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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. From the year 2011 Journal is in the data base COBISS and KoBSON presented.*

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 11^{rd} *Conference MMA 2012 Advanced Production Technologiesin Novi Sad (Serbia) and. new papers as well.*

Editor in Chief

Professor Pavel Kovač, PhD,

Journal of Production Engineering
Vol.16 No.1

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Journal of Production Engineering
Vol.16 No.1
Original Scientific Paper

Gostimirovic, M., Rodic, D., Kovac, P., Pucovsky, V., Sekulic, M.

MODELING OF MATERIAL REMOVAL RATE IN EDM USING NEURAL FUZZY SYSTEMS

Received: 1 July 2012 / Accepted: 7 August 2012

Abstract: *Material removal rate is an important performance measure in EDM process. Modeling approach material removal rate which uses artificial intelligence tools is described in this paper. The objective of this study is to design an adaptive neuro-fuzzy inference system (ANFIS) for prediction of material removal rate in EDM. The input parameters of model are discharge current, pulse duration and output parameter is material removal rate. The results indicate that the ANFIS modeling technique can be effectively used for the prediction of material removal rate in machining of manganese-vanadium tool steel.*
Key words: *EDM, material removal rate, ANFIS.*

Modeliranje proizvodnosti u EDM obradi korišćenjem neuro fazi sistema. *Proizvodnost je veoma bitna osobina EDM obrade. U ovom radu je opisan pristup modelovanja proizvodnosti pomoću alata veštačke inteligencije. Kao ulazni parametri modela su struja pražnjenja i dužina trajanja impilsa a kao izlazni parametar je prozvodnost. Cilj rada je izrada adaptivno-neuro-fazi sistema zaključivanja (ANFIS) za predviđanje proizvodnosti pri EDM obradi. Rezultati pokazuju da modelovanje pomoću ANFIS alata može se uspešno koristiti za predviđanje proizvodnosti pri EDM obradi magnezijum-vanadijum alatog čelika.*
Ključne reči: *EDM, proizvodnost, ANFIS*

1. INTRODUCTION

Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. Its unique feature of using thermal energy to machine electrically conductive parts regardless of hardness has been its distinctive advantage in the manufacture of mould, die, automotive, aerospace and surgical components. In addition, EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration problems during machining [1, 2]. EDM is used for machining complex geometry workpieces and difficult-to-machine materials, for which conventional methods are not applicable.

The machining of difficult-to-cut materials is an important issue in the field of manufacturing. Materials with unique metallurgical properties, such as tungsten carbide, titanium, vanadium based alloys and other super-alloys, have been developed to meet the demands of extreme applications.The material like manganese-vanadium tool steel is finding increased application in many fields now-a-days. They have excellent properties such as high strength, high specific strength, high damping and low thermal expansion compared with the simple steels. The material removal rate (MMR) these materials are very low and other limitations in machining parameters and workpiece shapes are imposed. Manganese-vanadium tool steel is very hard steel, typically in the range of HRc over 60.

Material removal rate is an important performance measure and several researchers exploredseveral ways to improve it. The material removal rate can be controlled and improved by controlling process parameters. The amount of energy applied during machining is controlled by peak current and pulse duration [3]. Longer pulse duration results in higher material removal resulting in broader and deeper crater formation. Material removal rate is highly affected by types of dielectric and method of flushing . Flushing is a useful procedure to remove debris from discharge zone even if it is difficult to avoid concentration gradient and inaccuracy [4, 5]. The influence of flushing on MRR and electrode wear has been studied by mathematical models and experimentally and many flushing methods have been proposed [6].

In the present work, the first parameter affecting the MRR is discharge current and second is impuls duration. An attempt has been made to develop the intelligent model for predicting material removal rate using adaptive-neuro-fuzzy-inference-system (ANFIS) mathematical method. The process parameters taken in to consideration were the discharge current (I_e) and pulse duration (t_i). The model predicted values and measured values were fairly close to each other. Model validation is the process by which the input vectors from input/output data sets on which the fuzzy-inference-system (FIS) was not trained, are presented to the trained ANFIS model, to see how well the ANFIS model predicts the corresponding data set output values. The data which not used for training the model have been successfully predicted. Their propinquity to each other indicates the developed model can be effectively used to predict the MMR in EDM process.

2. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. *Fuzzy inference system* (FIS) is a rule based system consisting of three components. These are:

- a *rule-base*, containing fuzzy if-then rules,
- a *data-base*, defining the Membership Functions (MF) and
- an *inference system that* combines the fuzzy rules and produces the system results.

The main problem with fuzzy logic is that there is no systematic procedure to define the membership function parameters. ANFIS eliminates the basic problem in fuzzy system design, defining the membership function parameters and design of fuzzy if-then rules, by effectively using the learning capability of neural network for automatic fuzzy rule generation and parameter optimization [7]. Using a given input/output data set, the toolbox function ANFIS constructs a fuzzy inference system 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 fuzzy systems to learn from the data they are modeling.

A network type structure of ANFIS is similar to 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:

Input nodes – layer 1:

The general structure of ANFIS with two inputs x and y and one output z is shown in figure 1. Example of model with two rules as follows:

$$Rule\,1: If\;\; x\; A_1\;\; and\;\; y\; is\; B_1\; then\quad z_1 = p_1 x + q_1 y + r_1$$
$$Rule\,2: If\;\; x\; A_2\;\; and\;\; y\; is\; B_2\; then\quad z_2 = p_2 x + q_2 y + r_2$$

where A_1, A_2 and B_1 and B_2 are fuzzy sets of input premise variables *x* and *y* respectively.

Each node in this layer generates membership grades of the crisp inputs and each node's output. An example of a node function is the generalized *Gaussian* membership function:

$$O_i^1 = \mu_{Ai}(x) = e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{1}$$

where *x*, *c* and σ is the parameter set.

