postupka mernog pipka pre svega utiče tačnost oblika i dimenzije kalibracione kugle, uslova okoline u kojoj se odvija kalibracioni postupak kao i softver koordinatne merne mašine. U ovom radu uticaj napomenutih faktora se zanemaruje i posmatraju se rezultati kalibracije u zavisnosti od položaja i orijentacije referentne sfere u radnom prostoru mašine kao i početne kalibracione tačke. Vršena je statistička obrada podataka i izvedeni su odgovarajući zaključci.*
Ključne reči: *Kalibracija mernog pipka, merni senzor, tačnost, KMM, ANOVA.*

1. INTRODUCTION

Coordinate measuring machine (CMM) is a universal measuring instrument in dimensional metrology. However, the CMM has many sources of errors and deviations that affect its precision and accuracy [1]. The accuracy of the results of the coordinate measurements depends on the accuracy of the measuring device, workpiece properties, environmental conditions, and especially operator procedures [2]. As a part of the latter, and usually the most important factor, is one of the crucial procedures for measuring accuracy, known as the probing system calibration (stylus calibration). The probing system in CMM includes a stylus and a stylus tip which have their own dynamic characteristics during the measuring process [3]. The exact calibration of the styli is the basic requirement for all measurements. Any deviation caused by an inadequate or incorrectly performed calibration process will affect every measurement done with the probing system, i.e. the measurement results could have significant errors. Calibration of the styli, at the very least, consists of two basic concepts. It defines the location of the stylus relative to a common source – the position of the calibration sphere, and it also defines the stylus size – relative to the known diameter of the calibration sphere. The accuracy of the calibration procedure using the stylus is primarily influenced by the accuracy of the shape and the dimensions of the reference sphere, the environmental conditions in which the calibration process is taking place, as well as the software of the coordinate measuring machine. In this paper, the influence of the aforementioned factors is neglected, and the calibration results are researched only in dependence on the position and orientation of the reference sphere in the working area of the machine, as well as the initial calibration points. Namely, there has been a series of experimental researches where, in the first case, the position of the reference sphere on the machine's working table was combined with the initial calibration point, and in the second case, the orientation of the reference sphere was varied without position alteration with the initial calibration point. This research had a purpose to present whether and to a what degree the operator can make an error in the case of alternating these three factors. The calibration stylus result is presented by standard deviation and this error is present in every subsequent measurements up to the next calibration. Hence, it is important to research the influential factors that directly come from the operator and in a certain manner, to determine the optimal position and orientation of the reference sphere, as well as the initial calibration point.

2. CALIBRATION STYLUS

Calibration stylus consists of the identification of diameter and of the position of the centre artefact with respect to the origins of the CMM reference system (Fig. 1). In essence, calibration defines where the probe (stylus) is located, and nullifies the effect of the probing forces on the accuracy. Measurement accuracy depends on the careful calibration of the probe stylus. Prior to measurements in the coordinate measuring machine (CMM), it is important to define three coordinate systems: the coordinate system of the machine, the coordinate system of the calibration stylus, and the coordinate system of the artefact. These three coordinate systems present the basis for calculating the measuring part dimensions. The coordinate system of the stylus is determined by calibration.

Calibration was initially introduced as a method of tying the relative positions of the styli to a common source, the reference sphere. The reference sphere has a known physical size and a fixed location in the CMM envelope. It is very important that the correct reference sphere is used and that its latest calibrated size is entered into the software. It is also essential that the stylus tip and calibration artefacts are scrupulously clean. The smallest amount of dust can lead to an incorrect probe calibration.

Measuring the length of a known artefact e.g. a calibrated block or plain setting ring, is a simple check on the probe calibration. If the difference between the calibrated size of the gauge block and the length one measures is not within the machine uncertainty at this length, the probe should be recalibrated and the check repeated [4].

For reliable calibration 25 to 50 touch points are recommended for each stylus tip.

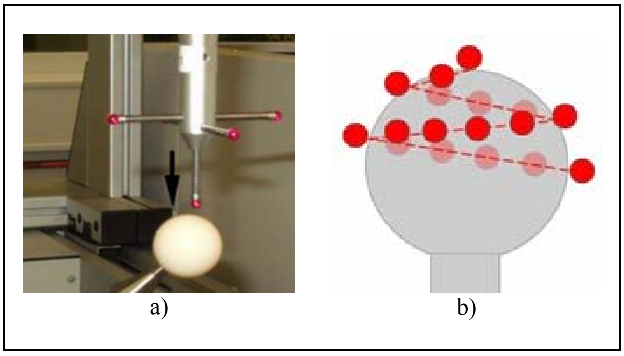

Fig. 1. An example for a calibration stylus (a. Probing of calibration artefact; b. Probing strategy with 16 points)

Since the calibration stylus impacts the results of all subsequent measurements up to the next calibration, a small uncertainty has to be ensured.

The calibration strategy includes in particular:

- Choice of calibrated artefact
- Choice of location and orientation of artefact
- Definition of number, location and sequence of probing points (for scanning mode: scanning lines, data rate, travelling speed).

2.1 Calibration of the styli of CMM "Carl Zeiss Contura G2 RDS"

The CONTURA G2 is a mid-range type CMM with advanced features and design strengths. All axes have 4-sided air bearings providing maximum stability and a very precise measurement. Ceramic guideways are thermally stable, minimizing the effect of temperature variation.

This experiment utilizes the RDS turning measuring head with the combination of VAST XXT scanning measuring sensor. As a replacement for trigger sensors, the VAST XXT offers the unmatched measurement capability, reliability, and accuracy (Fig. 2). With a large deflection range and a low measuring force, it is a very robust scanning sensor. It uses the styli lengths up to 250 mm, side and star styli, and a minimum ball radius of 0.3 mm. The VAST XXT has very low measuring forces and there is little influence when swivelling. When the RDS head is used, the CMM can probe the workpiece from a large number of different directions by adjusting A and B angles. Every RDS position wanted to be utilized for probing is considered to be its own stylus and must be calibrated separately.

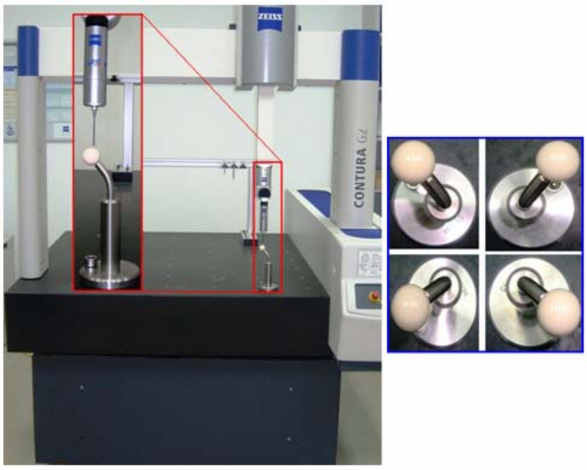

Fig. 2. CMM Carl Zeiss CONTURA G2 RDS, reference sphere, stylus, initial calibration point, position and different orientation calibration sphere.

A stylus must be qualified when and if there is a new stylus system installed and there is a demand for the recalibration of a stylus system, for example after a collision or due to thermal changes. The first mode in a calibration is to calculate the actual diameter of the stylus. The measurement of the sphere is with ball centre data. The second mode of the calibration is to calculate the offset of the centre of this measured sphere relative to the one measured with the master stylus. The calibration of the measuring stylus is

performed with the reference sphere. The reference sphere of the CMM is a sphere of a known diameter mounted on the measuring table via a stem. The software (Calypso) must know the exact position of this reference sphere for the orientation and in order to analyze the calibration correctly.
The position of the reference sphere on a measuring table is determined by the calibration of the master measuring stylus. After this calibration is performed, the next step is the calibration of the measuring styli. In order to decide whether the calibration result is acceptable, standard deviation can be used as a basics for the decision. Acceptable standard deviation depends primarily on the following factors: quality of the calibration, length and stability of the styli and extensions used, value of the temperature deviations and temporal thermal fluctuations on the CMM, degree of soiling, wear, damage of the reference spheres, existence of loose or damaged stylus and/or extension elements. The standard deviation should lie in the range of a few micrometers.
The first calibration of a stylus must be done manually. Once the stylus has been calibrated for the first time, future calibration can be done automatically [5]. Automatic calibration can be performed only if the reference sphere does not alter position and orientation on the machine table. The position, reference sphere orientation, and initial calibration point are selected randomly by the operator.

3. EXPERIMENTAL WORK

Measurements (calibration stylus with the radius of 3 mm) were performed in the Metrology Laboratory of the Department of Production Engineering at the University of Novi Sad. Two experimental researches were performed.
The first experiment combined the influence of the reference sphere position on the CMM table on the initial calibration point. Reference sphere held final four positions in the working volume of the measuring machine, while the orientation was toward the middle of the table in all four cases. Initial calibration point was the contact position between the reference sphere and stylus which initiates the calibration process; it was selected by the operator. This contact should happen at the point at the top of the calibration sphere, passing through by the axis line of the measuring sensor containing the measuring stylus centre and the axis line of the reference sphere. The described experiment was not followed by statistic analyses since its purpose was solemnly to present the location of the smallest deviation of the calibration points for all four cases where the value of the standard deviation passes the set limitations. For each of the four positions of the reference sphere, the calibration was performed in ten initial calibration points. The first calibration point was adequate to the coordinates of the calibration sphere centre and each subsequent one was moved for 0.5 mm until the final 5 mm. The experiment also investigated the differences in standard deviation for three sphere positions in relation to the fourth one where the sphere was mainly positioned to be adequate to the most distant position from the reference coordinate system (right bottom angle of the working area in CMM).
The second experiment combined the diverse orientation of the reference sphere on the working table of the machine with the initial calibration point. The sphere was in the right bottom angle of the working area in CMM. The values obtained in this research were a subject to statistic analysis; the two-factor variation analysis (MANOVA) was utilized.
The results of this research were obtained at the temperature of 20°C, with the same calibration method, operator and equipment, and they cannot be used as a reference for calibrations in variable conditions.

4. RESULTS AND ANALYSES

Based on the first experiment, where 240 calibrations were performed on the same stylus with the variations in positions and initial calibration points, it has been determined that, for the values of the initial calibration point deviations larger than 3.5 mm, the calibration procedure is unacceptable. Standard deviation obtained by the calibration up to the value of 3.5 mm is in the acceptable limits. This claim is adequate for all four positions of the reference sphere, so that the common sphere position can remain unchanged
This claim presented an introduction into the second experiment, so that the deviation value of the initial calibration points for all four orientations was 3.5 mm. It has been found that, in the total of 192 calibration procedures, the standard deviation does not exceed one tenth of a micrometer – Tab. 1 [6].

B \ A	1	2	3	4	5	6	7	8
1	0	0	0	0	0	0.1	0.1	0.2
	0.1	0.1	0.1	0.1	0	0.1	0.1	0.3
	0.1	0	0	0.1	0	0.1	0.1	0.2
	0	0	0.1	0	0.1	0.1	0.1	0.3
	0	0.1	0	0.1	0	0.1	0	0.5
	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.3
	0	0.1	0.5	0.1	0.2	0.1	0.4	0.2
	0	0.1	0.2	[illegible]	[illegible]	[illegible]	0.2	0.1
	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1

Table 1. Standard deviation [μm]

Two-factor variation analysis, where the initial calibration point is presented by the factor A and the reference sphere orientation is the factor B, provides the following computing and graphic results (Tab. 2 and Fig. 3).

	DF	SS	MS	F	p
Factor A	7	0.0001	0.0000	2.90	0.007
Factor B	3	0.0018	0.0006	113.14	0.000
Interaction AB	21	0.0003	0.0000	2.54	0.001
Residue (error)	160	0.0008	0.0000		
Sum (total)	191	0.0030			

Table 2. Results of the MANOVA procedure

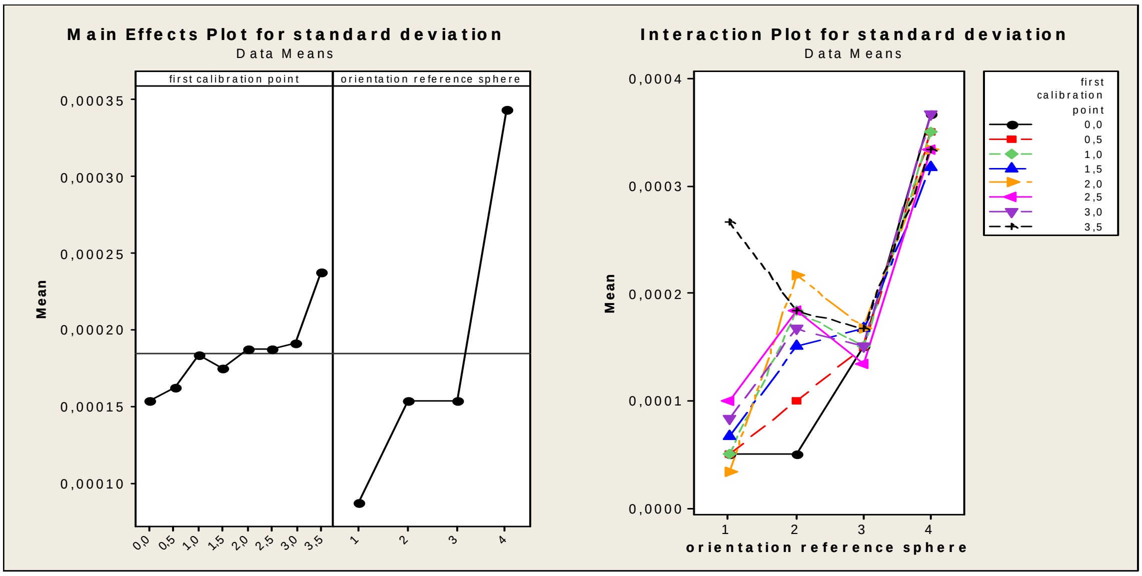

Fig. 3. Graphic presentation of the two-factor variation analysis

The following conclusions could be drawn out on the basis of the calibration result processing:

- Variation of the calibration results caused by selecting various initial calibration points is statistically significant at the 99% confidence level (p=0.007);
- Variation of the calibration results caused by changing the orientation of the reference sphere is statistically significant at the 99% confidence level (p<0.001); and
- Variation of the calibration results caused by the combined impact of the observed factors is also statistically significant at the 99% confidence level (p=0.001).

5. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

According to the aforementioned claims, the following can be concluded:

- Deviation of stylus and reference sphere contact point impacts the calibration results at constant environmental conditions,
- Operator will make an error if the deviation value of the initial calibration point exceeds 3.5mm,
- Operator will make the smallest error if the reference sphere orientation is adequate to the first position i.e. towards the reference coordinate systems for the position on which the sphere is usually situated (fig. 3).

The directions in future research are related to the introduction of another factor influencing the standard deviation value. Namely, the same experiment could be conducted in another metrology laboratory equipped with the same type of the CMM, except that the reference sphere, probing system and stylus would be from the first metrology laboratory. This experiment could determine the diversity between hardware components, power system and measurement system between the two machines of the same type.

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Original Scientific Paper

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INTERNET-BASED COLLABORATIVE SYSTEM FOR PROCESS PLANNING

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Abstract: *Advances in information technologies have enabled designers to more effectively communicate, collaborate, obtain, and exchange a wide range of design resources during development. Internet-based design environment is a new design paradigm for product development.*

This paper presents a framework for distributed and collaborative system, which could assist manufacturing organizations to evaluate, optimize, and select process plans for groups of manufacturing parts. The proposed system emphasizes the integration of the software tools and the resources involved in the design process to enable collaboration of geographically dispersed design teams and process planning experts.
Key words: *Digital Manufacturing, e-Manufacturing, Collaborative Engineering, Process planning, CAPP*

Internet-bazirani kolaborativni sistem za projektovanje tehnoloških procesa. *Napredak u razvoju informacionih tehnologija omogućava projektantima efikasniju komunikaciju, saradnju i razmenu brojnih projektantskih resursa tokom projektovanja. Internet-bazirano projektantsko okruženje predstavlja novu paradigmu u razoju proizvoda.*

Ovaj rad predstavlja okvire distribuiranog i kolaborativnog sistema, koji pruža podršku proizvodnim organizacijama prilikom ocene, optimizacije i izbora tehnoloških procesa izrade odgovarajućih grupa proizvoda. Predloženi sistem integriše različite programske alate i resurse uključene u projektovanje i omogućava kolaboraciju geografski dislociranim projektantskim timovima i ekspertima iz oblasti projektovanja tehnoloških procesa.
Ključne reči: *Digitalna proizvodnja, e-Proizvodnja, Kolaborativno inženjerstvo, Tehnološki procesi, CAPP*

1. INTRODUCTION

Shortening of product life-cycle and frequent changes in production programs have influenced the need for ever-faster and efficient transfer of information between engineers and other participants in design and manufacturing process.

In recent years, the Internet and local area networks have greatly increased the integration of engineering work, equipment, and other components which are required for design and manufacture. Introduction of digital documents has lead to a novel, modern way of operation, vastly contributing to modern society. Digitalization has introduced numerous innovations into the area of product development.

Within the modern environment, manufacture of complex products often takes place in a number of small and medium enterprises, taking the form of distributed manufacture. Single enterprises are specialized in partial manufacturing processes. Complex products consisting of a large number of parts, components, and modules, are assembled into functional units within a single enterprise but need not necessarily be produced under a single roof. Therefore, better coordination is in order between geographically dispersed teams collaborating on the same project.

2. DIGITAL MANUFACTURING

Digital manufacturing represents a technology, or discipline which offers strategic approach to development, implementation, and optimization of all elements of manufacturing process. The term ‘digital manufacturing’ implies a network of digital models and methods which define all aspects of manufacturing process. Digital manufacturing environment represents a combination of digital product and digital processes and resources [1]. This requires a common framework which integrates virtual model of manufacturing with its real physical counterpart. Digital manufacturing allows efficient monitoring and improvement of manufacturing process through utilization and control of data pertaining to development, planning, and validation of manufacturing processes. The goal is to integrate the data from various departments in the domain of product design and manufacture.