Rule nodes - layer 2:

The outputs of this layer called firing strengths, are the products of the corresponding degrees obtained from the layer 1.

$$O_i^2 = w_i = \mu_{Ai}(x)\mu_{Bi}(y) \quad i = 1, 2 \tag{2}$$

where μ_A and μ_B are the membership functions for A_i and B_i linguistic labels, respectively. Where w_i *is* output weight of each neuron.

Average nodes - layer 3:

The i-th node calculates the ratio of the i-th rule's firing strength to the total of all firing strengths. The firing strength in this layer is normalized $\overline{w}_i$ as:

$$O_i^3 = \overline{w}_i = \frac{w_i}{\sum_i w_i} \quad i = 1, 2 \tag{3}$$

Consequent nodes - layer 4:

Every node in this layer is with a node function $w_i f_i$ where w_i is the output of layer 3 and $\{p_i\ , q_i\ , r_i\}$ is the parameter set. These parameters are referred to as consequent parameters.

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i) \quad i = 1, 2 \tag{4}$$

Output nodes - layer 5:

This layer is called as the output nodes. The single node in this layer computes the overall output as the summation of contributions from each rule.

$$O_i^5 = f(x.y) = \sum_i \overline{w}_i \cdot f_i = \overline{w}_i f_1 + \overline{w}_i f_2 = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{5}$$

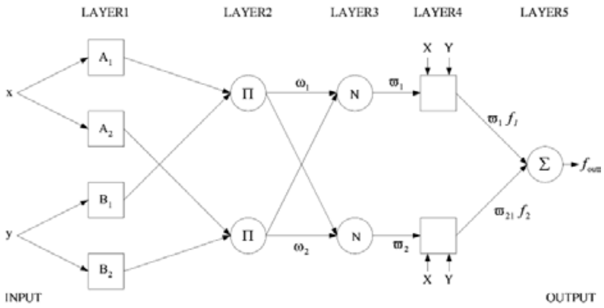

Fig. 1. Basic ANFIS architecture

The details and mathematical background for these algorithms can be found in [8].

3. DESIGN OF EXPERIMENTS

Experimental investigation was conducted on an EDM machine tool"FUMEC – CNC 21" in South Korea. The work material used in the experiment was manganese-vanadium tool steel, ASTM A681 (0,9% C, 2% Mn, and 0,2% V), hardness 62 HRc. The tool was made of electrolytic copper with 99,9% purity and 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 pulse duration. The range of the discharge current was I_e=1÷50 A (current density 0,5÷25 A/cm^2), while the pulse duration was chosen from the interval t_i=1÷100 μs to accommodate the chosen current. The rest of the parameters of electric impulse were held constant, according to the manufacturer's recommendations (open gap voltage U_o=100 V, duty factor τ=0,8 and positive tool electrode polarity).

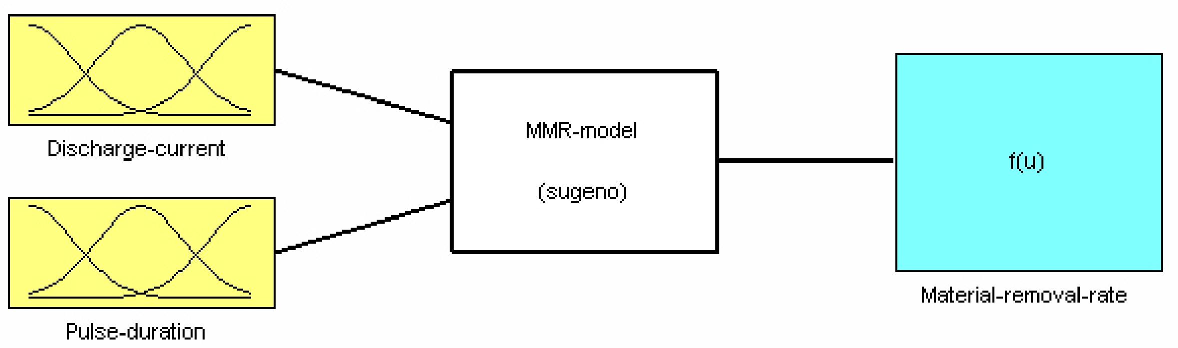

Fig. 2. Single-output Fuzzy Inference System

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.

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 [9].

4. ANFIS RESULTS AND DISCUSSION

Using a given input/output data set, the ANFIS method constructs a fuzzy inference system (Figure 2) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone, or in combination with a least squares type of method.

For this model, main parameters for the experiments are discharge current I_e, pulse duration t_i (input data set) and material removal rate *MMR* (output data set).

The training dataset and testing dataset are obtained from experiments. The input/output dataset was divided randomly into two categories: training dataset, consisting 24 of the input/output dataset and test data set (unknown to model), which consists 4 of data. Table 1 compare the predicted values and experimental data of material removal rate after training by ANFIS with triangular membership function.

Training process is accomplished by using Mat Lab 6.0. In order to determine the optimal network architecture, various network architectures were designed; different training algorithms were used. The number and type of membership functions, method optimization hybrid or back propagation, and number epoch were changed. Then the best adaptive network architecture was determined. The training epoch for each network is 500, hybrid method optimization, the best results given 4 membership functions triangular type (Table 2). When the network training was successfully finished, the ANFIS was tested with validation data.

Figure 3 exhibits the 3D surface profile obtained during neuro-fuzzy modeling and shows the influence of the machining parameters (discharge current and pulse duration) on the material removal rate. In this work parameters which improves resulting in higher MRR are discharge current (30-40 A) and pulse duration (40-60 μs) as shown figure 3.

Table 1. ANFIS architecture and training parameters

Number of layer	5
Size of input data set	24x2
Number of output	1
Membership function	Triangular
Learning rules	Least square estimation Gradient descent algorithm
Number of epoch	1000

Table 2. Test data

Discharge current	Pulse duration	Material removal rate Eksp.	ANFIS	Error abs. value
I_e (A)	t_i (μs)	$MMR_{eksp.}$ (mm^3/min)	MMR_{anfis} (mm^3/min)	E (%)
5	2	4,16	4,97	*15,09*
20	10	26,7	23,75	*11,04*
30	10	53,3	44,93	*15,71*
50	20	66,83	60,85	*8.90*
Test data Average Error = 12,68 %				

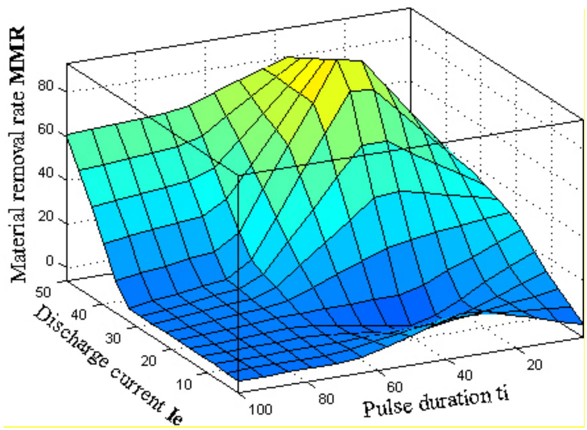

Fig. 3. 3D plot, influence of the machining parameters on the material removal rate

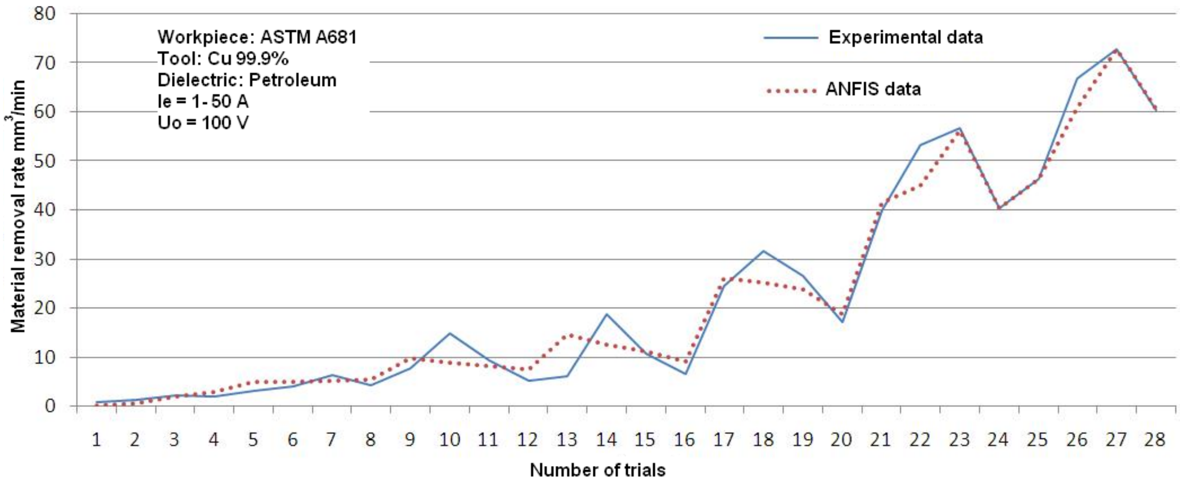

Fig. 4. Correlation between experimental and ANFIS value

Figure 4 describe the comparison of experimental and ANFIS results for the material removal rate, respectively. It proved that the method used in this paper is feasible and could be used to predict the MMR in an acceptable error rate for EDM. The compared lines seem to be close to each other indicating with good agreement.

5. CONCLUSION

In this paper an ANFIS is used to estimate material removal rate in EDM. Table 1 shows the compared values obtained by experiment and estimated by ANFIS model. The average deviation of the training data is 3,92 %, average deviation of the checking data is 2,41%, while the average deviation data which unknown to the model is 6,72%. Research showed that ANFIS model gives accurate prediction on material removal rate. The ANFIS predicted material removal rate values show a good comparison with those obtained experimentally. It is evidence that the fuzzy logic technique can be help to better prediction of the experimental data.

The material removal rate can be controlled and improved by controlling process parameters. In this work the first parameter affecting the MRR is discharge current and second parameter is puls duration. At values discharge current (30-40 A) and pulse duration (40-60 μs) the best results are achieved MMR. This values improves material removal rate and in future work should be define influences these parameters on tool wear and surface quality.

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Original Scientific Paper

Homar, D., Kopač, J., Dolinšek, S.

ADDITIVE MANUFACTURING AND HIGH SPEED CUTTING INCLUDED IN HYBRID MANUFACTURING

Received: 05 June 2012 / Accepted: 17 August 2012

Abstract: *The aim of this paper is to present the benefits if we use two manufacturing processes to make one product. In our case we use subtractive and additive manufacturing technology. Subtractive process is the high speed cutting and additive process is the selective laser melting. We want to combine these two technologies in hybrid manufacturing. Hybrid manufacturing combine benefits of both processes and eliminate limitations. On the end of this paper is presented developed computer software which analyse a geometric design of product and determine which part of product will be done with specific technology.*
Key words: *Hybrid manufacturing, additive manufacturing, high speed cutting, conformal cooling*

Aditivna proizvodnja i visoko-brzinsko rezanje kao deo hibridne proizvodnje. *Svrha ovog rada je da predstavi prednosti korišćenja dva proizvodna procesa u cilju izrade jednog proizvoda. U ovom slučaju su korišćene tehnologije dodavanja i skidanja materijala. Proces skidanja materijala je visoko-brzinsko rezanje a proces dodavanja materijala je selektivno topljenje pomoću lasera. Naš cilj je kombinacija ove dve tehnologije u hibridni proces proizvodnje. Hibridna proizvodnja kombinuje prednosti oba procesa i eliminiše ograničenja. Na kraju ovog rada je predstavljeno razvijeno softversko rešenje koje analizira geometrijski oblik proizvoda i odlučuje koji deo proizvoda će se izrađivati konkretnom tehnologijom.*
Ključne reči: *hibridna proizvodnja, aditivna proizvodnja, visoko-brzinsko rezanje, konformalno hlađenje*