Exchange of information and engineering collaborative processes are crucial for digital manufacturing, as well as for optimization of manufacturing [2], *Fig. 1*.

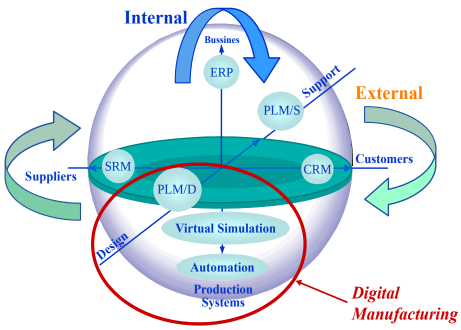

Fig. 1. Digital manufacturing's position in the collaborative manufacturing management model [3]

Today's trend of accelerated advancement of Internet technologies allows development of distributed software applications which surpass traditional physical and chronological limitations, helping us to connect geographically dispersed users, systems, resources, and services. By means of *web*-based collaborative systems, designers and engineers can exchange and share tasks and knowhow on a global level, using Internet/intranet networks, *Fig. 2*.

Fig. 2. An example of a global manufacturing infrastructure [4]

3. e-MANUFACTURING

3.1. The concept of e-Manufacturing

In a wider sense, electronic manufacturing *(e-Mfg)* can be described as an application of Internet in manufacturing. Electronic manufacturing integrates buyers, systems, electronic shops, and suppliers in a single manufacturing process, thus creating a strategic framework for manufacture which is based on Internet technologies. This concept is most often applied in hi-tech industries, but is also common in companies which integrate the Internet into their manufacturing processes in order to boost profits. Modern companies utilize Internet for various forms of e-Commerce and e-Business, but also to create manufacturing environment, i.e., the e-Manufacturing. Various Internet services allow the transfer of information regardless of distances, as well as the control of manufacturing processes which involves manipulators, robots, CNC machines, and other similar industrial equipment. The synthesis of Internet technologies an the concept of digital factory constitutes a framework for e-Manufacturing.

From the aspect of global hierarchical levels within e-Manufacturing one can discern between two primary groups of activities: engineering, and manufacturing, *Fig. 3*. On an inter-company level, the engineering aspect includes a so called *Engineering Chain* which allows realization of required engineering tasks.

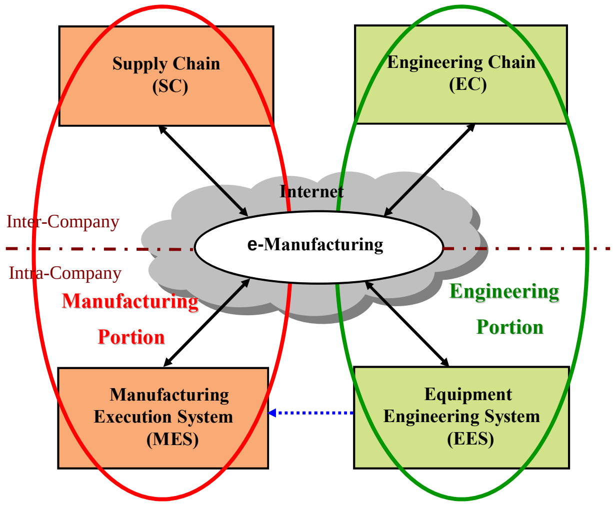

Fig. 3. e-Manufacturing components [5]

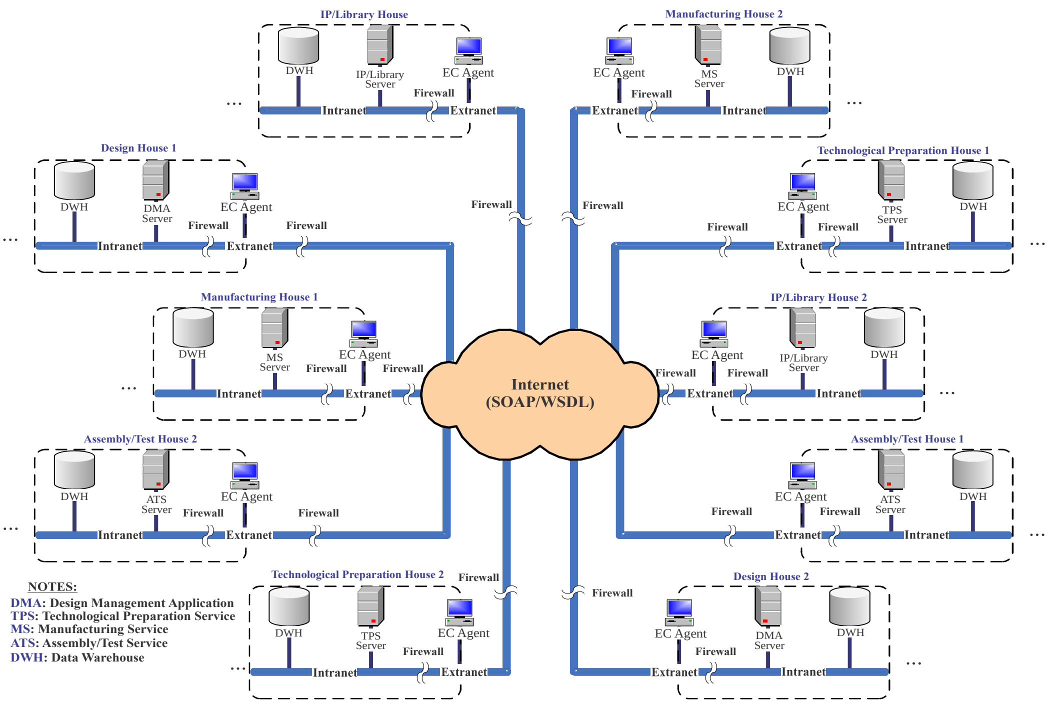

Fig.4. Vision of global Engineering Chain system

3.2 Engineering Chain

The Engineering Chain on an inter-company level, and the in-house systems of engineering equipment represent the basic infrastructure necessary for execution of engineering processes within e-Manufacturing. This Engineering Chain represents a network of engineering objects and services, *Fig. 4*, which allow product design and process planning based on valid engineering data. In addition, manufacturing process is monitored by means of the systems of engineering equipment and executive manufacturing systems.

4. COLLABORATIVE PROCESS PLANNING

4.1. Collaborative design environment

Collaborative environments for integrated design allow various groups involved in design process to work together on the development of an efficient digital model which pertains to a product or process. Such approach opens new possibilities in the domain of marketing analysis, multi-criteria product design assessment, and manufacturing process plan variants, optimization of product characteristics with the aim to increase quality, reliability, productivity, easy assembly and maintenance.

Shared virtual environments allow engineers in remote locations to analyze a virtual prototype together and simultaneously in a center where the product is being developed, *Fig. 5*. Moreover, such environments allow engineers and designers to gain better understanding of products, increasing the quality and providing design for manufacture from the very beginning, thus reducing the need for expensive re-work during later stages of development

Present-day CAD/CAPP/CAM and CAE systems incorporate Internet support for collaborative engineering. This support allows designers to compare and harmonize their model with those of other designers which share the common collaborative environment.

Fig. 5. Global collaborative design environment

4.2. Process planning collaborative environment

Process planning for manufacturing is one of key tasks which need to be solved in a distributed manufacturing environment in which various companies and engineers take part in collaborative product development. In such environments, the activities related to process planning are often realized by means of CAPP systems. Thereby, procedures are applied which take engineering drawings, bills of materials, and other manufacturing specifications to identify and select apropriate machining processes, resources, sequences and other parameters necessary to transform a blank into a finished product. However, the knowledge implemented into a typical CAPP system is subject to frequent updates with newly acquired expert knowledge. Market conditions are constantly changing, while the prices, terms of delivery, and production volumes require modifications of current process plans [3].

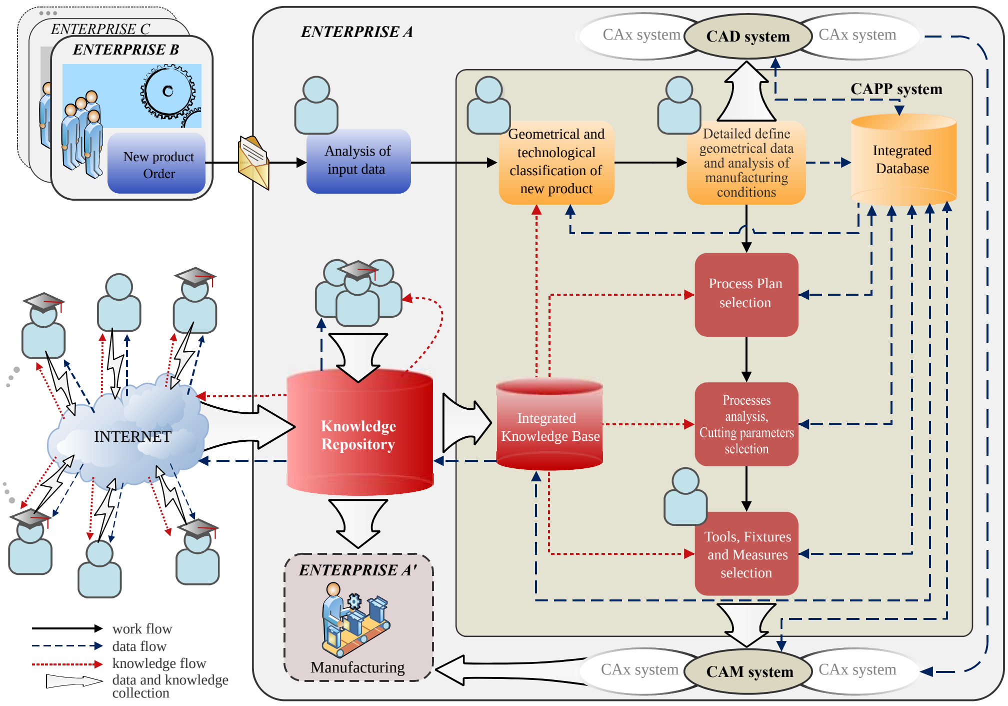

Fig. 6. Workflow activities and information flow in the Internet-based process planning collaborative system

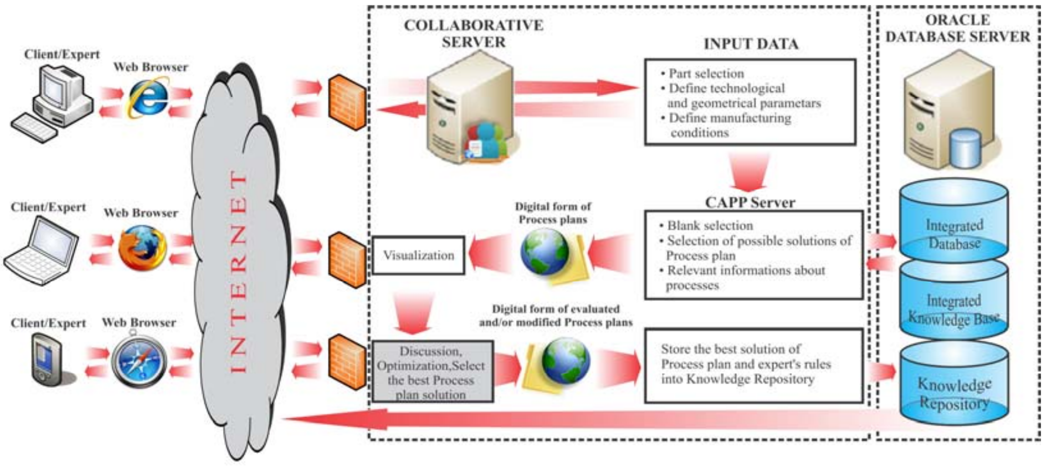

Fig. 7: Architecture of the Internet-based process planning collaborative system

Shown in *Fig. 6* is an example of a Internet-based collaborative process planning system within a company which manufactures a group of products. Beside various CAx systems and human resources within the company, the collaborative environment also includes geographically dispersed experts which are nevertheless included in the collaborative process via Internet. External associates cooperate in the process planning and evaluation, on a par with in-house experts and engineers.

Figure 7 shows the proposed three-tier architecture of a process planning collaborative system. In addition to clients, i.e., experts whose number is not limited, also includes collaborative- and database servers.

Fig. 8. Access to the online process planning collaborative system through a web browser

This collaborative system provides expert analysis, discussion, and evaluation, which results in an optimal process plan for the given production conditions. Furthermore, experts are not expected to use any of the commercially available software systems for process planning or interaction with collaborative environment, due to the fact that the collaborative process takes place exclusively through a web browser, *Fig. 8.*

5. CONCLUSION

Efficient exploitation of novel design and manufacturing technologies is possible only within a flexible and collaborative working environment. In addition, the Internet technologies are rapidly and overwhelmingly changing the traditional way of thinking and doing business within the manufacturing industries. The proposed Internet-based system, dedicated to collaborative process planning for manufacturing, represents another step in the direction of advancement of modern distributed manufacturing.

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Original Scientific Paper

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INFLUENCE OF FRICTION COEFFICIENT ON WORKPIECE ROUGHNESS IN RING UPSETTING PROCESS

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Abstract: *In forming processes contact friction significantly influence metal flow, stress-strain state and process parameters. Furthermore, tribological conditions influence workpiece surface quality and its dimensional precision. This paper presents research results of the influence of contact friction coefficient on a workpiece surface quality in ring upsetting by flat plates. Workpiece surface roughness is measured using atomic force microscope. Ring upsetting experiments are conducted with ion implanted and nonimplanted dies.*
Key words: *ring upsetting, ion implantation, nanoroughness, AFM, friction coefficient*

Uticaj koeficijenta trenja na hrapavost obratka u procesima sabijanja prstena. *U procesima deformisanja kontaktno trenje značajno utiče na tečenje metala, naponsko-deformaciono stanje i parametre procesa. Pored toga, tribološko stanje utiče na kvalitet površine obratka i na njegovu dimenzionu preciznost. Ovaj rad predstavlja rezultate istraživanja uticaja kontaktnog koeficijenta trenja na kvalitet površine obratka pri sabijanju prstena ravnim pločama. Površinska hrapavost obratka je merena atomskim mikroskopom. Eksperimenti sabijanja prstena su izvedeni sa jonski implantiranim i neimplantiranim alatima.*
Ključne reči: *sabijanje prstena, jonska implantacija, nanohrapavost, AFM, koeficijent trenja*

1. INTRODUCTION

Quality of a metal forming process is often controlled by the interfacial friction between the contacting die and workpiece surfaces. If the interfacial friction forces are large enough, the strain condition and formability of the workpiece may deteriorate and the energy required to form the part may be unacceptably high [1].

A basic premise of the theory of friction is that apparently flat, smooth surfaces are not so smooth when viewed on a microscopic scale. Surfaces of metals are actually rough, and asperities representing the roughness of the surface are present in surfaces of metals. Workpieces, dies and tools are characterized by surface roughness. Until all asperities are flattened, surface roughness has an influence on the friction properties of those surfaces, especially at the beginning of metal forming processes. During forming process asperities plough into each other, and thus a small sliding always exists. At the beginning of the process, since the tool is in contact just with the peaks of the asperities, the friction properties depend on the distribution of asperities, on their height and their deformation during the process, e.g. on the roughness of the contact surface. With the flattening of asperities the contact with the tool gets larger and this leads to varying friction properties [2, 3, 4, 5].

Such friction produces a tangential (shear) force at the interface between die and workpiece which restricts movement of the material and results in increased energy and press forces. The magnitude of the shear friction stress influences the deformation pattern, the temperature rise, the tool deflection and the total force in metal-forming [6]. The prediction of how quick the die will failure is an important objective to guarantee good output from a cold forging process. The failure of a tool does not only require it to be replaced but it also stops production, causes rejection of the workpieces, and requires new adjustment of the machine. The replacement of the dies planned according to a predictive maintenance program less affects productivity than unexpected stops [7].

2. FRICTION IN METAL FORMING PROCESS

During metal forming process working surface of the die is in continuous contact with the workpiece surface. In the contact between the die and workpiece high values of normal and tangential stresses are present together with the displacement and sliding of material. Contact surfaces of the die and workpiece have initial roughness which changes during metal forming process.

Contact friction corresponds to a resistance of relative movement between two bodies in contact, with normal stress present in between them (fig. 1).

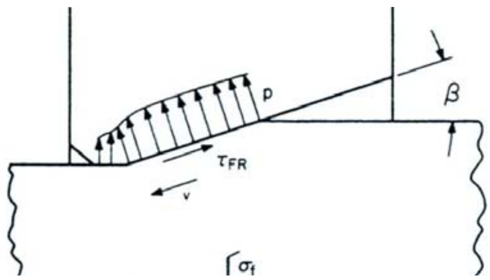

Fig. 1. Contact between workpiece and die [4]

In between those surfaces lubrication is present which lowers contact friction. During metal forming process removal of workpiece's material and wear process initiates on the surface of the die and workpiece, which modifies initial tribological conditions in forming process.

Since relative movement between die and workpiece is always present in metal forming process, friction is integral part of every metal forming process (with an exception of uniaxial tension). Contact friction is negative event since it causes an increase of required force and work, die wear and nonuniform deformation. Rolling process is exception, since friction is required for process to be carried out.

During metal forming process peaks of asperities found on workpiece and die are in contact, while other areas of the contact surface are separated by lubricant (fig. 2).