1. INTRODUCTION

Because with the CNC milling is impossible to do certain geometric shapes, we decide that we combine this process with additive process in hybrid manufacturing. For additive process is chosen selective laser melting. In last 10 years that process progressed in process which can produce parts with similar mechanical properties as have the parts made by conventional processes. In the past some researches combined this two technic of production parts, but their main purpose were make near-net shape and then milling on the end shape. [1] Other scientists divided CAD model of products into two or more modules, where some modules make with milling and another with additive process, subsequently assembled in end product. [2] In our case milling combines with metal powder bed additive manufacturing or Selective Laser Melting (SLM). SLM is the process where the layer of metallic powder is melted and fused together layer by layer with the high powered laser, direct from CAD data, to create functional metal parts. Our goal is in order to part of product which is possible produce with conventional subtractive process will be manufacture with this milling and another part of product with complex geometry, which is difficult, impossible or very costly to machine, it will be manufactured with SLM. Therefore the product will be split, with straight plane, before the processing into two parts. For this purpose, we developed computer software for automatic splitting CAD model that is described below. The basic part, in most cases the biggest part, will be manufactured with milling and then the operator or robot will move the intermediate product from milling machine in machine for SLM. Subsequently, operator will fill building chamber with metal powder and then a machine will start building the second part of product from the upper surface, where the milling machine finished the its part of product.

2. BENEFITS AND LIMITATIONS OF BOTH TECHNOLGIES

There are two or more processes at hybrid manufacturing. In our case it is about adding and subtracting materials. Every process of production has its advantages and disadvantages. The main goal of hybrid manufacturing is combining both processes and thus eliminating as much disadvantages as possible. The cutting process enables us to produce very accurate products with a high quality surface in a relatively short amount of time. Problems occur with products which have a complex geometrical structure. That is because the geometrical shape of the tool itself prevents us from producing a complexly structured product. The process of adding steel powder (our particular case is selective laser melting) is the exact opposite of the cutting process. The selective laser melting enables us to create any form because the product is created by adding materials in layers. But this process is not suitable for manufacturing big parts with relatively basic geometry, because is too time-consuming and too expensive for this kind geometry. On the other hand conventional manufacturing achieve high production speed for massive parts. The highest downside of all additive manufacturing processes is bad roughness of surface due building the products layer by layer and this principle leave the stair on surface known as the stair-stepping phenomenon. [3] This stair is eliminated with finishing machining. Therefore our goal is to make most of the product with cutting as it is a much faster and cheaper process. The product of the cutting process would than serve as the base on which we would begin to add materials with the selective laser melting process. This is in order to produce the part which we could not be made by conventional cutting because of the geometrical structure of conventional tools. The subtractive processes have a lot of material consumptions, but the additive processes have minimized material consumption. Because of these reasons, additive manufacturing is good options for production some part of the product where it is necessary to subtract a lot of material if a product is machined from cylindrical or cuboid of raw material. The cost of machining product increases with increasing the amount of subtracted material and with geometric complexity of products. But the cost of product, which is made with additive technology, increases with increasing the amount added material, while the complexity doesn't affect the cost of product. On the Fig. 1 you can see that the cost depending on amount of subtracted/added material increase faster for additive manufacturing than the machining. [4]

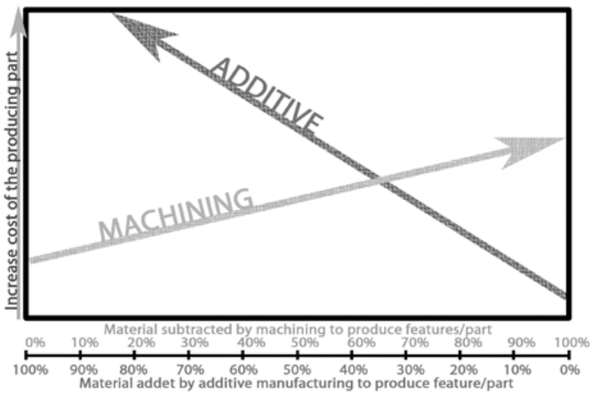

Fig. 1. The graph shows increasing the cost for machined part and additive manufactured part depend on amount of subtracted or added material.

Nowadays the materials, which are available for additive manufacturing, have excellent mechanical properties. Furthermore SLM process can build the part in variable material composition. The biggest problem with additive technology is that it isn't very known by toolmaker or other technologist and because this is very rarely used in manufacturing. Many technologists are very conservative, and with thus they are afraid to use new technology for manufacture products.

3. TOOL INSERT WITH CONFORMAL COOLING

Hybrid manufacturing is primarily intended for manufacturing injection moulding tool inserts with conformal cooling system. The conformal cooling system is a term for cooling channel which conform to the contours of the insert or cavity of injection moulding tool or tool for die casting. Difference between conventional cooling management and conformal cooling management is presented on Fig. 2. [5]

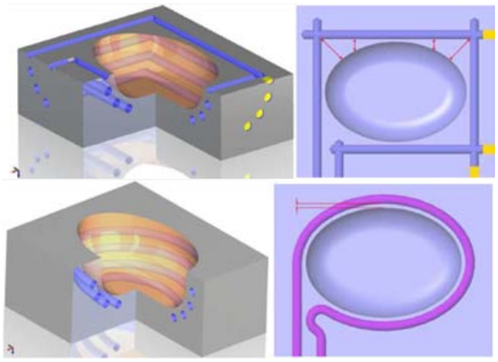

Fig. 2. Above: conventional cooling management; below: conformal cooling management [5]

With conformal cooling system is achieved a better dimensional accuracy of the moulded part, better mechanical properties of the part and reducing cycle time of injection moulding up to 40% [6, 7]. Every toolmaker wants to do the tool, with conformal cooling channel. But for conformal cooling system is decided by toolmaker only in special cases, due is not possible to do this system with conventional processes and additive manufacturing processes are too expensive for making entire tool. With hybrid manufacturing, we want to do moulds for injection moulding with conformal cooling channel cheaper, that it will be accessible for more toolmaker. On Fig. 3 we can see the example of tool insert with conformal cooling channels.

Fig. 3. Tool insert with conformal cooling channels [8]

4. ALGORITHM FOR THE AUTOMATIC SECTION OF THE CAD MODEL

We developed computer software which analyse a geometric design of product and determine which part of product will be done with CNC milling and which part will be done with additive technology. Subsequently it split the CAD model of product on two or more part and save part for CNC milling in format which is used for making CNC code and save part for additive manufacturing in STL format. This means that we developed algorithm for automatic determining the most suitable manufacturing sequences and technologies and also for converting this algorithm in computer software. Algorithm is implemented in Solid-Works CAD software by C# programing language.

Within the research project a hybrid manufacturing whose purpose is the development of tool inserts for the injection of polymers with adjusted cooling channels is developed [9]. Such an insert is shown on Fig. 4. The lower massive part of the insert will be produced with the cutting process as the cooling channels in this part are only straight. The upper part however has its cooling channels adjusted to the surface of the tool and therefore do not have a straight shape. This is not possible to machine with conventional milling, so this part shall be developed by the technology of adding steel powder.

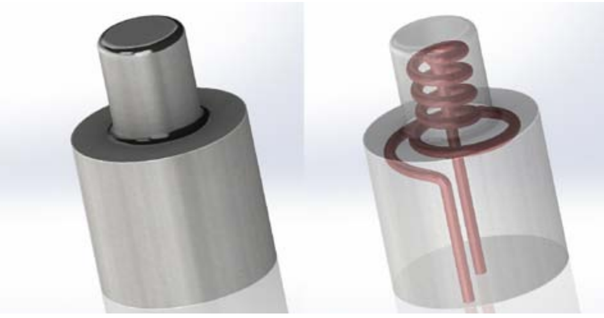

Fig. 4. Tool insert with conformal cooling channel

The goal is to achieve a high level of automation of hybrid manufacturing. That is why we are also developing an algorithm for the section of the CAD model into two parts. We are aiming to insert the whole CAD model into the control system of the hybrid cell, after which the computer will recognize by itself to which altitude can it produce the model by means of cutting. Following this, the program would divide the analysed part into two and it would save the upper part in the STL format, which is the most wide spread format for layer manufacturing technologies. Lower part would be saved in the STEP or any other format which enables the generation of the CNC code for the milling machine.

4.1 How algorithm works

We have developed a new algorithm model for the automatic section of the CAD model. Figure 6 presents a flowchart of the aforementioned algorithm. It works by first enveloping two points. The first one represents the minimal coordinates of the presented model and the second one represents the maximal coordinates. Further analysis shall be carried out in a rectangular space which is defined by these two points. Then we start to intersect the model with parallel vectors. The starting points of the vectors are beneath the basic plane. The vectors are perpendicular to the basic plane, as shown on Fig. 5.

The key data for the analysis are the intersections of the vectors and the model (entrances and exits of vectors which are going in out of the model). Only vectors that have more than 3 intersections with the model shall be used. That is because the model also has an inner form at such spots. A minimal value of the Z coordinate of the first vectors exit with more than 3 intersections is a height to which the model can be made. On the basis, that a vector cannot reach the highest point of the model without intersecting, we can conclude that the cutting tool cannot reach the highest point without collision. That is why we can use the cutting process only to the aforementioned height.

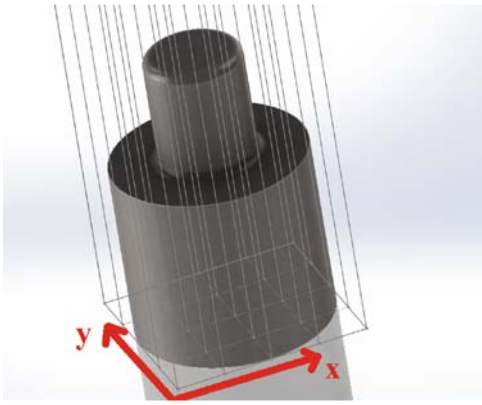

Fig. 5. Presentation of analysed model with vectors

4.2 Algorithm implemented in computer software

The algorithm has been implemented into the Solid-Works modeler through the API interface which enables us to automatize function of the programs, those which already exist. Also, new functions with mathematical support and support other operations can be generated. API allows us to write programs in different programming languages. Our algorithm has been implemented with using C#. The main added value is introduction of the vectors and how to search for the intersections with the model.

Developed algorithm defines the height to which it is possible to produce with conventional tools. After which the program on the defined height inserts a reference plane which parallels the main lower plane of the developing tool. At last it divides the CAD model into two pieces. The program saves the lower part in the STEP format in the folder which contains the former CAD model. The STEP format is meant for generating CNC code for milling. The upper part is saved in the STL format, for it is the most wide spread entry datum among technologies for adding materials.

5. FURTHER WORK AND CONCLUSION

The aforementioned algorithm needs to be further developed, for it enables a correct analysis only for models which have the beginnings of the cooling channels at the lower basic plane of the insert. In contrast, many of tools' inserts for injection-moulding of polymers have the cooling channel's beginnings at the side of the insert. Therefore it is appropriate that we apply the aforementioned analysis to more than just the lower side, as it is conducted now. We would then combine the results of different directions and acquire the correct height of the division of the CAD model.