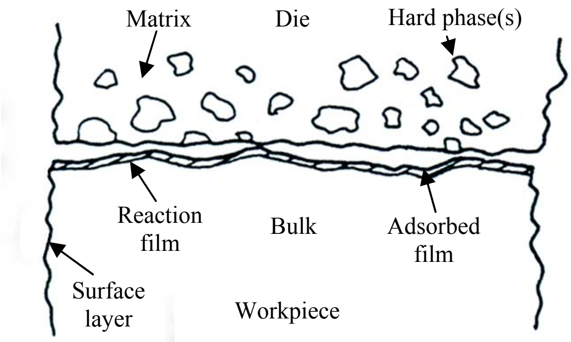

Fig. 2. Peaks in contact [4]

Composition of anti-friction material is changing during metal forming process, because friction generate workpiece and die wear, oxidation and corrosion of metal which affects friction and lubrication conditions. Surface roughness of tools and final parts is important for adequate lubrication and it also stands as a wear criterion in the metal forming process. Surface profile consists of many peaks and valleys that get deformed in the forming process. Those deformed peaks and valleys affect lubricant film sustainability and because of that surface topography affect the maintenance of lubricant film. For this reason, the surface topography is very important in metal forming processes.

According to [2] friction coefficient increases with surface roughness decrease except when samples were made of brass (tab. 1). For samples made of aluminum and steel, highest friction coefficient values are obtained in case of polished surface, while lowest values are obtained for machined only surface.

Trial no.	Deformation ratio (%)	Pre-upsetting surface roughness of parts (Ra-µm)	Friction coefficient
	x_1	x_2	μ
1	19.2	1.85	0.08
2	19.3	1.75	0.09
3	39.4	2.20	0.08
4	42.8	2.25	0.12
5	58.0	2.05	0.13
6	59.0	2.09	0.12

Table 1. Friction coefficient and factor values [2]

Since the contact area between die and workpiece is smallest at machined samples, and highest for polished samples, the lowest friction coefficient values were obtained on samples whose surface is only machined.

Various instruments are being used for measuring surface topography and for topography measurements in nano and micro scale atomic force microscopy can be successfully used.

As universal method for friction coefficient measurement in bulk metal forming processes, ring upsetting by flat plates (dies) have been used [4, 7, 8].

3. RING UPSETTING EXPERIMENT

Fig. 3 shows contact friction coefficient determination by ring upsetting method.

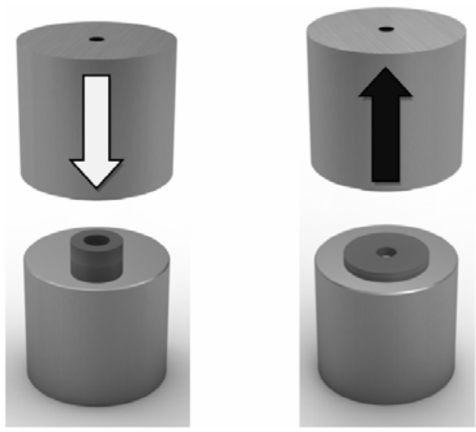

Fig. 3. Ring upsetting method

Method consists of establishing the dependence between deformation of inner ring's diameter and ring's height. This dependence is taken into etalon chart and compared with existing within the chart.

Ring upsetting has been performed incrementally, with a height deformation around 10%. After each upsetting stage ring's dimensions were measured. Incremental upsetting has been carried out until total deformation of the ring's height has reach around 70%.

Once the ring upsetting has been completed, deformation of the ring's inner diameter and deformation of the ring's height has been calculated for each upsetting increment. By connecting all the pairs of height and inner diameter deformation curve was defined.

In order to find the friction factor for the completed upsetting process, it is necessary to compare the curve with an existing ones from the etalon diagram.

Ring upsetting has been carried out with two different pairs of dies. One pair of dies has been grinded, polished and ion implanted with $2 \cdot 10^{17}$ N^+ 50 keV, while another pair of dies has not been ion implanted. Dies were made of X210Cr12 cold work tool steel (Č.4150) with dimensions ø50×45 mm. Rings were made of Ck15 unalloyed carbon steel (Č.1221) with initial dimensions D_2:D_1:h=18:9:6 mm. Hardness of the dies was 58+2 HRC, while hardness of the ring upset with nonimplanted dies was 167 HV-10 and hardness of the ring upset with implanted dies was 161 HV-10. Upsetting was done without contact surface lubrication.

4. RESULTS

4.1 Ion implantation simulation by SRIM software

In order to ensure successful ion implantation into X210Cr12 steel, SRIM simulation software was used to evaluate the effect of $2 \cdot 10^{17}$ N^{+} 50 keV ion implantation into die's surface. As it can be seen from fig. 4, ion implantation depth was around 100 nm. For the convenience, SRIM simulation on fig. 4 was completed with 10000 ions.

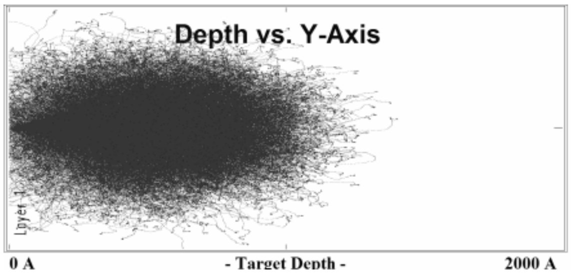

Fig. 4. SRIM simulation of ion implantation into steel

Based on the results of simulation, ion implantation of the dies has been carried out in Institute of Nuclear Sciences "Vinča".

4.2 Ring upsetting – contact friction coefficient

Fig. 5 shows comparison of friction factors obtained from a ring upsetting experiment while tab. 2 shows friction factors and friction coefficients values.

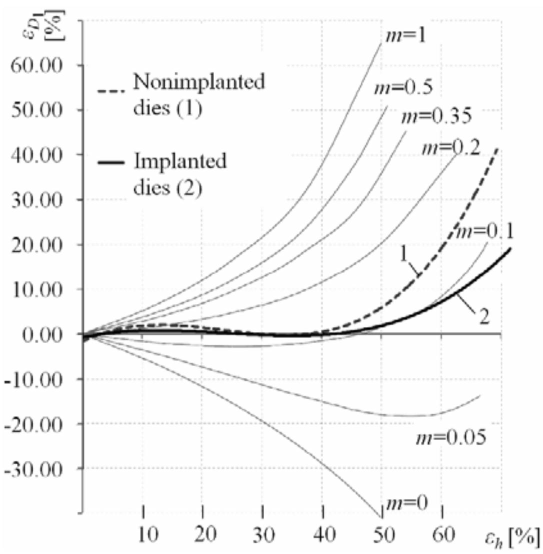

Fig. 5. Comparison of friction factors for rings upset with implanted (2) and nonimplanted dies (1)

Dies	Friction factor (m)	Friction coefficient (μ)
Nonimplanted	0.15	0.087
Implanted	0.11	0.064

Table 2. Friction factors and friction coefficients for rings upset with implanted and nonimplanted dies

4.3 Measurement of ring's surface roughness change

Purpose of die and workpiece topography measurement prior and after ring upsetting was to determine the influence of die's surface ion implantation on friction and dimensional accuracy, i. e. workpiece surface quality at metal forming processes. By comparing the roughnesses between corresponding rings, influence of die's surface ion implantation on ring's quality and accuracy can be established.

Topography of the ring was measured with VEECO "di CP II" atomic force microscope.

To evaluate the effect of die surface ion implantation on ring's surface roughness during upsetting, ring roughness has to be determined before upsetting was carried out. Fig. 6 displays topography of the ring that hasn't been upset with dies and tab. 3 shows average roughness values of rings before upsetting.

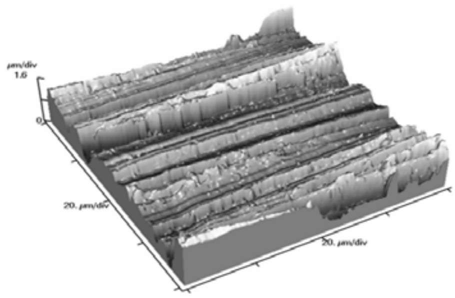

Fig. 6. Topography of the ring's surface before upsetting

Ring for upsetting with	R_a [nm]
ion implanted dies	126.75
nonimplanted dies	137.65

Table 3. Average values of R_a for ring before upsetting

Fig. 7 shows measuring points where surface roughness was measured using atomic force microscopy, while tab. 4 shows average ring's roughness values after upsetting. Distance between measuring points on the rings is approximately 1 mm.

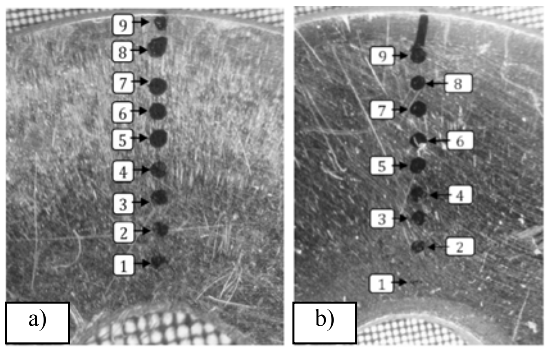

Fig. 7. Measuring points on the ring upset with a) nonimplanted dies, b) implanted dies

Ring upset with	R_a [nm]
ion implanted dies	11.11
nonimplanted dies	23.79

Table 4. Average values of R_a for ring before upsetting

Fig. 8 shows topography of the ring upset with nonimplanted dies at measuring point 7 (see fig. 7), while fig. 9 shows topography of the ring upset with implanted dies also at measuring point 7.

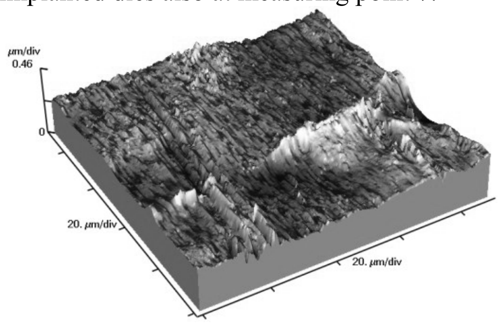

Fig. 8. Topography of the ring upset with nonimplanted dies measured at point 7

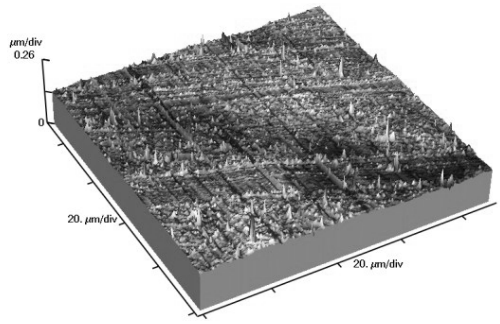

Fig. 9. Topography of the ring upset with ion implanted dies measured at point 7

Fig. 10. shows roughness comparison between the rings upset with nonimplanted and ion implanted dies.

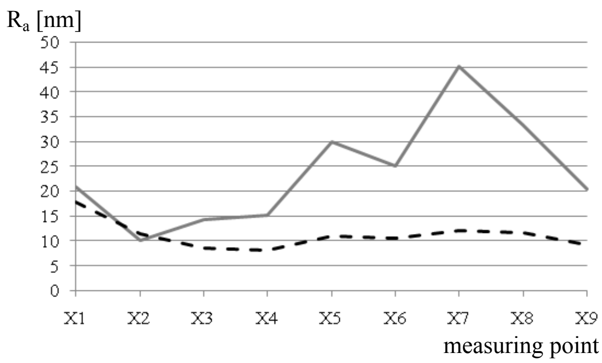

Fig. 10. Roughness comparison between the rings upset with nonimplanted and ion implanted dies

5. DISCUSSION

It is evident from diagram (fig. 5) that ion implantation has influence on friction coefficient in ring upsetting process, since friction coefficient is 1.36 times lower in case of upsetting with ion implanted dies.

According to tab. 4 ring upset with ion implanted dies has average roughness (R_a) that is 2.14 times lower than ring upset with nonimplanted dies. Also, it is obvious from fig. 8 and 9 that rings upset with ion implanted dies has smoother surface compared to ring upset with nonimplanted dies.

Diagram on fig. 10 shows that ring upset with ion implanted dies has roughness in narrower range compared to ring upset with nonimplanted dies.

6. CONCLUSION

Based on the results presented in this paper, it can be concluded that ion implantation can reduce the friction coefficient and improve surface roughness and quality at bulk forming process. AFM application is essential for researching surface nanomorphology in bulk forming processes. Results obtained in this paper contribute to development of ultraprecision engineering.

ACKNOWLEDGEMENTS

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Original Scientific Paper

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MULTI-CRITERIA ASSESSMENT OF ENVIRONMENTAL AND OCCUPATIONAL SAFETY MEASURES IN DENTAL PROSTHETICS LABORATORIES

Received: 01 September 2011 / Accepted: 12 January 2012

Abstract: *Technicians in dental prosthetics laboratories are exposed to environmental dust and various occupational health hazards, and therefore appropriate protection is necessary. This paper deals with assessment of safety mesures in dental prosthetics laboratories and aim of this work was to assess ten dental laboratories in Novi Sad using the multi-criteria analysis as a assessment tool. Multi-criteria analysis revealed the dental prosthetics laboratories with improper safety measures.*
Key words: *dental laboratories, multi-criteria analysis, fullers triangle, safety measures*

Vrednovanje mera bezbednosti i zaštite životne sredine u laboratorijama za izradu dentalnih nadoknada *Tehničari u laboratorijama za izradu dentalnih nadoknada su izloženi prašini i različitim rizicima po zdravlje zbog čega je neophodna primena adekvatnih zaštitnih sredstava. Ovaj rad se bavi vrednovanjem mera bezbednosti u laboratorijama za izradu dentalnih nadoknada i cilj rada je vrednovanje deset dentalnih laboratorija u Novom Sadu primenom višekriterijumske analize kao alata za vrednovanje. Višekriterijumskom analizom identifikovane su dentalne laboratorije sa neodgovarajućim merama bezbednosti.*
Ključne reči: *dentalne laboratorije, višekriterijumska analiza, fulerov trougao, mere bezbednosti*

1. INTRODUCTION

Making fixed and removable dentures on the conventional way in dental laboratories includes "dirty technology". A variety of materials are used in dental laboratories for manufacturing of different types of dental prosthesis such as crowns, implants, bridges, chromium-cobalt frameworks, acrylic dentures, and other dental products. The uses of these materials have caused respiratory diseases, dermatological problems and allergies [1, 2].

Environmental protection and occupational health safety are moral and legal obligation. Adequate and efficient protection should be considered to prevent occupationally related diseases. Consequently, the use of face mask and efficient ventilation systems is strictly necessary to ensure safety with respect to air pollution in the working environment of dental laboratories.

If the dental technicians do not use appropriate protection, parts of metal filings, ceramic and acrylate dust and other filth, which is present in the air of the dental laboratory during making of dentures, can damage their health [1]. In the first place, the respiratory system can be injured. Long time exposure to inorganic dust could lead to pneumoconiosis, pulmonary fibrosis, lung cancer, cancer of the paranasal sinus and throat cancer [3]. The dust that origins from the cobalt-hroma alloy and cobalt-hroma-molybdenum alloy can lead to pneumoconiosis and lung cancer [4]. While grinding the esthetic part of the fixed partial denture ceramic dust can be found in the air. Particles of ceramic dust, carbid and metal particles can lead to pulmonary silicosis and other pathological changes in airways [2].

Allergic contact dermatitis is considered one of the most common occupational caused illnesses of the dentists, dental technicians and dental assistants, usually occurring after the direct contact of the skin with the allergen. While making the mobile dentures dental technician uses the acrylate monomers, which can cause contact dermatitis. It usually occurs on distal phalanges and palmary surfaces of the fingers [5]. Also, there is a risk of mechanical injury in dental laboratories. Eye injuries can be mechanical and chemical. Erosion of cornea is the most common eye injury in the dental laboratory and it occurs when mechanical force destroys epithelium of the cornea. In that part of cornea remains tissue and distal parts of nervus ophthalmicus without protection of epithelium. Because of that, every movement of the eyelid causes pain. Beside pain photophobia, epiphora and hiperemia occurs. [6, 7].

Considering that environmental and occupational health hazards present great threat to technicians working in dental prothetics laboratories, this paper deals with assessment of safety measures in dental prosthetics laboratories. Aim of this work is to assess ten dental laboratories in Novi Sad using the multi-criteria analysis as a assessment tool.

2. MULTI-CRITERIA ANALYSIS AND WEIGHTING METHODS

In cases where multiple alternatives, on the bases of multiple parameters, need to be evaluated multi-criteria analysis presents a valuable tool [8, 9]. There are many methods and their variations for multi-criteria analysis, however the following can be distinguished as widely applied: Analytic Hierarchy Process (AHP) [10], TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method [11], Compromise programming (CP) [12], ELECTRE (ELimination Et Choix Traduisant la REalité) methods [13], PROMETHEE (Preference Ranking Organisation Method of Enrichment Evaluation) methods [14], SAW (Simple Additive Weighting) [11], Delphi process [15].

Multi-criteria analysis has wide applications in decision making problems, and it can be a useful tool for evaluation of dental services [16]. Questionnaire is a common way to obtain data needed for multi-ciriteria analisis and it was used in a study [17] that evaluated dental service quality. Dental service quality was evaluated with multi-criteria method AHP and the patients found "dentist attitudes" and "pain relief" as the major determinants of service quality. Furthermore, a multi-criteria analysis and a questionnaire was used by Dome´jean-Orliaguet at all [18]. They asked a sample of dental practitioners to record the characteristics of preventive or restorative treatments made on vital permanent teeth and afterwards they used a multi-criteria analysis to investigate the influence of patient and practitioner characteristics on the provision of restorative dental services.

Criteria weighting gives certain criteria level of importance, thus playing an important role in multi-criteria evaluation. One of the roughest methods of weight assignment is the direct weighting technique. With this technique, weights are assigned through direct assessment of the importance of one criteria over another, without considering how much the parameter actually contributes to the total score of the alternatives [19]. The next widely applied technique is pairwise comparison the Fuller triangle and AHP. The first one is based on the forming of triangular matrices of criteria pairs within which criteria weighting is performed [20]. Unlike the previous method, the AHP method, developed by Saaty [10], allows criteria to be classified into hierarchical levels and uses a finer scale to compare their significance. According to the tradeoff weighting method, the decision maker compares two alternatives which only differ in two criteria while the others are kept at the same level [21]. Swing weighting [19] is based on a questionnaire according to which the decision maker first assigns maximum number of points to the criteria he/she considers most important and then assigns less points to the remaining criteria.