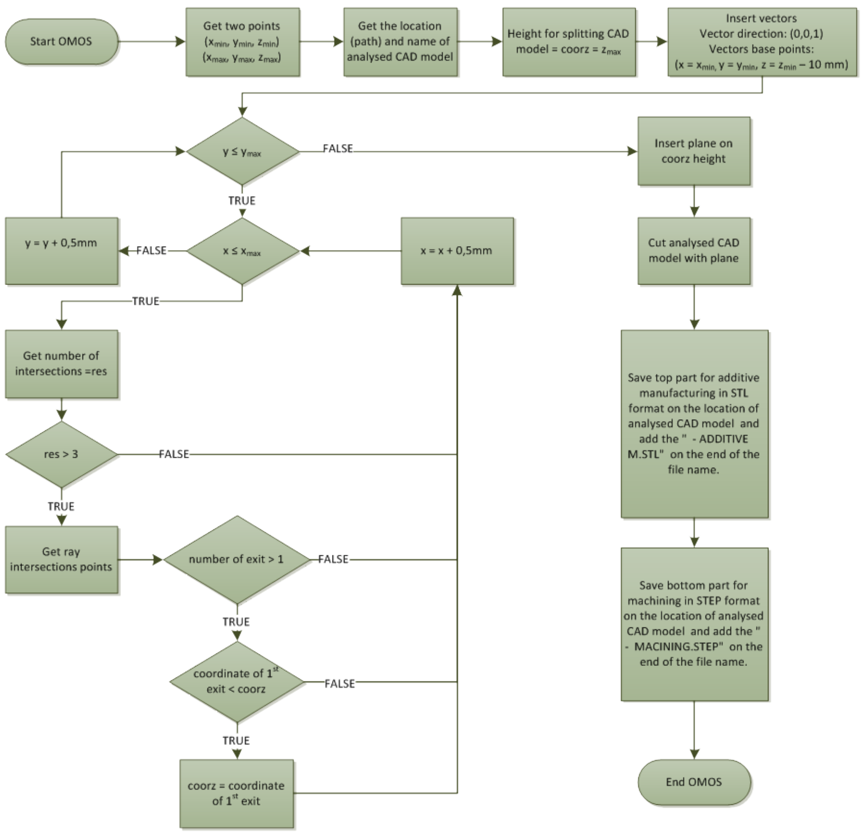

Fig. 6. Flowchart of algorithm for CAD model analysis

The hybrid production shall enable to produce one work-piece with two different processes. As such we will enable manufacturing of products in any form with minimal production expenses. It is quite visible, that technologists avoid accepting new technologies if they are not easy to use and/or if they produce more expenses. We expect that they will be more warmly open the aforementioned technology when most of operations will be automated. In conclusion, in such a way we would be more effective in introducing layer manufacturing technologies into the tool shops, as selective laser melting of metal powders.

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Original Scientific Paper

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EFFECT OF CUTTING PARAMETERS ON DELAMINATION FACTOR IN ROTARY ULTRASONIC MACHINING OF FIBERGLASS

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Abstract:*The article deals with influence of cutting parameters on delamination factor of fiberglass in rotary ultrasonic machining. In machining of fiberglass the effect of delamination occurs. Delamination is negligible effect in machining process, where the layers of fibers are damaged at the edge of material after machining process. The aim of the experiment described in the article was to verify, if the rotary ultrasonic machining is suitable for machining fiberglass and how does the technology and its parameters affects the delamination. Input parameters are cutting speed, cutting fluid´s pressure and feed. Based on experiments, the delamination depends on feed and cutting fluid´s pressure at the most. The values of delamination coefficient were from 1 to 2. The disadvantage of rotary ultrasonic machining is the need of cutting fluid in the machining process. The cutting fluid damaged the fiberglass, because of the saturation of fiberglass which raises the delamination factor.*
Key words: *ultrasonic machining, fiberglass, delamination*

Efekat parametara rezanja na faktor delaminacije pri rotacionoj ultrazvučnoj obradi fiberglasa. *Ovaj rad se bavi uticajem parametara rezanja na faktor delaminacije fiberglasa pri rotacionoj ultrazvučnoj obradi. Pri obradi fiberglasa se javlja efekat delaminacije. Delaminacija je neizbežna pojava pri obradi, prilikom koje dolazi do oštećenje ivica materijala usled obrade. Cilj eksperimenta, opisanog u radu, je bio da se ustanovi pogodnost rotacione ultrazvučne obrade za obradu fiberglasa i uticaj parametara na proces delaminacije. Ulazni parametri su brzina rezanja, pritisak tečnosti i pomak. Sudeći po rezultatima eksperimenta na delaminaciju najviše utiču pomak i pritisak rezne tečnosti. Vrednosti delaminacije su u granicama od 1 do 2. Nedostatak rotacione ultrazvučne obrade je neophodno prisustvo rezne tečnosti pri rezanju. Radna tečnost oštećuje fiberglas zbog osobine saturacije fiberglasa koja podiže delaminacioni faktor.*
Ključne reči: *ultrazvučna obrada, fiberglas, delaminacija*

1. INTRODUCTION

Composites are materials created by at least two different materials usually the matrix and fibers. Composite materials can be machined as other standard materials, however due to their structure there are some limits. Because of the fibers are usually very hard in comparison to the matrix, there is high tool wear is conventional machining and also the delamination is negligible effect. These negligible effects may be reduced by optimizing cutting conditions and by using covered carbide tools.

On the other hand there is possibility to use new, nonconventional machining technologies to lower delamination and tool wear. One of the machining technologies, where the tool wear is at very low level is rotary ultrasonic machining. Based on theoretical knowledge, the vibrations of the tool help to reduce burrs [1]. The burr origin is similar to the delamination process; therefore there is a presumption that rotary ultrasonic machining may help to reduce delamination of fiberglass.

2. THEORETICAL BACKGROUND

Delamination is splitting of layers of composite material, such as fiberglass. The delamination is highest in drilling, where the feed of the tool is perpendicular to the layer according to Figure 1. The red lines in the figure are the layers of composite material, the tool feed direction is figured with arrows. As can be observed from the figure the last layers are pulled off when the tool is coming through the material called push down delamination. Beside low tool wear rate, on the advantages of ultrasonic machining presented in literature are lower cutting forces in comparison to the conventional milling or drilling. Therefore the pressure on layers of composite materials should be lower, which provides lower delamination [3]. Delamination in drilling is the ratio of maximum delamination and tool diameter.