3. MODEL FOR ASSESSMENT OF SAFETY MEASURES IN DENTAL PROSTHETICS LABORATORIES

Considering that weight assignment has a important influence on the final assessment result, model for multi-criteria assessment of environmental and occupational safety measures in dental prosthetics laboratories has implemented the weighting methods: fullers triangle (FT), analytic hierarchy process (AHP) and reduction coefficients (RC).

Basic concept of the model for multi-criteria assessment is developed in modular structure according to [22], Fig. 1.

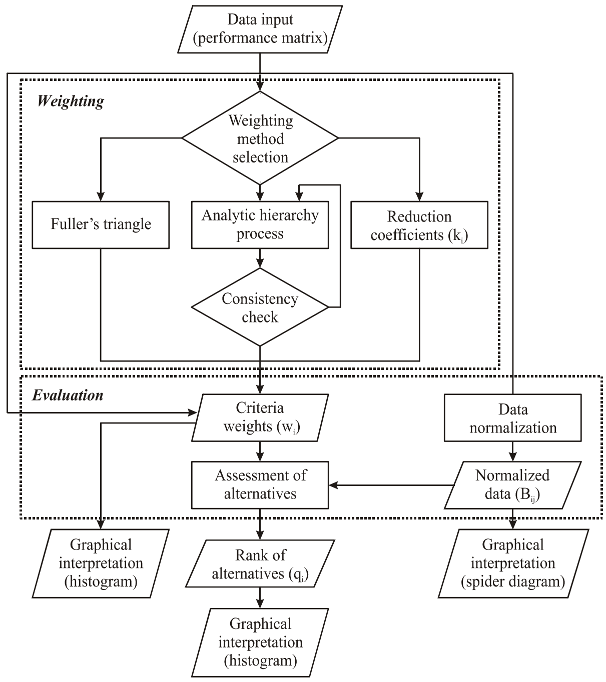


Fig. 1. Flow chart of model for assessment of safety measures in dental prosthetics laboratories

Final score for the alternatives is performed by multiplying the normalized criteria values with the assigned weights:

$$q_i = \sum_{j=1}^{m} w_j b_{ij}, \quad i = 1, 2, ..., n, \tag{1}$$

where: b_{ij} - normalized criteria, w_j - criteria weight, m - number of criteria, n - number alternatives.

Criteria weights are assigned using one of the three previously mentioned methods (FT, AHP, RC), while the normalization is done according to:

$$b_{ij} = \frac{a_{ij} - u_j}{s_j}, \quad i = 1, 2, ..., n;\ j = 1, 2, ..., m, \tag{2}$$

where: a_{ij} - ordered value of j-criteria (assigned +/- for y_{ij} values depending on the j-criteria type), u_j - artificial vector (minimal values from a_j), s_j - standard deviation of ordered j-criteria:

$$s_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(a_{ij} - \bar{a}_j\right)^2}, \quad j = 1, 2, ..., m, \tag{3}$$

where: $\bar{a}_j$ - j-mean value of criteria.

Difference between the criteria that have to be minimized/maximized is done multiplying the j columns of performance matrix $Y=[y_{ij}]$, whose environmental impact is obviously negative, by -1. This results in a matrix $A=[a_{ij}]$, with ordered values of j-criteria, which has the same dimensionality as Y. Higher dimensionless values q_i of the i-th alternative indicate better safety measures and vice versa.

4. ASSESSMENT OF DENTAL LABORATORIES

The aim of the work was to evaluate safety measures performed in every day work for 10 dental laboratories in Novi Sad and its suburbs (Fig. 2). It is important to note that the dental laboratories have been chosen unintentionaly.

Fig. 2. One of the dental prosthetics laboratorie

Research was conducted through the questionnaire presented in [2] and the results were summed in Table 1. All the assessment criteria had a positive influence on the safety measures except number of employed technicians. Number of technicians was presumed to have a negative impact because when it increases the air dust increases also. The goal, criteria, and the alternatives were defined according to Fig. 3.

Fuller triangle (FT) was chosen for weight assignment because of the simple and fast use, Fig. 4. Each pair - made up of two parameters being compared - carries one point, where the point is awarded to the more significant parameter (which is then encircled). If a decision is made that they are of equal importance - the parameters get half point each (this pair is then enclosed in a rectangle). Once the evaluation is finished, the points awarded to parameters are summed up, and the sums represent their weights. Use of the air dust aspirator and safety glasses were found to be the most important criteria, while the least important criteria was number of technicians, Table 1.

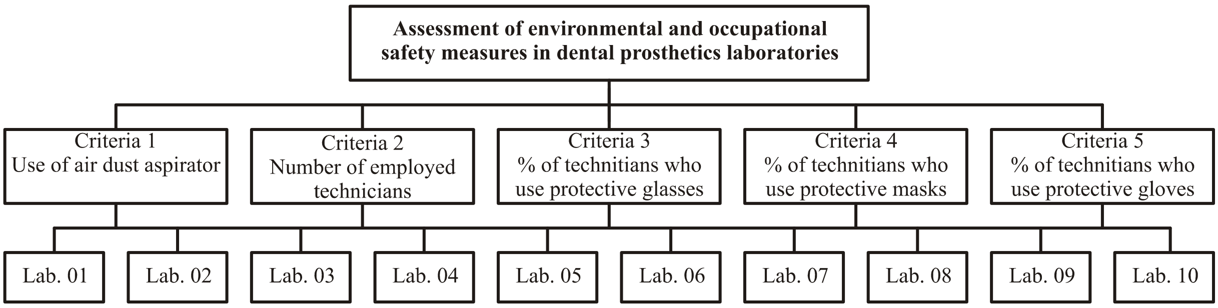
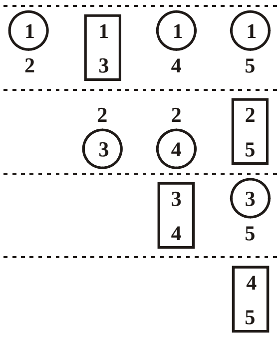


Fig. 3. Decision tree for assessment of environmental and occupational health safety measures



Criteria number:
1 - Use of air dust aspirator
2 - Number of employed technicians
3 - % of technicians who use protective glasses
4 - % of technicians who use protective masks
5 - % of technicians who use protective gloves

Fig. 4. Criteria weighting according to Fullers triangle

Crit. weight	3.5	0.5	3.0	2.0	1.0
Crit. type	Max	Min	Max	Max	Max
Dental Lab.	Use of air dust aspir.	No. of technic.	% of tech. who use protective		
			Glasses	Masks	Gloves
01	No - 0	10	40,00	50,00	10,00
02	No - 0	11	54,55	36,36	0,00
03	Yes - 1	9	55,56	44,44	22,22
04	No - 0	2	100,00	0,00	50,00
05	Yes - 1	3	33,33	0,00	33,33
06	No - 0	1	0,00	100,00	0,00
07	No - 0	4	75,00	50,00	0,00
08	No - 0	5	60,00	60,00	0,00
09	Yes - 1	5	100,00	100,00	60,00
10	No - 0	4	50,00	25,00	0,00

Table 1. Performance matrix for dental laboratories

Criterion with “min” type was multiplied with -1 and obtained results were normalized according to equation 2. Final results of multi-criteria analysis (Fig. 5) clearly show that the laboratory 9 has the best rank while the laboratories 1, 2, 6 and 10 have the smallest rank. It is important to highlight that the best ranked laboratories had a functional air dust aspirator, the criteria with the largest weight coefficient.

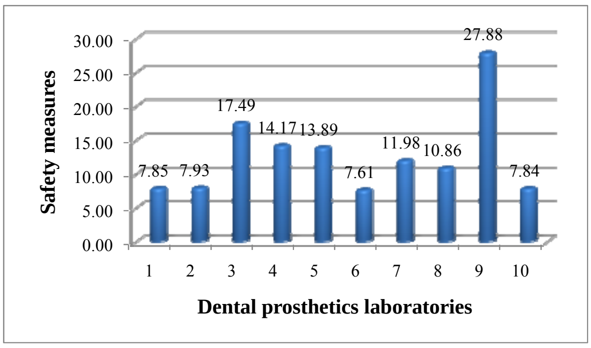


Fig. 5. Multi-criteria analysis results

5. CONCLUSION

Questionnaire results showed that only three laboratories had a ventilation system, and all the laboratories had the protective eye glasses, masks and gloves, but the technicians did not always use them.

That leads to the conclusion that the dental technicians were not well informed about the possible harmful effect if the safety measures are not undertaken.

Multi-criteria analysis revealed dental prosthetics laboratories with improper safety measures. Although the multi-criteria analysis was done with criteria considering safety measures in dental prosthetics laboratories, future research should comprehend extended number of criteria such as dentures materials, microclimate parameters, type of processing and modelling, and noise for obtaining of more valid and relevant results. Furthermore, AHP and RC weighting methods can also be included if there are such requirements.

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Original Scientific Paper

Bosák, M., Schwarczová, H.

MODEL FOR EVALUATION OF THE ENGINEERING PROJECTS ENVIRONMENTAL QUALITY

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Abstract: *The constant pressure and shortening delivery time of products to the market, increasing sort, quality and lowering production costs mean a considerable complexity of problems. Today many firms are beginning to more intensively involve new organizational structures, forms of better - utilizing human potential yet also seeking an ecological strategy culminating in "clean manufacturing ".*
Ecological industry is projected into the creation of conditions for developing "clean" works which do not pollute the water, air, soil and other parts of the living environment. It is concerned mainly with production conceived with respect to the protection of the living environment, as well as new principles of constructing products (Green engineering) and methods of recycling products and energy.
Key words: *environmental quality, clean manufacturing, green engineering*

Modeli inženjerskih projekata za ocenu kvaliteta životne sredine. *Konstantan pritisak i skraćenje vremena isporuke proizvoda na tržište, povećanje sortiranja, kvaliteta i smanjenje troškova proizvodnje podrazumeva znatnu kompleksnosti problema. Danas mnoge firme počinju sve intenzivnije da uključuju nove organizacione strukture, u cilju boljeg - korišćenja ljudskog potencijala ali takođe tražeći ekološku strategiju za kulminiralo "čiste proizvodnje".*
Ekološka industrija se projektuje u na stvaranju uslova za razvoj "čistih" poslova koji ne zagađuju vodu, vazduh, zemljište i ostale delove životne sredine. Ona se uglavnom bavi proizvodnjom koncipiranom u pogledu zaštite životne sredine, kao novi principi konstruisanja proizvoda (Zeleno inženjerstvo) i metoda za recikliranje proizvoda i energije.
Ključne reči: *kvalitet životne sredine, čista proizvodnja, zeleno inženjerstvo*

1. INTRODUCTION

Environment strictly refers to people and consists of general environmental background as well as economic, social and cultural structures created by itself. Therefore a study of the relation between an engineering work and the environment must not be reduced only to economic aspects. It must cover also other structures.

The reason of the study of the relation between engineering activities and the environment is to “compare the ecological violation degree with the economic and social benefits”. It is necessary to chose and define the components, which describe system, form and the purpose of their application, and standardise them as the indicators not only for ecological but also for socio-economic part of the system. After technical revision they can be used also as control or warning limits (Figure 1).

The aim of standardisation is to determine the target values (the most suitable values) as well as critical values. These values should not exceed (they must not exceed from the ecological point of view although it can theoretically exceeds in economics).

A, B, C, D: eventual development.

A: integral of maximum ecological and economic target values.

B: integral of maximum ecological target values and minimum socio-economic target values.

C: integral of maximum economic target values and minimum ecological values.

D: integral of minimum ecological and economic target values.

The progress of trajectories (c) and (d), which characterises the decline of ecological conditions because of engineering works, does not show such economic effects as trajectories (b) and (a) does. Despite of equal ecological violations engineering works (a) and (b) are considerably better referring to their economic benefit.

Figure 2 illustrates these coherences therefore different operation conditions for each application system. The ideal situation is when “no ecological changes follow maximum socio-economic benefit”. There exist also transient zones and ecological marginal range state on the assumption of minimum socio-economic benefit. [1, 2]

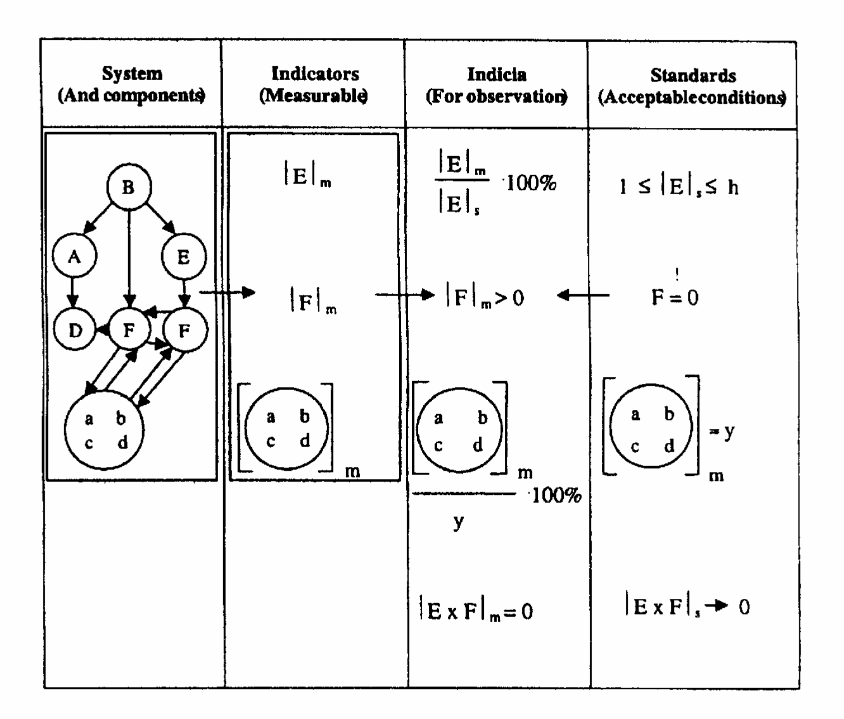

Fig. 1. Systems, indicators, standards and indices definition and their mutual operating

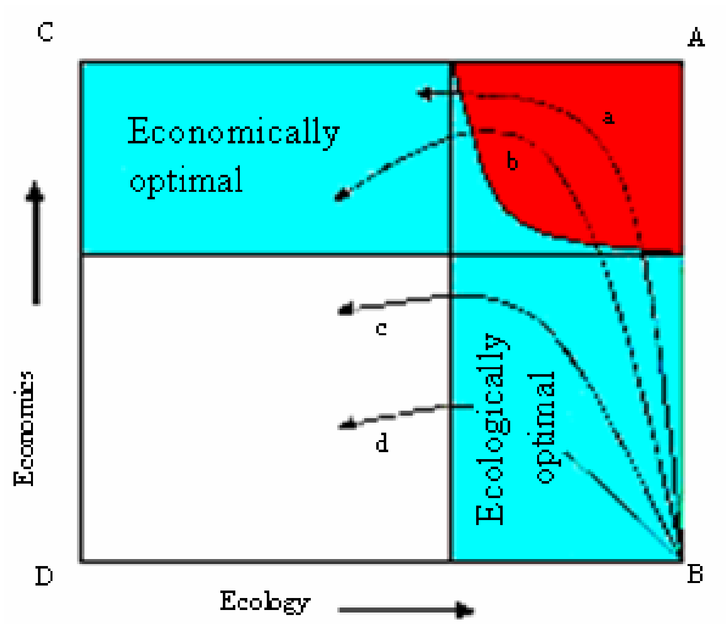

Fig. 2. Ecology-economical continuity and the source of its compartments

2. MATHEMATICAL EVALUATION MODEL

Ecology and socio-economic are not simple components, they consists of number of other components. Both integrals are divided into smaller compartments and these are divided into basic components.

Integral of the ecology is created from following elements:

- water quality (with the basic indicators: pH-value, acid volume, faecal contamination),
- biology (indicators: flora and fauna diversity, protected species),
- ground frame (indicator: amphibians and waterfowl diversity, rare species) if it relates to river analysis, considered as a source of the water-power).

Integral of socio-economic would consist for example of following items:

- water-power equipment costs,
- economic benefit (indicators – working posts, workers' earnings),
- social benefit (indicators – housing conditions, health), which are adherent to the system.

It is possible to deduce from the listed above following procedure for the evaluation of the engineering actions tolerance:

- Analyse the task,
- Determine the geographical bounds,
- Evaluate the target socio-economic concepts,
- Define important socio-economic and inferior parts (for the system and application targets),
- Determine inferior parts important basic indictors,
- Standardise the basic indicators using upper and lower limits,
- Execute zero calculations.

When indicators are defined and standardized, actual measure values can be determined and normalised as indices (see equation (1)). So every normalised value lies between 0 and 1.

- After standardization every basic value of each part can be integrated as the second order indices. We can assign different significance level to basic values using factors (a_{ij}) as well as value power (P). Value (a) presents different weight of the basic indicators over their total width (P).
- When "second order indices" are computed, they are integrated to the total index for. Different weight is possible using factor (a), in this case it is the order of the power exponent.
- Computed relevant values for the ecology and socioeconomic are depicted into a graph. Their difference from values $x = 1$ eventually $y = 1$ presents the stress or differentiation to the socioeconomic target conception.

Then distance from the ideal point $A(1, 1)$ can be computed (4). The smaller is that value the better the system nears to optimum.

3. INDICES COMPUTATION

Standardisation of the basic indices

$$\dot{L}_i = \frac{(l_b - l_a)}{(l_b - l_s)} \qquad (1)$$

Integrated second order indices computation

$$\ddot{L}_j = \sqrt[\ddot{P}j]{\sum_{i=1}^{n} \left[\left(a_{ij} . \dot{L}_{ij}^{\ddot{P}j} \right) \right]} \qquad (2)$$

Integrated third order indices computation

$$\dddot{L}_k = \sqrt[\ddot{P}k]{\sum_{j=1}^{m} \left(b_{jk} . \ddot{L}_{jk}^{\ddot{P}k} \right)} \qquad (3)$$

Integrated system index computation

$$L = \sqrt{\left(c_1 \dddot{L}_1^2 + c_2 \dddot{L}_2^2 \right)} \qquad (4)$$

l – basic indicator, defined through the zone width ($l_b - l_s$) and actual value l_a

$\dot{L}$ – standardised value of the basic indicators (refers to ideal point)

a – relative significance (value) of the standardised basic indicators value

$\ddot{P}$ – critical (dominant) factor of the basic indicators set

$\ddot{L}$ – index for the subsystem characterisation

b – relative significance of the subsystem

$\dddot{P}$ – dominant factor for the set of subsystems

$\dddot{L}$ – index for the ecological and socio-economic components characterisation

c – relative significance of the ecological and socio-economic components

L – integrated index for the whole system characterisation

Note: All indices ($\dot{L}, \ddot{L}, \dddot{L}, L$) present the distance from "ideal point"!

4. METHODICAL TECHNIQUE

1. Determine geographical bounds of the investigated system.
2. Define subsystems of the ecology and socio-economics of the investigated system.
3. Chose basic indicators $l_{(i)}$ and clarify the choice
4. Determine the basic indicator zone width using its better and worse value and actual system value.
5. Calculate standardised first order indicators $\dot{L}_{(i)}$, from (1)
6. The set of indicators $\dot{L}_{(i)}$, separated by subsystems j and their values of relative significance, with the condition that single measure values $a_{(i)}$ inside each subsystem j equal to 1. Domination assumption ($\ddot{P}$ i of the subsystems j. Second order indicators calculation $\ddot{L}_{(i,j)}$, hence consequently integrated indices $\ddot{L}_{(j)}$, hence, integrated indices $\ddot{L}_{(j)}$.
7. Determine indices $\ddot{L}_{(j)}$ corresponding to ecology ($k = 1$) and to socio-economics ($k = 2$). The advantage for the subsystem preference $b_{(j)}$ and sum of all $b(j)$ inside each group k must equal to 1, as well as advantage of the domination ($\dddot{P}$) of each group k. Third order indicators $\dddot{L}_{(j,k)}$, hence integrated indicia $\dddot{L}_{(k)}$ computation.
8. $k = 1$ for ecology and $k = 2$ for socio-economic produce indices $\dddot{L}_{(k)}$ measured as the distance from (theoretical) "ideal point".

9. Computation from the integrated system – index *L*, integral of the partial ecology and socio-economics system has equal preference (c = 0,5) and equal dominance (P = 2). System index *L* is the distance from the (theoretical) "ideal state" in three-dimensional space, which expands through *L* like variant target.

10. Analogically computation can be performed for various considered alternatives, which are completed with the sensitivity analyses according to different preferences and dominances impacts. [3, 4]

5. CONCLUSION

As any other methods even this one have its own weakness. The greatest one comes from choice and standardisation of the basic indicators. Type of indicators as well as determination of optimal and minimum values opens the space for manipulations and speculations. The same reasons can be the method's strengths. The problem is that choice and standardisation of the basic indicators must be clearly defined. Then they are controllable and correction able. The method obliges also to cooperation between different science disciplines. The team must elaborate choice as well as standardisation. They are usually the results of the compromises. Compromises are possible only if the system and target conception are clearly defined.

Another weakness of the method (and the strength at the same time) depends on the right degree of importance determination. There would be also space for certain manipulations if the importance would not result from the professional discussions between different experts of several specializations. Different opinions on importance allow to change the centre of system and then to correct target conceptions during system performance.

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Original Scientific Paper

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RISK MANAGEMENT AS A TOOL RAISING OF ENVIRONMENTAL QUALITY PROCESS

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Abstract: *The development of manufacturing and consuming processes, activities, services is today and will be in the future tightly connected to the ecologisation and sustainable development. The authors present an approach of the environmental risk prevention and present the Environmental Management System (EMS) as effective tool of the environmental risk prevention and raising of environmental quality process. The identification of the environmental aspects, impacts and risks and their characteristics and assessment in the specific register is the first and key step of the environmental risk prevention. Positive experience of the environmental management system applications is a motivation for the continual development of the processes with expected syenergistic effects and reduced risk.*
Key words: *Environmental Management System (EMS), environmental quality process, effects*

Upravljalje rizicima kao sredstvo za podizanje kvaliteta životne sredine. *Razvoj proizvodnje i primenjujućih procesa, aktivnosti, usluga je danas i biće u budućnosti tesno povezan sa ekologizacijom i održivim razvojom. U radu autori predstavljaju pristup životnoj sredini radi sprečavanja rizika i predstavljanja sistem upravljanja zaštitom životne sredine (EMS) kao efikasno sredstvo za sprečavanje rizika po životnu sredinu i podizanje kvaliteta životne sredine. Identifikacija ekoloških aspekata, uticaja, rizika i njihovih karakteristika, i procena u specifičnom registru je prvi i ključni korak u prevenciji rizika životne sredine. Pozitivno iskustvo primene sistem za upravljanja zaštitom životne sredine je motivacija za stalnim razvojem procesa sa očekivanim sienergetskim efektima i smanjenjem rizika.*
Ključne reči: *sistem upravljanja zaštitom životne sredine (EMS), podizanje kvaliteta životne sredine, efekti*

1. INTRODUCTION

The subject of environmental security, assessment and prevention of the environmental aspects, impacts and risks has dynamic character. The numbers of methods were developed and used for risk identification sources, assessment and risk prevention in the past. Today‘s systematic dealing with the risk management is definitively preferred. It is the subject of an interest of local and international participated organizations dealing with environmental safety and environmental engineering problems in global, with target to implement unique standardized system.

2. ENVIRONMENTAL MANAGEMENT SYSTEM

The prevention can be identified as an expected environmental damage, to which we are able to avoid by taking an appropriate actions or choosing less dangerous activities. In some specific cases specific correct measurement could be implemented late and it is to late avoid environmental disaster. The prevention should be a part of everyday activities for organization. The management can use available tools such as Environmental Impact Assessment, Life Cycle Assessment (LCA), Environmental management system, Environmental Audit and Environmental Statement [1].

Environmental management system (EMS) is part of voluntary group preventive tools of environmental policy. The system is implemented to manage the significant environmental aspects and meet the legislation requirements. Thus, the EMS is a common used tool of the organization control management which joints the basic environmental protection approaches of the and leads to environmental achievements and business goals.

EMS includes organisational structure, planning, responsibilities, processes, procedures and resources for developing, implementing, reviewing and maintaining environmental policy [2].

EMS implementation guarantees well structured process to identify all relevant aspects, which are helping to reduce environmental risks. Monitoring of the prevention process and EMS continual improvement can help to reduce environmental risks (negative environmental impact reduction).

It is important to be fully committed to issues in environmental management. By doing that you are more likely reducing exposure of environmental risk. The implementation and performance of EMS guarantee the prosperity to organisation and its competitivity, that decrease material and energy utilization, minimalizes waste, builds green company image, reduces fees of pressure on the environment, decreases financial penalty and increases manufacturing quality overall [3], [4], [5]. The Fig. 1 shows the organization‘s benefits after EMS implementation process [6].

There are two standards of EMS implementation. The first one is applied according to ISO 14000 series, that represent worldwide transparent normative documents developed by ISO *(International Organization for Standardisation).* Standard norm for the implementation and EMS certification is the norm ISO 14001.

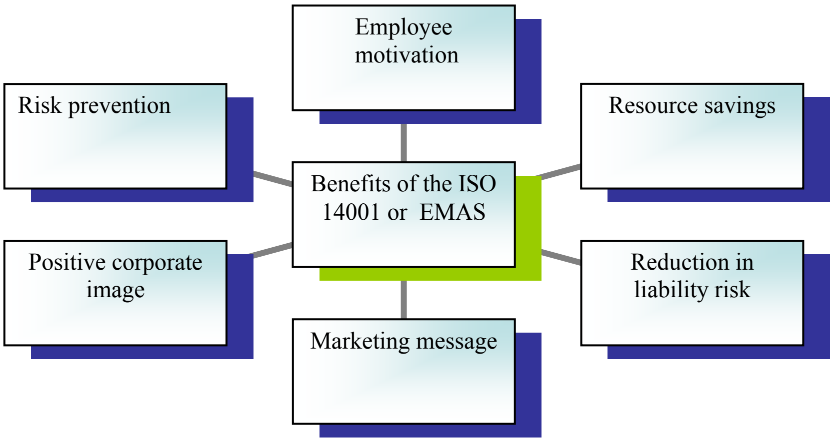

Fig. 1. Benefits of the EMS implementation

The second standard is EMAS scheme *(Environmental Management and Audit Scheme)*, which is the EMS establishment according to the Regulation of the European Parliament and the Council (ES) No. 1836/1993, and/or EMAS II No. 761/2001 after revision. Another option for the EMS implementation could be one of the numbers of informal environmental management tools, i.e., LCA, environmental benchmarking, cleaner production, etc.

3. RISK REGISTER

Prior to risk management process the risk, the risk identification is necessary (it is the basis for the risk management). Register of environmental aspects and impacts can be used for that purpose. It is basis for procedure recognition inadequate burden and identification and risk assessment. That is solving the problems in environment and safety. Each organization has created its own register, because even for the same task every organization has different working conditions, sources the procedures are also different. An environmental aspect refers to an element of an organization, activity, product or service that can interact with the environment. An environmental impact refers to any change which takes place in the environment as the result of the aspect. It is important to identify each negative environmental aspect whether it has direct or indirect impact [7].

Aspect	Impact	Occur-ance	Situation of occuran-ce	Significance aspect	Aspect control/management
Placement of hazardous material (P)	Soil contamination	rarely	Regular operation	**Moderate**	Waste separation Waste legislation
Use of electricity (P)	Depletion of natural resources	regular	Regular operation	**Major**	Monitoring of electricity consumption
Use of energy (P)	Depletion of natural resources	regular	Regular operation	**Minor**	Monitoring of energy consumption
Use of water (P)	Depletion of natural resources	regular	Regular operation	**Minor**	Monitoring of consumption and quality water
Use of paper products (P)	Soil erosion	rarely	Regular operation	**Minor**	Waste separation
Sewage water (N)	Water and soil contamination	rarely	Regular operation	**Minor**	Water legislation
Solid waste (P)	Soil contamination	rarely	Regular operation	**Moderate**	Waste separation Waste legislation

Table 1. Register of Environmental Aspects and Impacts (P-direct, N-indirect)

The organization while assessing significant environmental aspects should consider following:

- The probability of an environmental adverse outcome,
- Vulnerability of the environment (local, regional, global),
- The amount and frequency of aspect and impact,
- Compliance with all legal and other requirements,
- Views of stakeholders.

The environmental aspect identification is very important input for organization in planning for environmental management system EMS. The organization should establish, implement and maintain a procedure [3]:

- to identify the environmental aspects of its activities, products or services, with the defined scope of its EMS that can monitor and those it can influence taking into consideration planned or new development, or new modified activities, products or services,
- to determine those aspects that have or can have significant impact on the environment (i.e., significant environmental aspects).

By means of the risk matrix, the register can be integrated by values (numbers) to make it more transparent. To do this, the input and output activities must be identified first, followed by environmental aspects (direct and indirect) derived from the activities. The category of the aspects includes emission, water pollution, waste, land contamination, usage of resources, water consumption, etc. Finally, the environmental aspects are assessed as is shown in the Tab.2 [4]. Significance of environmental impacts is assessed according the Tab.3.

Level	Description
1 Never	Little or no stakeholders interest
2 Unlikely	Small arrangements are necessary.
3 Possible	Negative aspects are visible. Management control is necessary.
4 Likely	Aspect control is necessary during processes.
5 Almost	All aspects shall be controlled during processes.

Table 2. Environmental impact assessment

Level	Description
5Catastrophic	Significant off-site toxic release with long term environmental damage
4 Major	Off-site release with short term or minor environmental impact
3 Moderate	Off-site release with minimal environmental impact or on-site release requiring outside assistance
2 Minor	On-site release contained, but the effect is minimalized
1 Insignificant	Minor fully contained release, without negative environmental change

Table 3. Severity of impact

Here we include the level of emission, probability of serious accident occurrence, pollution, the number of complaints, and aspect perception by public. Next by using Tab.2 and Tab.3 and taking risk matrix (Tab.4) in to the consideration, the final values of risk are calculated. These values we can record in to the register of aspects, impacts and risks [4].

Consequences		**5 Catastrophic**	**4 Major**	**3 Moderat e**	**2 Minor**	**1 Insignificant**
Probability						
5	**Almost certain**	**25**	**20**	**15**	10	5
4	**Likely**	**20**	**16**	**12**	8	4
3	**Possible**	**15**	**12**	9	6	3
2	**Unlikely**	10	8	6	4	2
1	**Never**	5	4	3	2	1

Tab. 4 Risk Rating Matrix

Another form of the register of environmental aspects is its number representation (Tab.5). The value is calculated as probability multiplied by effect (consequence) followed by the addition of particular aspects (the weight of the risk is from range 1 to 3). Effectual impact as a number representation shows column 10 (labeled as „Total“) of the Tab.5 [5].

Number			1	2	3	4	5	6	7	8	9	10
	Risk											
Aspect	Probability	Impact	Product	Previous events	Unconfortability	Exceptionability	Local/global	Time limit	Future activities	Legislation	Lack of information	**Total**
Air emission	3	3	9	2	2	2	2	2	1	3	0	**23**
Water emission	2	3	6	2	1	2	1	1	1	3	0	**17**
Solid waste	1	1	1	1	3	3	1	2	1	2	3	**17**
Energy use	1	1	1	1	1	1	1	1	1	0	0	**7**
Noise	1	2	2	2	1	1	1	1	1	0	0	**9**
Visible impact	1	1	1	1	3	2	1	1	1	1	1	**12**
Ecosystem	1	2	2	1	1	1	2	1	2	0	0	**10**
Transportation	1	1	1	1	1	1	1	1	1	1	0	**8**
Supplies	1	1	1	1	1	0	1	1	1	1	3	**10**

Table 5. Environmental aspects and impacts register (number representation form)

4. CONCLUSION

Environmental program and its short and long term goals of each organization (company) helps understand the organization‘s (company‘s) activities to improve its environmental behavior. The organization should be able to show distinctive connection between significant environmental aspects and its improvement plans, and put its short and long term goals in to relation with significant environmental aspects and their impacts.

If environmental aspect is a source of significant environmental impact, then this environmental aspect is marked as significant environmental aspects and has to be integrated in to the environmental management system.

From the viewpoint of the planning process, the ESM as a tool of prevention helps to define and/or assess all significant environmental aspects of products and activities in relation of their significant impact on environment. The designation and follow the procedure to identify these aspects is important and is taken in to the consideration in process of organization’s long term environmental goals statement.

To prefer prevention against the elimination of unacceptable consequences (events) in relation to environment, and application of principles of systematic improvement is the right direction to the sustainable development. ESM can be considered as a tool of environmental risk prevention because of its approach to the environmental protection of all involved parties.

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Original Scientific Paper

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UTILIZATION OF METHODS AND THEIR FINAL ELEMENTS IN THE AUTOMOTIVE

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Abstract: *This article introduces the most common methods based on the CAD and FEM. As well, briefly explains the principles of the model preparations, analysis set up and the ways of solvers calculation. Also shows a few examples of their implementation right into the automotive industry research and production.*
Key words: *CAD, FEM, FEM calculations, model.*

Primena metoda konačnih elemenata u automobilskoj industriji. *Ovaj rad prikazuje najčešće metode koje se primenjuju, zasnovane na CAD i FEM analizi. Pored toga dobro i jednostavno objašnjava principe pripreme, analize i metode rešavanja proračuna. Takođe je prikazano i nekoliko primera njihove primene konkretno u istraživačkoj automobilskoj industriji i proizvodnji.*
Ključne reči: *CAD, FEM, FEM proračun, model.*

1. INTRODUCTION

As well as in every technical area, there is visible a growing effort in automotive industry to implement new, methods for quality [1,2] and progressive methods right into the process of structural design and the production itself. If we consider the process of structural design development to be a search for optimal alternative, than the utilization of these new ways of constructions creation makes it more effective and may bring the optimal results (in compliance with all requirements) in shorter time period and with less expenses. These methods are basically divided into two major sections. The first group consists of CAD methods (computer aided design). Those are primary designed for the modeling of three dimensional structural components and systems from the point of their shape and geometry properties. In fact, they used to be the first step for designers and constructors. Their output (modeled geometry) may become an input for the second group so-called CAE (computer aided engineering) which is mainly based on FEM (final elements methods) and provides a wide range of possibilities. Still developing, this progressive method has already become very powerful and effective tool for predictions and modifications of components behavior even before the first real prototypes are prepared for tests.

2. FINAL ELEMENTS METHODS

The basic idea is quite simple and comes from the fact, that every component may be considered as a material continuum which consists from the infinite number of mass points. Naturally, it is not possible to work with or calculate the structure like this. The only solution is to replace the components volume or middle surface with the finite number of 1D, 2D or 3D elements connected trough the nodes to homogeneous mesh that corresponds with the original geometric shape. Now we are getting the mathematical model with the same material and mechanical properties as the real components has, but due to finite number of used elements the solver is now able to run and finish required analysis. In general, the more elements with lower dimensions we use the more precise results we may obtain. In this way, it is possible to model and set-up for the calculation any real components and if necessary implement them into the sub-systems and major units (Figure 1).