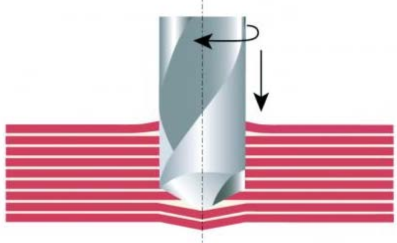

Fig. 1 Delamination in drilling [2]

The schematic model of delamination in drilling is depicted in Figure 2a.The blue circle is the maximum delamination, the red color is real shape of the delamination and the yellow one is the tool diameter.

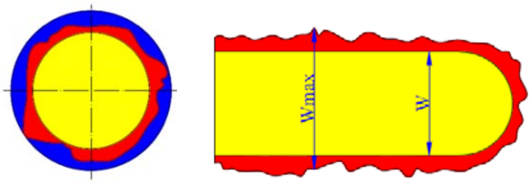

Fig. 2. Schematic model ofdelamination in
a) drilling b) miling

Thedelamination in millingisdepicted in Figure 2b. thecolorschemeisthesame. Thereisthediferenceoftoolfeedaccording to thelayerbetweenmilling and drilling. Thereforetheeffect on delaminationshooudbedifferentfordriling and formilling.

The critical force of delamination F_A can be calculated as:

$$F_A = \pi\sqrt{\frac{8G_{IC}E(nh_t)^2}{3(1-\upsilon^2)}}$$

where: G_{IC} is fracture toughness
E – Young modulus
n – number of non-machined layers
h_t – thickness of one layer,
v – poissons ratio.

The delamination is evaluated by a number which is obtained from following equations. The value of delamination factor for drilling is calculated as:

$$F_d = \frac{D_{max}}{D_0}$$

Where: $F_d$isthefactorofdelamination
D_{max}isthe maximum delamination
D_0isthediameter ofthetool

And formillingas :

$$F_d = \frac{W_{max}}{W}$$

Where: $F_d$isthefactorofdelamination
$W_{max}$is the maximum delamination
W is the diameter of the tool

3. EXPERIMENTAL SETUP

Based on theoretical knowledge written herein before an experiment was designed. The input variables were cutting fluid´s pressure and feed. Rotations are constant. The levels of input variable for driling are in Table1. Each experiment were performed three times. Cutting conditions for milling are in Table 2.

Feed	Cutting fluid´s pressure	Rotations
50,100, 150 mm/min	5, 10 bars.	2000 min^{-1}.

Table 1. Cutting conditions for driling.

Feed	Cutting fluid´s pressure	Rotations
500,1000, 2000mm/min	5, 10 bars.	4000 min^{-1}.

Table 2. Cutting conditions for milling.

The delamination factor was evaluated in drilling and milling using rotary ultrasonic machine tool DMG Sauer Ultrasonic 20 linear with diamond tools. For driling the Schott HB-Da.8-0,6-8-35-D107H was used and for milling Schott F-Da.8-1,5-6-20-MES-D107H. Both tools are coated with diamond grains using metal binding with diameter of 8 mm and the grit size 107 µm.

The material of workpiece is fiberglass, mechanical properties are in Table 3.

Table 3. Mechanical properties of workpiece

Young modulus	Tensile strength	Yield stregth	Hardness	Fracture toughness
20 GPa	180 MPa	150 MPa	15 HV	12 MPa.m$^{1/2}$

4. EXPERIMENTS EVALUATION

The delamination was evaluated for drilling and milling in the same way, using equations written herein before. The principle of evaluation is in the next for the first cutting conditions in drilling. Results from other experiments are summed in the next without the calculation.

Cutting conditions for the first drilling experiment:
rotations = 2000 ot.min^{-1},
feed = 150 m.min^{-1},
material ´s thickness = 3 mm,
cutting fluid´s pressure = 10 bar

Measured values of delamination $D_{max}$are in Table 4.

Run	Ø D_0 (mm)	Ø D_{max} (mm)	Delamination factor
1	8	16,897	**2,112**
2	8	16,963	**2,120**
3	8	15,693	**1,962**

Table 4. Max. delamination and delamination factor.

Delamination factor calculation:

$$F_{d1} = \frac{D_{max}}{D_0} = \frac{16{,}897\ mm}{8\ mm} = 2{,}112$$

$$F_{d2} = \frac{D_{max}}{D_0} = \frac{16{,}963\ mm}{8\ mm} = 2{,}120$$

$$F_{d3} = \frac{D_{max}}{D_0} = \frac{15{,}693\ mm}{8\ mm} = 1{,}962$$

Total delamination factor:

$$F_{dv1-1} = (F_{d1} + F_{d2} + F_{d3})/3 = \frac{6{,}194}{3} = 2{,}065$$

Values of delamination factor in drilling according to cutting conditions are in the Table5. The results of delamination for miling are in the Table 6.

From measured values it is clear, that the delamination is higher with higher cutting fluid´s pressure and with higher feed for drilling. The graphical interpretation of results from drilling is in Fig 3.

Rotations [min^{-1}]	Feed [mm/min]	Cutting fluid´s pressure [MPa]	Delamination factor [-]
2000	150	10	2,065
2000	100	10	1,995
2000	50	10	2,056
2000	150	5	2,159
2000	100	5	1,891
2000	50	5	1,610

Table 5. Delamination factor in drilling

Rotations [min^{-1}]	Feed [mm/min]	Cutting fluid´s pressure [MPa]	Delamination factor [-]
4000	2000	10	1,263
4000	1000	10	1,557
4000	500	10	1,237
4000	2000	5	-
4000	1000	5	1,973
4000	500	5	1,599

Table 6. Delamination factor in milling

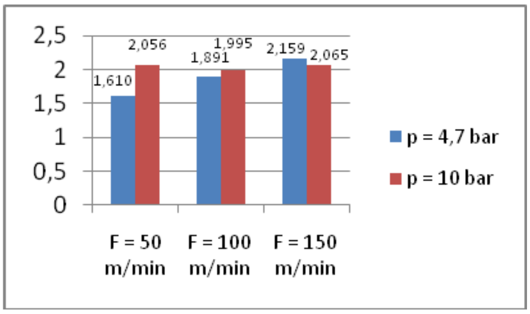

Fig. 3. Delamination in drilling.