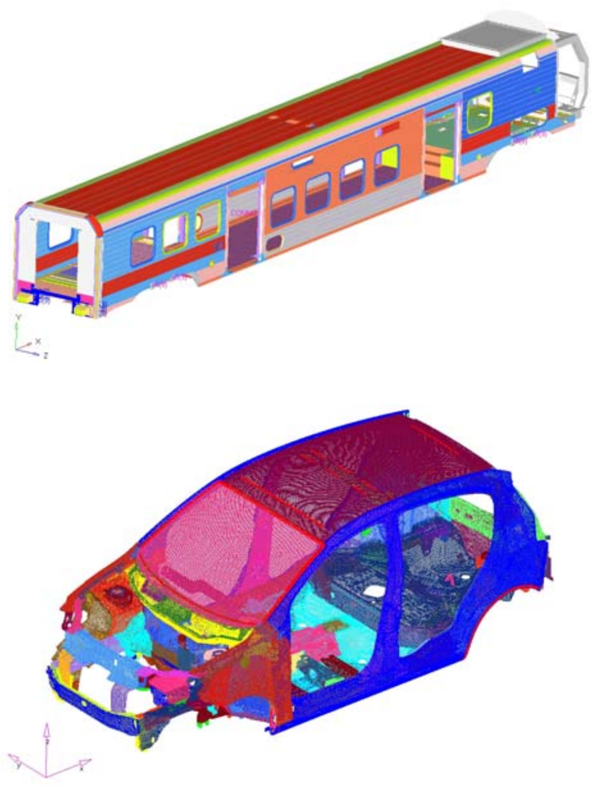

Fig. 1. Examples of structural models from automotive industry created from the final elements

Of course, in order to create the whole systems (including the vehicles of any type), it is not sufficient to know just the geometry of each component, but it also requires the knowledge about their positions, relative interactions, ways of connection etc. and simulate them with highest possible precision. It becomes even more important when the performed tasks are non-linear and includes the dynamic load cases like crash tests, mold flow calculations, fatigue analysis and others. In all of the mentioned cases, the way we describe all known boundary conditions has the significant influence on how close the simulation is able to approach to the real load distribution through the structural system. In general, linear problems based on the static loads acting are considered to be the basic and less difficult tasks. To solve them, just simple linear modules as optistruct are sufficient. Nevertheless, during the components mechanical life span the acting of non-combined static load cases are not very frequent, and in the FEM calculations we usually define them just in two cases:

1) If it is possible to neglect the changes of the acting forces in time or eventually if the constructor already has a knowledge (either from the previous experiences or it results right from the task) that the differences obtained after we change the dynamic problem to static are acceptable for the results and they are not adequate to higher time consumption which is required for the dynamic problem preparations.
2) If there is a request for the stiffness determination of the structure. In the automotive industry the final structures often has to satisfy particular standards (from the point of their mechanical properties), usually defined by the constraints based on the local and global stiffness. The objective may be for instance the simulation of local, short-time loading corresponding to the real situations which may occur as forces caused by the wing maintenance, airframe assembly operations, and moving parts impacts etc. (see Figure 2). As well, the global stiffness attestations are often required (see Figure 3) [3,4]. In all of the mentioned cases, just the boundary conditions and simple loads and moments are applied on the specific positions of FE model. Evaluating the stiffness, not the stress distribution is interesting but the deformations (displacements in case of forces and angles of rotation for moments) in the direction of acting load. With the results, using the simple relation between the acting force and corresponding deformation we are able to get the stiffness values (the force needed for the unit deformation). In real automotive production it may be quite an important information, because it can help to prevent the construction from irreversible plastic deformations.

More difficult problems are presented by the situations, if it is not possible to neglect the effect of the acting forces in time. In these cases we speak about the dynamic loading, so they can not be considered as linear problems. In comparison with the basic linear static tasks, these require more precise understanding of the real situation we are going to simulate.

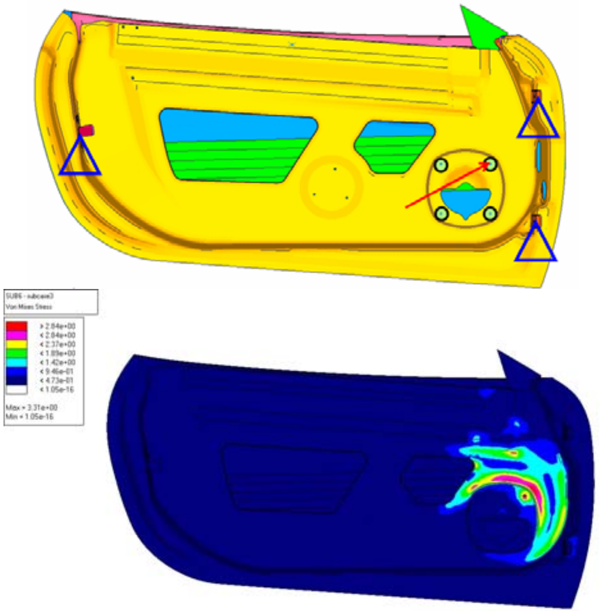

Fig. 2. Local stiffness analysis performed on the internal side of the car doors in positions where the speaker are about to be mounted. Blue triangles shows the constraints, red arrow is the position of the force.

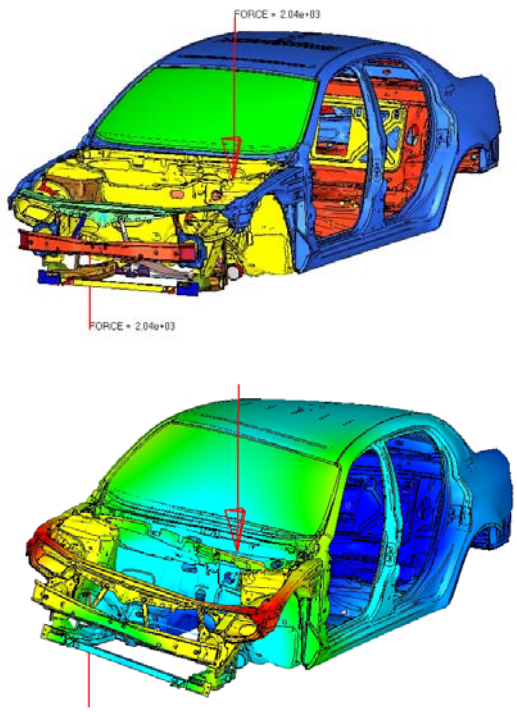

Fig. 3. Global stiffness analysis of the cars chassis.The deformations scale is 1:200.

The preparation itself becomes more difficult, even though we may use exactly the same final elements model like in linear static. The reason is that the main difference does not consists in the model, but in definition of boundary conditions taking into account the load changes in time and what is even more important, in definition of possible relative contacts between the components. As an example we can mention the impact forces during the crash tests. Nowadays it has become usual proceeding that precise virtual simulation using FE methods and non-linear modules precedes the real tests performed with the physical prototypes. Right here the set up of all boundary conditions and contacts shows its correctness, because just the deformation of the few components positioned in front of the car is caused by immediate impact to barrier. All the others parts situated beyond them depend on their deformations and displacements which are distributed continuously trough their relative contacts. From these reasons it is very important to understand the rules of simulated action as well as the environment of the dynamics solvers in order to obtain reliable results. On the other hand the utilization of these methods during the structural design creation (or modification) is very effective mainly if we consider all expenses needed for the real test.

Another separated area (although always depending on the results of basic mechanical analysis mentioned above), visibly growing in automotive industry is the structural optimization using final element methods. In general, this process helps constructors to find an optimal equilibrium between mechanical requirements (structure stiffness, deformations, maximum stress values etc.) while still having the best possible structural properties (low weight, effective structural design without useless material and consequential expenses saves etc.). And exactly the structural optimization represents the solution how to reach optimal design of the components and whole structures. Three main structural optimization disciplines, or categories, have been developed: sizing, shape and topology optimization. Their principles are shown on Figure 4.

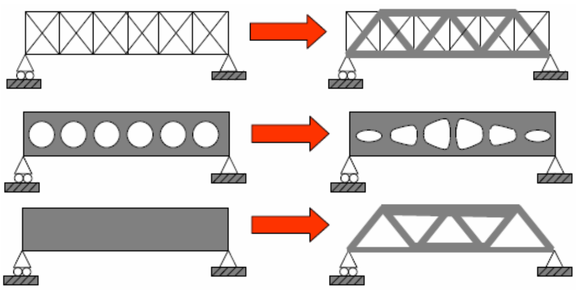

Fig. 4. From up to down: size optimization,shape optimization and topology optimization.

In fact, the process itself comes from quite a simple idea and requires the same finite elements model as any other analysis except that now the optimization set up has been added. It contains mainly the information about the objective (minimize mass, volume, displacements etc.) and constraints (maximum allowed displacement, stress value etc.) Than, during the calculation the solver is trying to find the optimal amount and position of the material in components volume, taking into account all load cases as well as physical and optimization constraints. On Figure 5 we can see the example – the rib of the wing with the thicknesses values suggested by the optimizer. As we can see, elements in shown in red lays right in the path of load distribution trough the model so these areas requires the highest thicknesses. Areas shown in blue are without or under the very low stress so the necessity for the material carrying acting loads decreases[5].

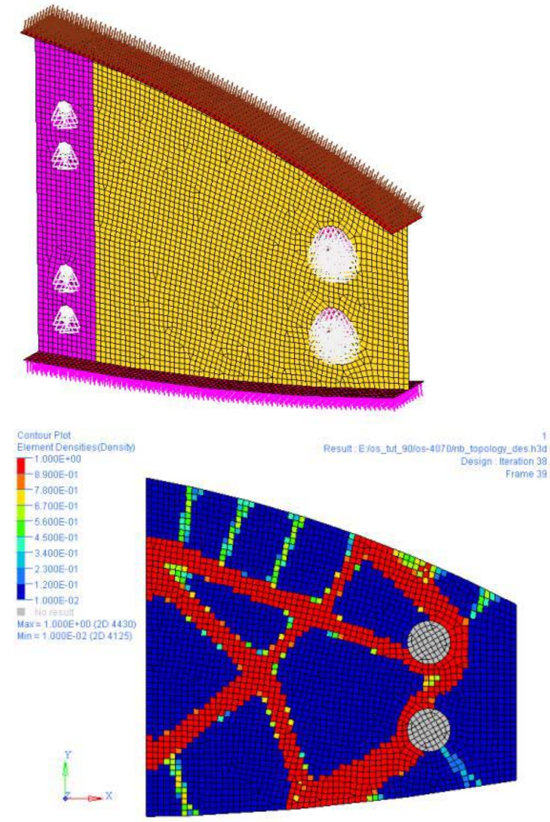

Fig. 5. Topology optimization of the wings rib. Elements in red shows the areas with highest stress concentrations where the major amount of material is required.

Virtual optimization may be used mainly in two basic cases. The first and naturally less efficient way is the application with the existing structural parts in order to improve their properties. Nevertheless, in this way original components design has been already created by standard methods and implemented into the main system assembly, so the possibilities of modification are usually bounded, for instance by the connections with surrounding parts. On the other hand, optimization process may be also used at the beginning of the design process, when the component does not physically exists yet. In general, this is the better solution because constructor has much more freedom in the creation of the optimal components design right in the first phases of projection. Using the proper optimization method, it is possible to explore the material volume which has just a very rough shape of component. Than, according to the required parameters, boundary conditions and loads distribution, optimizer is able to suggest the shape very close to optimal design. It is usually done by using so-called density method, where a single continuous variable $\rho(x)$ is defined for each element included within the components design area. This variable is virtually connected with the element stiffness by the following relationship:

$$E_{ijkl}(x) = \rho(x)^p E^o_{ijkl}, p > 1,$$
$$\int_\Omega \rho(x) d\Omega \leq V; 0 \leq \rho(x) \leq 1.$$

In these equations x represents the position vector and E^o_{ijkl} the stiffness matrix according to the material properties. The term $\rho(x)$ is usually presented as density, mainly if consider that the volume is calculated as $\int_\Omega \rho(x) d\Omega$. And because we can say that $E_{ijkl}(x, \rho = 0) = 0$ as well as $E_{ijkl}(x, \rho = 1) = E^o_{ijkl}$, the density control the existence of each element. So it means, that optimizer evaluate the necessity of each element and decide whether its presents has the significant meaning for the loads distribution trough the volume. According to this, the values between 0 and 1 are assigned for every element where 0 means that no material is needed and 1 requires the full density of material to carry the acting loads.

As an example we can mention door support arm of the airliner. In order to decrease the weight and remove redundant material, chosen components including this arm has been optimized. After the application of the topology optimization and all necessary geometry modifications according to the optimizer suggestions the final shape has been received (see Figure 6). The new design, while still passing all stiffness and deformations requirements has lost almost 20% of its original weight.

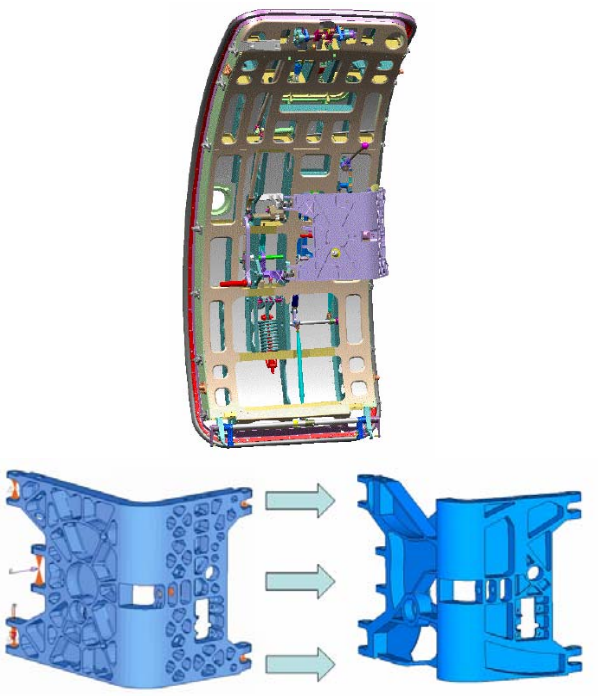

Fig. 6. Topology optimization of the door support arm. Component in the middle is the one with the original design, on the right is the same part after the optimization process.

3. CONCLUSION

As we can see, the techniques of structural design projection mentioned above are able to make the design process and virtual testing easier and more effective. Their utilization may significantly decrease the time consumption and economic expenses along with the same or even increasing mechanical properties of the components and material saves. A lighter structure positively affects the parameters of all vehicles, what is mainly visible in the aircraft industry. Proceedings and possibilities related to FE methods are wide and wise usage may eliminate time wasting, iterative process based on tries and mistakes.

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Preliminary Note

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LAYOUT DESIGN OF VACUUM EFECTOR HEAD FOR MANIPULATION WITH FLOPPY MATERIALS

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Abstract: *The article deals with the selection of appropriate vacuum holding components and their localization in the handling system that is to hold and move rectangular plates . In this article the method of designing and creating the calculation and the program that will enable the automatic selection of the suction elements, as well as their optimal localization in relation with the permitted deflection of the handled object. The calculation is verified by FEM modeling.*
Keywords: *effector, gripper, suction gripper, suction cups, construction of gripping effectors, object handling.*

Plan projektovanja vakumskog nosača za manipulaciju pločastih materijala. *Rad se bavi izborom adekvatnih vakumskih komponenti i njihove lokalizacije pri rukovanju sistemom za prihvat i držanje pravougaonih ploča. U ovom radu je predstavljen metod projektovanja, proračuna i programsko rešenje koje omogućuje automatsku selekciju usisnih elemenata, kao i njihovu optimalnu lokalizaciju sa obzirom na dozvoljen ugib manipulacionog objekta. Proračun je verifikovan FEM modelovanjem.*
Ključne reči: *vakumski nosač, čvrsto držanje, usisna snaga, usisna šolja, konstrukcija vakumskog nosača, rukovanje objektom.*

1. METHOD PROPOSITION FOR THE SELECTION AND DEPLOYMENT OF VACUUM COMPONENTS OF THE HOLDING SYSTEMS

The proposed solutions and the calculation were done for items intended for the manipulation of the vacuum effectors according to the following conditions: manipulated object is flat - sheet metal or metal plate, or a part of it, with a maximum dimension of 2000 x 1200, material - steel plate thickness of 0.2 to 7 mm.

The selection of the required size (diameter) and the number of effectors is such to ensure the safe manipulation with the object and the optimal deployment is done according to the permitted deflection of the manipulated object, where this value is entered into the program by the user [1,2]. In the case of solving one vacuum effector, we can simplify the manipulated object to a circular plate held at the center D_p.

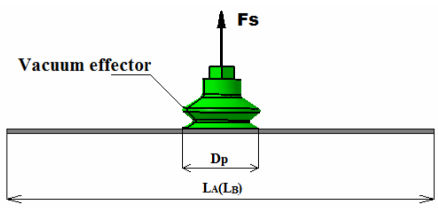

Fig. 1. Using one effector

For the deflection of the plate is true that [4]:

$$Y = \frac{-0,53 + 1,53\left(\frac{2D}{D_p}\right)^2 - \frac{0,94}{\left(\frac{2D}{D_p}\right)^2} - 3,21.\ln\left(\frac{2D}{D_p}\right) - 3,55\left(\ln\left(\frac{2D}{D_p}\right)\right)^2 - \frac{0,89}{2}\ln\left(\frac{2D}{D_p}\right)}{1,3\left(\frac{2D}{D_p}\right)^2 + 0,7} \frac{p.(D/2)^4}{E.h^3} \quad (1)$$

The case of holding with several effectors, where the object handled is of circular shape of radius R we suggest the deployment of the effectors on a circle of diameter R_u [3].

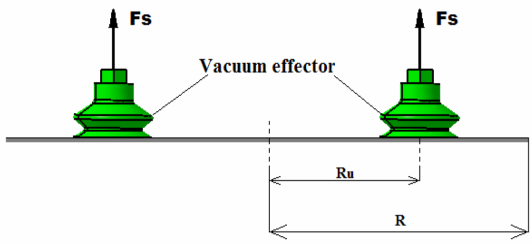

Fig. 2. Using several effectors

Solving the following equations we get the equation of deflection on the perimeter [4],

$$Y_Y = \frac{239}{208}\frac{R^4.\rho.g}{B.h^2} - \frac{141}{104}\frac{R^2.R_u^2.\rho.g}{B.h^2} + \frac{43}{208}\frac{R_u^4.\rho.g}{B.h^2} + 3\frac{R_u^2.R^2.\rho.g}{B.h^2}\ln\frac{R_u}{R} \quad (2)$$

and the deflection of the plate in the center is:

$$Y_S = \frac{143}{208}\frac{R_u^4.\rho.g}{B.h^2} + \frac{R^2.R_u^2.\rho.g}{B.h^2}\left(\frac{57}{104} - \frac{3}{2}\ln\frac{R}{R_u}\right) \quad (3)$$

The total deflection of the circular plate is then expressed as the sum of those two deflections:

$$Y = Y_Y + Y_S \quad (4)$$

The problem of rectangular plates can be solved with sufficient accuracy, by representing the rectangle as two circular plates with diameters responding to the lengths of the sides of the rectangle (Fig. 3) [5].

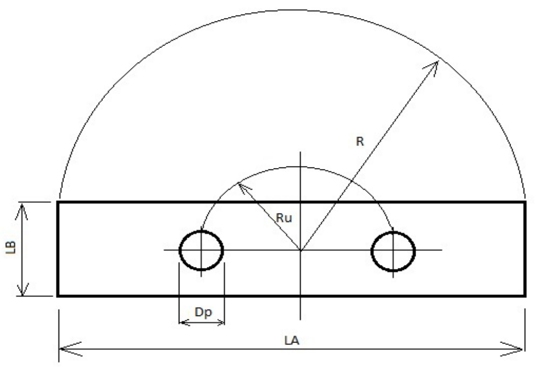

Fig .3. Substitution of rectangular plates by circular ones

2. PROPOSAL FOR AUTOMATED SELECTION AND DISTRIBUTION OF VACUUM COMPONENTS IN THE HOLDING SYSTEMS

In this study, the software used was the 2009 version of SolidWorks software with an integrated program SolidWorks Simulation used for solving model situations. This sub-program operates on the principle of FEM. Following the establishment of a network of elements, it calculates the parameters in nodes by applying specified material properties. The accuracy of the calculation is then given by the delicacy of the network. Therefore, for these relatively simple cases the criteria selected are very strict in addition to the controlled formation of a curvilinear grid. The force action is represented by the acceleration of gravity.

Material that was used:

- Metal 11 343.0 heat rolled
- Modul of elasticity E = 2. 10^5 MP
- Poisson's ratio μ= 0, 28
- Modul of shear stress G = 8. 10^4 MPa
- Density ρ = 7, 80 g/mm^3
- Tensile strength Rm = 325 MPa
- Yield strength Re = 180 MPa

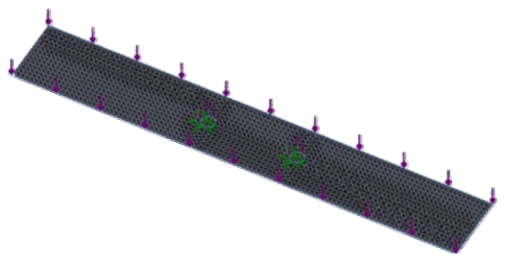

Fig. 4. Volume network of the plate

2.1 Analysis of deflection using one vacuum effector

This simple situation gives us an initial idea of the deformations and tensions in the material. The used structure resulted in 82,576 computing nodes and 45,879 elements. The resulting effect is accentuated by the deformation ratio of 4:1 (Fig. 5). In this case, we can control the deflection only by changing the effector diameter.

Input Data:

- Diameter of the effector D_U = 40 mm
- Central deployment
- Semi-product 350 x 600 x 0,5 mm

Output Data:

- The deflection of the free end(corners) Y=15 mm
- Maximum stress in the areas marked red is 59.8 MPa

Table 1. Deflection Values of semi-product 350x600

Dimensions: 350 mm x 600 mm						
thickness [mm]	0,5	1	1,5	2	5	7
deflection[mm]	15,08	3,78	1,70	0,87	0,12	0,053

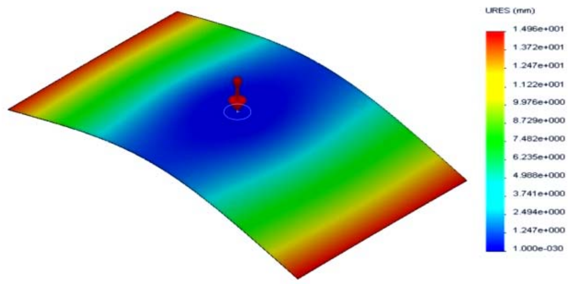

Fig. 5. The course of deformation show in scale 4:1

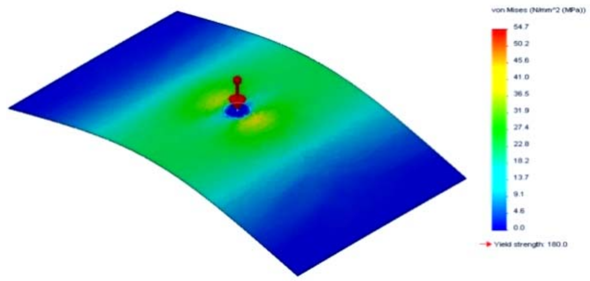

Fig. 6 The course of stress

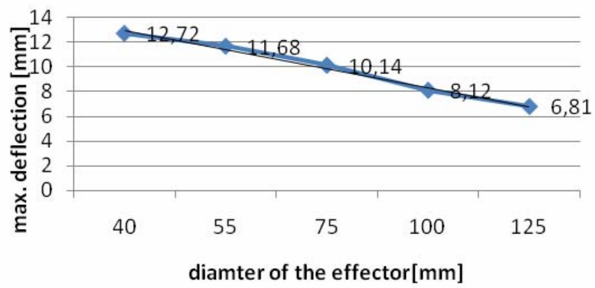

Fig. 7. The relation between deflection Yand the diameter of the effector D_p

2.2 Deflection analysis in the case of using two or more vacuum effectors

In the case of using two effectors deployed along the length of the axis, the regulation of the deflection of the free ends was done by changing the distance separating the effectors fro each other. The contours of the effectors are represented in the images below as circles.

Input Data:

- Diameter of effector D_p = 40 mm
- Number of effectors n = 2
- Diameter of the pitch circle Du = 90,125 mm
- Semi-product650 x 1000 x 0,5 mm
- Permitted deflection 100 mm

Output Data:

- Deflection Y = 109 mm > Y_{DOV} = 100 => doesn't meet required conditions

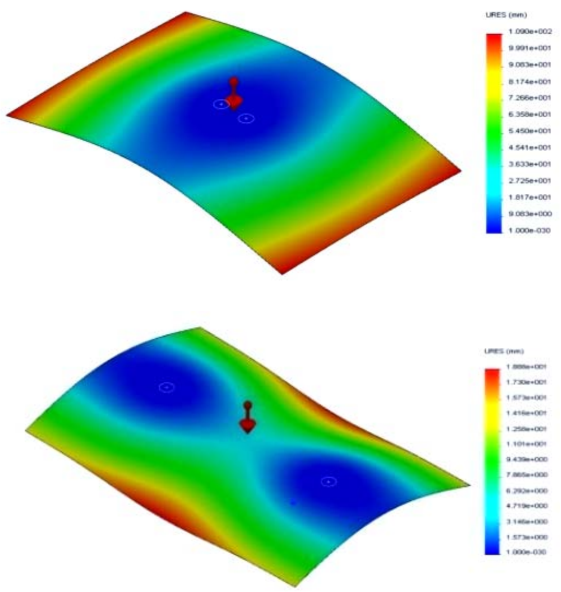

Fig. 8. Using two effectors a, b

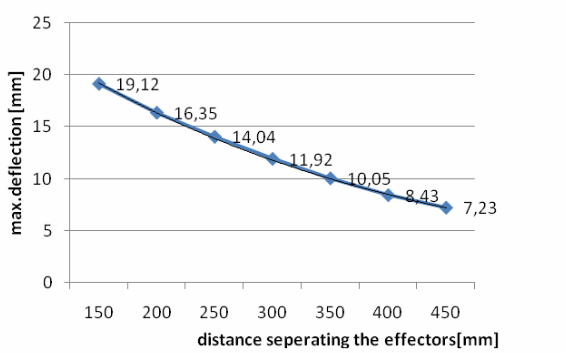

Fig. 9. The relation of the deflection Y and the distance between the effectors

To highlight the benefits of using multiple mounting in cases with high strain, dependence was obtained between the deflection of the free end and distances separating the holding elements. The calculation was performed for semi-product of dimensions 1200 x 750 x 1.5 mm. When using an element with a diameter of 125 mm, we calculated 26 mm of deflection and tension in the critical areas reached values up to 100 MPa. As the chart shows the change in distance, results in an exponential decrease of the value of the deflection.

When using several vacuum effectors, whether because of force-stress on the elements or due to the reduction of the deflection, after consideration the solution should be chosen in, so that it best meets the requirements of no additional costs. And chosen a solution that will best meet the requirements of no additional costs to deal with. This confirms the dependence shown in Fig. 10th The result confirms that the arrangement of elements in the form of a ring, affects the deflection only by the use of 4 effectors.

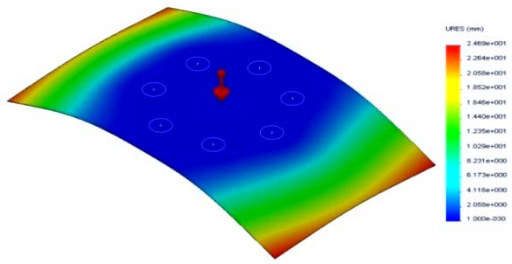

Fig. 10. Holding using more several effectors

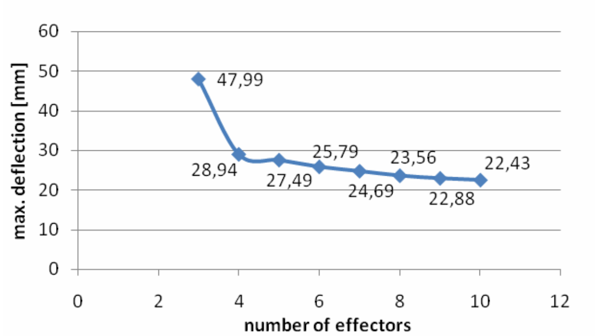

Fig. 11. The relation between the deflection Y and the number of effectors n arranged in a circle n

2.3 Effect the arrangement of elements on the deformation

This example illustrates the different deformation patterns at different ends of the plate and the way it is deformed in relation to different arrangements of the effectors. Choice between these arrangements depends on the requirements, like which side should enter the forming machine. Choosing the right arrangement is evident from Fig. 12 and Fig. 13.

Input data:

- diameter of the effector D_P = 125mm
- number of effectors n = 3
- diameter of pitch circle D_U = 516,0775 mm
- semi-product 1200 x 2000 x 1,5 mm

Output Data:

- difference of deformation of opposite corners $\Delta = 47,2$ mm
- difference of deformation of opposite corners $\Delta = 54$ mm

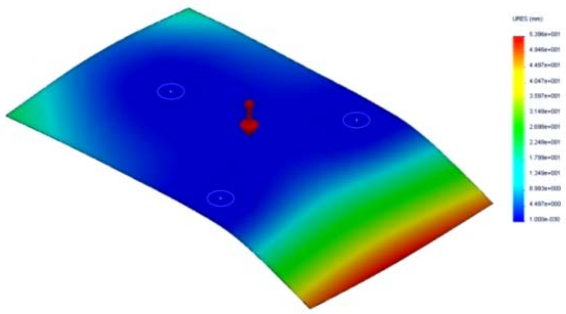

Fig. 12. Deformation with a symmetrical longitudinal arrangement

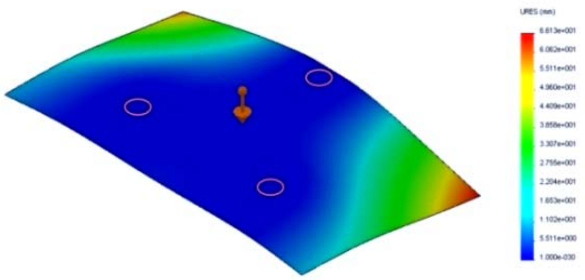

Fig. 13. Deformation with diagonal symmetrical arrangement

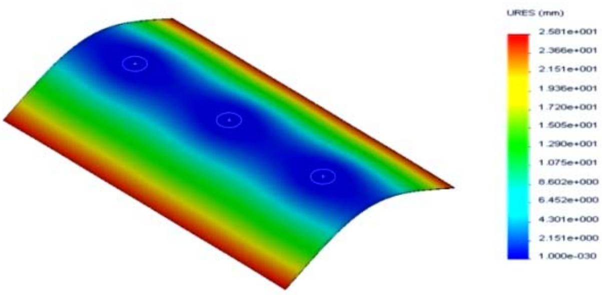

Fig. 14. Deformation with linear arrangement along the larger dimension

3. CONCLUSION

The research presented in this paper was to obtain visual images, and numerical values while examining the handling process when manipulating a metal sheet plate in the form of a rectangle. The results obtained are in the form an image, which shows the plate as well as the place it s holded from and colors showing the intensity of the deflection and stress all over the plate. Numerical values represented the extreme stresses and deformations of the material.

In the second part of the presented research results in the case of one gripping element, the impact of variations of the diameter of the vacuum effectors on the resulting deflection. In all the cases studied, the deformations occurring where only elastic deformations. The case of using two vacuum effectors was analyzed, were the dimensions f the vacuum components where chosen in such a way to satisfy the force requirements for ensuring a safe grip on the manipulated object. In the last part our attention goes to the issue of using more effectors arranged in a defined circle. Based on the values obtained, it can be argued that it is economically advantageous to use the maximum number of four elements. Further an increase the value of the deflection significantly doesn't appear. Additionally, the effect of rotating the trio of elements with an angle of 45° and the linear arrangement on the value of the deflection.

The presented approach helps to simplify the work of a designer in the design of the vacuum grips. It helps the user to select the correct size and number of effectors in handling a steel sheet as well as choosing the best location. In the calculations, the dynamic page of the problem in hand has not been solved or calculated. The safe grip of the object was ensured and secured by a safety factor.

Practical Application of the new methodology of appropriate deployment of the holding elements is used to manipulated and handle materials with large diameters and perimeters and of small thickness. In these cases it is possible to replace the intuitive deployment calculation method described in this paper. The result is a rational determination of the size and number of the vacuum effectors.

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Preliminary Note

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SUPPLY OPTIMIZATION IN THE CASE OF DETERMINISTIC UNEVEN CONSUPTION

Received: 12 January 2011 / Accepted: 16 July 2011

Abstract: *The article deals with the supply optimization in the case of deterministic, uneven consumption. The problem of making the right decision in the supply area is one of the most important areas of logistics. The first part of the article deals with the characteristic of deterministic optimalization method in case of uneven consumption. The second part describes the characteristic of company in which we applied the selected method. The specific situation of supply optimization with using the selected method is realized in the third part by using MS Excel.*
Key words: *supply, optimization, deterministic method, uneven consumption*

Optimizacija zaliha u slučaju determinističke neravnomerne potražnje. *U ovom radu je predstavljena optimizacija zaliha u slučaju determinističke, neravnomerne potražnje. Problem donošenja ispravne odluke u oblasti zaliha je jedan od najvažnijih oblasti logistike. U prvom delu radu se predstavlja karakteristike determinističke optimizacione metode u slučaju neravnomerne potražnje. Drugi deo opisuje osobine kompanije u kojoj je primenjen odabran model. Specifičnost situacije optimizacije potražnje korišćenjem odabranog modela je realizovan u trećem delu radu uz pomoć MS Excel-a.*
Ključne reči: *zalihe, optimizacija, deterministički model, neravnomerna potrošnja*

1. INTRODUCTION

When installing the large complex devices we meet the situation when the future consumption of a stock item through the planning period is completely known, but unewen. The stocks of these items are complemented by orders from suppliers. Fixed costs are connected to each order which are independent of order size. The costs for maintaining the inventories rise from storage of each unit of the item inventory amount [1,2]. These costs are directly proportional to storage time.

2. THE CASE OF DETERMINISTIC, UNEVEN CONSUMPTION

The main task of the model is to determine the size of orders in such a way that the total cost of maintaining inventories and total costs of all orders for the period T have to be minimal [3].

2.1 Characteristic of selected method

For calculation in the case of deterministic, disproportionate consumption we need to introduce the following relationships:

Parameter	**Sign**
C_s	The cost per one order
C_1	The cost of maintaining the amount in stock per unit time
Q_i	Number of considered item of stocks
The cost of maintaining inventory is calculated as the stock lying in stock supplies for the entire period.	

Table 1. Parameters determining the calculation process

The size of the orders in time i:

$$x_i = Q_i,\ x_i = Q_i + Q_{i+1}, \dots\ \dots, x_i = Q_i + \dots + Q_n \quad (1)$$
$i = 1, 2, \dots, n$

For determining the calculation process is necessary to know the following parameters [4,5]:

ti – beginning of the i-th period
Qi – amount of the estimated consumption

n(i,j) – total costs of the order, which has to satisfy the demand in the i-th and j-th period and the costs of maintaining inventories

$$n(i,j) = C_s + C_1 \sum_{k=i}^{j} (t_k - t_i) Q_i \quad (2)$$

$i = 1, 2, \dots, n, \quad j = i, i+1, \dots, n$

f(j) - minimal achieved costs to ensure the necessary supplies for covering the estimated consumption from the beginning of planning period to j-th period

$$f(j) = \min_{1 \le i \le j} [n(i,j) + f(i-1)] \qquad (3)$$

$$f(1) = Cs$$

From the equation written above we will gradually calculate f(2), f(3), ...,f(n). The last member of this sequence f(n) represents the minimum achievable costs throughout the planning period.

3. APPLICATION OF DETERMINISTIC METHOD FOR SELECTED COMPANY

Company that gave us the information for development of selected method is an important European producer of the annealed moldings from magnetic electrotechnical plates. Company focuses its production on the following products [6, 7]:

Fig. 1. Moulding for the production of stator

Fig. 2. Mouldings for transformers

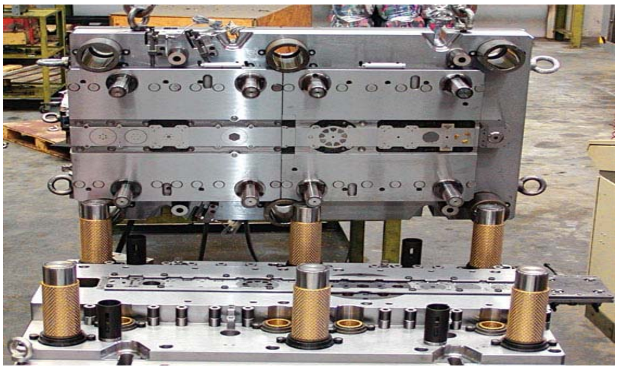

Fig. 3. Compression mould

Period	1	2	3	4	5	6	7	8	9	10	11	12	Sum
Count (pieces)	51	51	66	76	84	47	39	65	98	86	52	97	**812**

Table 2. Production plan

Date (i)	1	2	3	4	5	6	7	8	9	10	11	12	Sum
Period (month)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
Count (pieces)	102	102	132	152	168	94	78	130	196	072	104	194	**1624**

Table 3. The overwiev for the ordered quantity

3.1 Optimization strategy

The main material for production of mouldings is plate. That is the reason why we decided to choose this item and applied it to the method of deterministic, disproportionate consumption.

Using this method we will find the optimal strategy. Tables 2 and 3 include the production plan of metal plate and the overview of the ordered quantity.

Costs associated with one order:
Price of material item: 6,50 €/1 piece
Cost for storage: 40 €/m^3
Costs connected to 1 order (transport): 36,4 €
Dimensions of material item: 45 x 100 x 25
Weight: 0,830 kg
$V = \pi \cdot r^2 \cdot v = 3{,}14 \times 0{,}50^2 \times 0{,}25 = 0{,}19625\ dm^3 = 0{,}0002\ m^3$

Share of costs from storage = lease x volume x utilization rate =
= 40 x 0,0002 x 2 = 0,016

Cs = 36,4 €

C_1 = 6,50 x 0,03 x 0,016 = 0,211 €

3.1.1 Calculation procedure

On the base of values listed in table 3 we determined the values of n (i,j) according to the formula (2).
MS Excell was used to get the results.

On the base of calculations we determined the amount of the minimum costs according to the formula (3).
The procedure of calculating the costs is given in table 5. We also used MS Excell to get the results.

Time	1	2	3	4	5	6	7	8	9	10	11	12	Sum (pieces)
ZO	1	2	3	4	5	6	7	8	9	10	11	12	
Q_i	102	102	132	152	168	94	78	130	196	172	104	194	1 624
C_s	36,40 €												
C_l	0,21 €												

i/j	1	2	3	4	5	6	7	8	9	10	11	12
1	36,40											
2	57,922	36,40										
3	113,62	64,252	36,40									
4		128,4	68,472	36,40								
5			139,37	71,848	36,40							
6				111,52	56,234	36,40						
7					89,15	52,858	36,40					
8						107,72	63,83	36,40				
9							146,54	77,756	36,40			
10									72,692	36,40		
11									116,58	58,344	36,40	36,4

Tab. 4 Table values of n (i,j)

	1	2	3	4	5	6	7	8	9	10	11	12
f(x)	36,4 €	57,92 €	94,32 €	126,39 €	162,79 €	182,63 €	215,65 €	246,46 €	282,86 €	319,15 €	341,20 €	**377,60 €**

Tab. 5 The minimal achievable costs

On the base of calculations we found out that the company achieves the minimum achievable costs of f (12) = 377,60 €.
Optimal strategy of supply optimization leads to these orders:
Ordering 204 pieces for covering the consumption in the 1st and 2nd period.
Ordering 452 pieces for covering the consumption in the 3rd, 4th and 5th period.
Ordering 172 pieces for covering the consumption in the 6th and 7th period.
Ordering 130 pieces for covering the consumption in the 8th period.
Ordering 472 pieces for covering the consumption in the 9th, 10th and 11th period.
Ordering 194 pieces for covering the consumption in the 12th period.

4. CONCLUSION

The results of calculations show us that using the deterministic method in the case of deterministic, uneven consumption in company would lead to supply optimization. Reducing the excess inventories allows to reduce the places for storage the materials and it leads to more flexible production program.

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Preliminary Note

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QUALITY ASSESSMENT OF CUTTING FLUIDS WITH REGARD TO FACTORS OF INDOOR WORKING ENVIRONMENT

Received: 12 Oktober 2011 / Accepted: 16 December 2011

Abstract: *This article deals with a assessment of cutting fluids with regard to the changes which occur after the influence of individual factors and/or their combination in a working media during given technological operations. Cutting fluids are changed qualitatively and their applicability with factors in indoor working environment. The main factors, responsible for a change of fluid characteristics, are indoor specifications, working regimes and time of application. Change of cutting fluid characteristics affects quality of work-pieces as well as quality of working environment for present workers. Cutting fluid often becomes allergizing elements predominately after changes of its origin characteristics. The contribution presents the proposals how can be these changes regulated and negative impacts minimized.*
Key words: *cutting fluids, assessment, indoor environment*

Procena kvaliteta rashladnog sredstva sa obzirom na faktore u zatvorenoj radnoj sredini. *Ovaj rad se bavi procenom kvaliteta rashladnog sredstva u odnosu na promene koje se dešavaju posle uticaja pojedinih faktora i / ili njihovih kombinacija sa radnim medijima tokom datih tehnoloških operacija. Rashladna sredstva menjena su kvalitativno i njihova primenljivost sa faktorima u zatvorenoj radnoj sredini. Glavni faktori, odgovorni za promenu karakteristika fluida, su specifikacije zatvorenog prostora, režimi rezanja i vreme primene. Promena karakteristika rashladnog fluida utiče na kvalitet obratka, kao i kvalitet radne sredine radnika. Rashladna tečnost često reaguje na elemente pretežno nakon promene njenih početnih karakteristika. Doprinosi rada su prikazani predlozi kako su ove promene regulisane i negativni uticaji minimizirani.*
Ključne reči: *rashladno sredstvo, procena, zatvorena sredina*

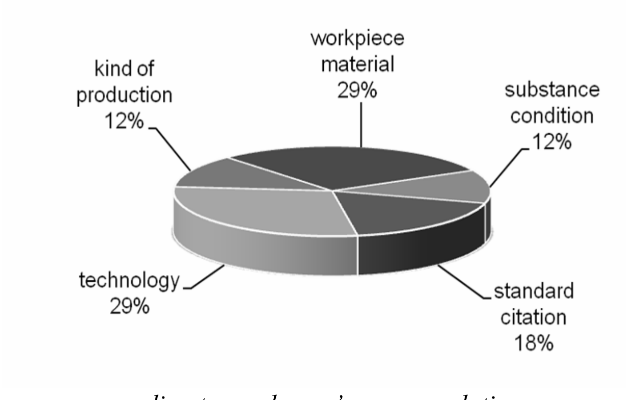
1. INTRODUCTION

Operational characteristics of cutting emulsions consist of its simplicity of preparation, operational persistence, foaming quality and health harmlessness. The important parameter, which has got ecological impacts, is durability of industrial emulsions. The industrial emulsions wear eventually with physical or chemical influence or ones actuating in indoor working environment. The aim of technology is to decrease a wear influence of industrial emulsions, to extend their durability or to regenerate them, [1, 2].

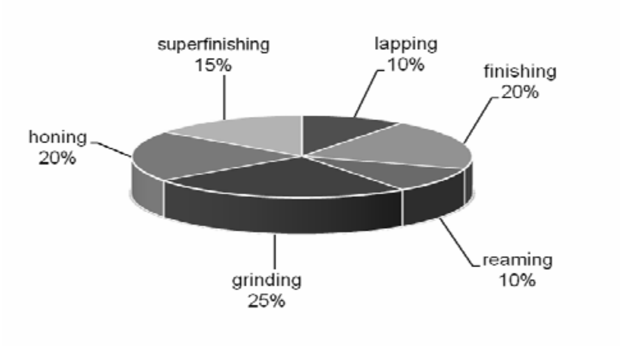
A user of technological liquids and lubricants obtains the basic information following producers' recommendations or sales representatives. The basic recommendations cover predominately technologies, i.e. what circumstances are suitable for liquid/lubricant application. There is approximately the same quantity of information of suitability of lubrications for certain group of work pieces, [3, 4].

Many supporters point out that an application of certain category of substance can link with actual kind of production (piece production can show other characteristics of substance), [5].

The citations of various standards represent the relatively wide dataset which can check a substance state and its characteristics, Fig.1 and Fig.2.

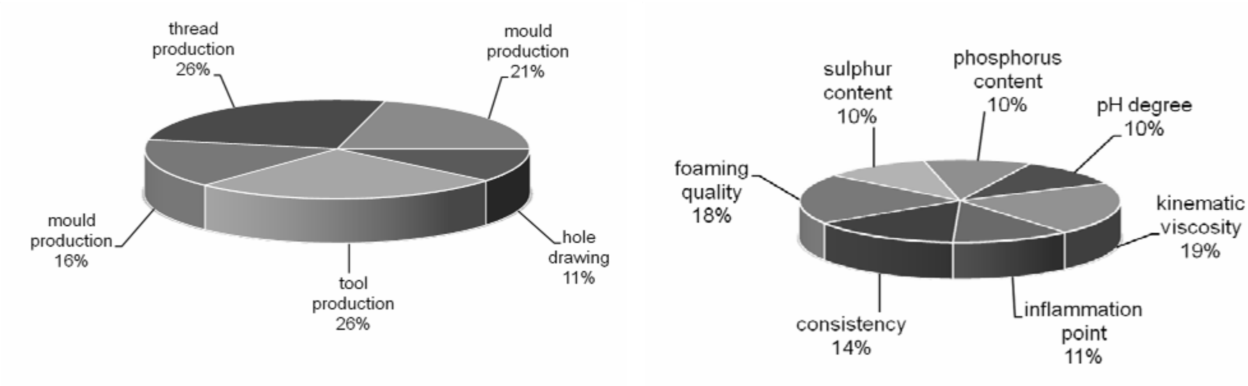


according to producers'recommendations



substance representation according to technology

Fig. 1 Substance and lubricant dataset - type 1



according to a shape of produced subjects and surfaces *data representation about substance characteristics*

Fig. 2 Substance and lubricant dataset - type 2

Our experiments were performed in six selected Slovak workshops with three types of cutting fluids: Blasocut 25, Ecocool 68 CF, Emulzín H. Blasocut 25 is a universal cooling and lubricating, water-soluble substance without chlorine contents with a high cutting performance.

An application field is from light to medium hard chip-forming machining. Ecocool 68 CF is a universal cooling and lubricating fluid for machining of steel and cast iron for soft and hard machining and grinding. It has got recommended concentrations: grinding 2÷3%, machining 3÷5%, hard machining cca 10%. It does not contain biocides, chlorine, nitride not even PCB, [6,7].

Four workshops were localised in industrial plant (PP01,PP02, PP03, PP04) and two were in the frame of university laboratories (UL01, UL02), [8].

2. TEMPERATURE AND PH ASSESSMENT FOR CUTTING FLUIDS

The temperature assessment of cutting fluids was performed by means of the thermometer integrated into pH-meter, type Metrohm 713. The pH measurement of cutting fluids were performed according to STN 65 6299, Part A by means of pH-meter with ion-selective electrode, which potential is controlled with a diaphragm, [9].

During any operation a cutting fluid "gets old" and releases H_2S, which decreases pH value. By pH decreasing of cutting fluids a corrosion predisposition of machines, tools and work pieces increases and lubricating power decreases.

In indoor working environment there was a worker displayed bad smell from decomposing organic compound of cutting fluid, this a oil and there was higher risk of allergizing reactions whether dermatologic or respiratory [10, 11].

3. ESTIMATION OF CHEMICAL OXYGEN DEMAND (COD)

We estimated COD with a semi-micro-methodology by means of a spectrophotometer and thermoreactor, brand Merck and the solutions, which are supplied especially for COD estimation together with these devices.

COD, as a criterion of water pollution from organic substances, is also limit parameter for waste water according to an actual statutory order.

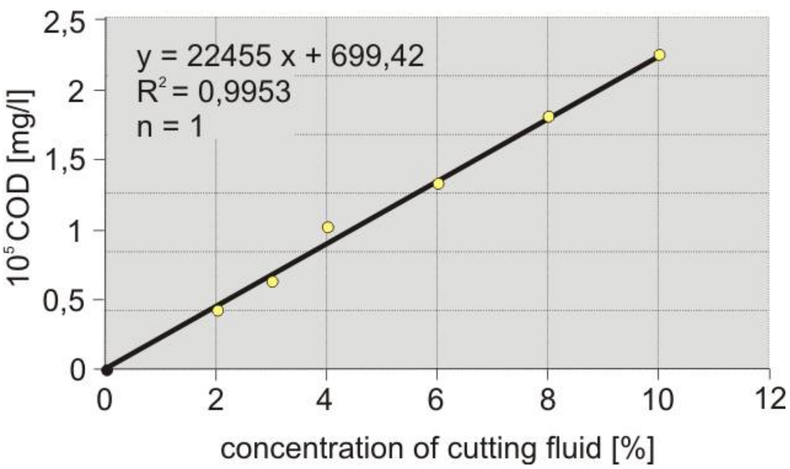


Fig. 3 Calibration curve of COD for cutting fluid Blasocut 25

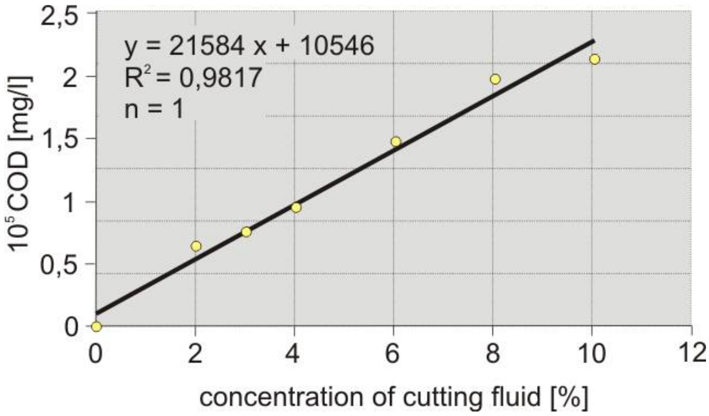


Fig. 4 Calibration curve of COD for cutting fluid Ecocool 68 CF

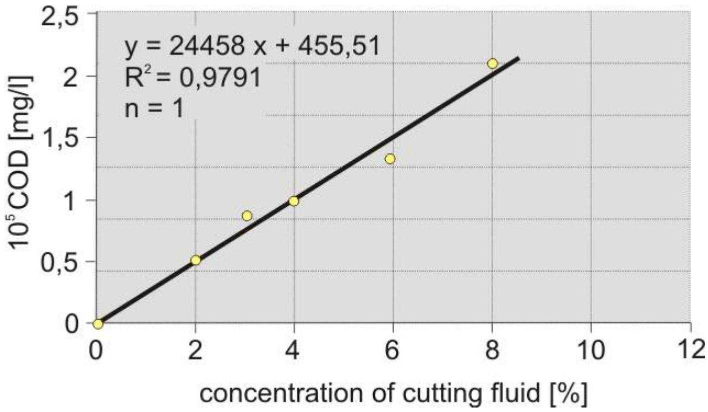


Fig. 5 Calibration curve of COD for cutting fluid Emulzín H

Used spectrophotometer has got calibration curves of given extensions. It is necessary to observe any change in composition of supplied solutions due to a correct using of an apparatus. If composition is changed then the apparatus was again calibrated according to an apparatus reference manual. Verification of measurement can be verified with the measurement of COD standard substance. Calibration curves of COD for selected cutting fluids are given in Fig. 3, 4 and 5.

The sample is oxidized with the hot solution K2Cr2O7 in a hot sulphur acid, containing silver sulphate as a catalyser (chlorides are masked a admixture of mercuric sulphate). The concentration of consumed Cr2O72- or Cr3+ is determined in a spectrophotometrical way. The method is corresponding to EPA 410.4, US SM 5220D, ISO 6060 [12, 13, 14].

4. OZONIZATION OF CUTTING FLUIDS

Individual selected samples of used cutting fluids were ozonized (in 5, 10 and 15 minute-exposures). So the samples from industrial workplaces were ozonized as the samples with selected concentration of all applied cutting fluids were done and during the ozonization there was observed its influence on given physical-chemical parameters, [15, 16].

The samples of Emulzín H, Ecocool 68 CF and Blasocut 25 were ozonized. In 16 measurements from 22 the ozonization caused a depression of COD in the range from 0.4 to 39.2%. Regarding the ozone is a high oxidizer; it is possible that as well present organic components can oxidize during the performed ozonization. The cutting fluid abilities: heat removal and lubrication can be decreased by an oxidation. As well the influence on other characteristics is not eliminable and moreover it also is necessary to study an ozonization influence on emulsion stability and a decreasing of COD for cutting fluid disposal.

An influence of ozonization on change of cutting fluid pH was not provable either in one case from machining types of steels and cast-irons, [17].

5. CONCLUSIONS

By means of the examination of industrial workplaces and the assessment of individual qualitative parameters of cutting fluids we can formulate the following results, [18]:

- cutting fluids most often started to „deteriorate“ for too long cleaning period of machines and fluid reservoirs,
- to avoid an indoor environmental decline, it is necessary to add a sedimentation container and a filter in recirculation of cutting fluids like that small chips, filings a softer particles will be separated,
- to recommend the additive BIOSTAT® L for used

cutting fluids. This additive does not cause allergic reactions of respiratory or dermatologic characters. Then it is possible to extend cutting fluid durability therefore cleaning period.

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No. of pages:	4 DIN A4 pages
Margins:	left: 2,5 cm
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