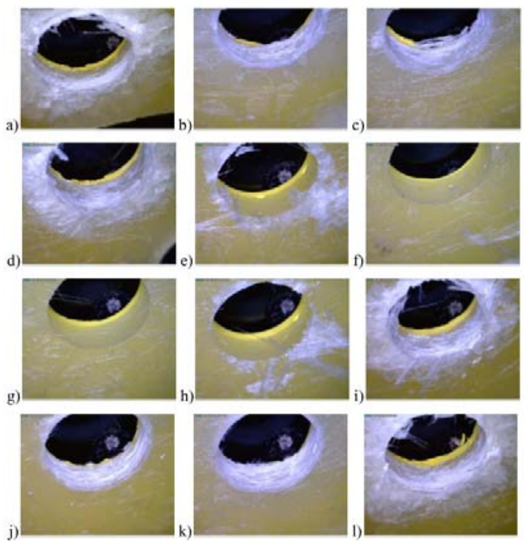

Fig. 4. Delamination in drilling, magnification 25 x

The photograph of delamination is in the figure Fig.4. Cutting conditions for each hole are as following:
a) F = 150 m/min , P = 4,7 bar,
b) F = 150 m/min , P = 4,7 bar,
c) F = 100 m/min , P = 4,7 bar,
d) F = 100 m/min , P = 4,7 bar,
e) F = 50 m/min , P = 4,7 bar,
f) F = 50 m/min , P = 4,7 bar,
g) F = 50 m/min , P = 10 bar,
h) F = 50 m/min , P = 10 bar,
i) F = 100 m/min , P = 10 bar,
j) F = 100 m/min , P = 10 bar,
k) F = 150 m/min , P = 10 bar,
l) F = 150 m/min , P = 10 bar.

The lowest value of delamination is visible in Fig. 4f and 4g which stands for low level of feed, but both high and low level of cutting fluid´s pressure.

The same observation was performed for milling experiment, Fig.5. The cutting conditions according to the figure are as following:
a) F = 2000 m/min, P = 10 bar,
b) F = 500 m/min, P = 10 bar,
c) F = 1000 m/min, P = 10 bar,
d) F = 1000 m/min, P = 4,7 bar,
e) F = 500 m/min, P = 4,7 bar.

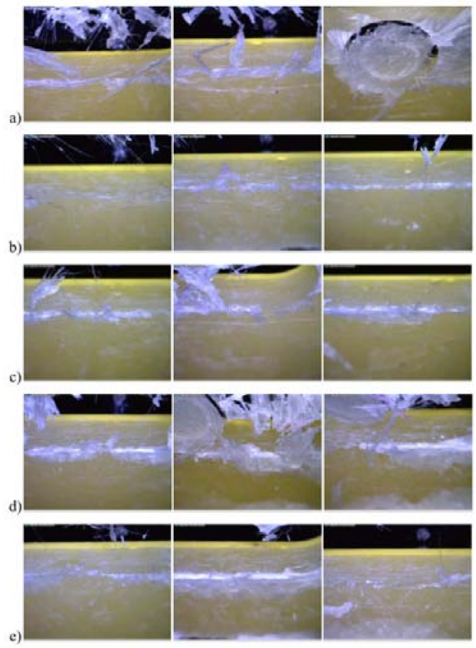

Fig. 5. Delamination in milling, magnification 25 x

It can be concluded that the lowest level of delamination was earned for lowest level of feed, however the difference is not so high as or drilling, which is caused by the different kinematics of processes and the relation between feed direction, ultrasonic vibrations direction and fibers direction in the material.

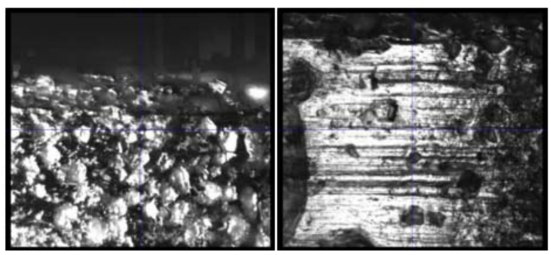

Fig. 6. Tool wear in rotary ultrasonic fiberglass machining, magnification 200x
a) new tool, b) used tool

The tool wear was also observed as can be seen in Fig.6. On the left figure is new tool, on the right the one after experiments. The scratches from fibers in binding are clearly visible, as well as diamond grains. The surface of the tool after the process is full of the matrix material from the fiberglass because the temperature in machining process was higher than the melting point of the material. This is negligible effect which leads also into higher tool wear; the tool has to be cleared respectively.

5. CONCLUSION

In submitted article the delamination in composite materials is explained. Since it is a serious problem, more techniques for its reduction were proposed in literature. The one possibility of delamination lowering is using non-conventional machining technology such as rotary ultrasonic machining [4]. A set of experiments were performed using ultrasonic machine tool in order to verify the presumption that vibrations may reduce the delamination factor both for drilling and milling. The influence of machining variables was evaluated in the next. Based on experiments following conclusion can be stated. The delamination factor is affected both by feed and cutting fluid´s pressure. In the first experiment the holes were created by diamond drill with vibrations frequency of 21300 Hz, rotations of 2000 min^{-1}, and three levels of feed and cutting fluid´s pressure. The lowest level of delamination was measured for the lowest level of feed 50 mm/min and low level of pressure 5 bar. Very similar value of delamination was also observed for the combination of low feed and high cutting fluid´s pressure. According to that can be assumed, that the level of cutting fluid´s pressure has no significant effect on delamination in drilling. On the other hand the effect of feed was significant and the relation of delamination factor on feed is quasi linear. That means for lower delamination the lower feed is suitable, which confirms the presumption. In general can be said, the cutting fluid has negligible effect on delamination, because of the destruction of layers. The matrix of fiberglass is absorptive [5]. During the machining process the material absorb cutting fluid and damage the edge of machined hole. However it is not possible to machine without cutting fluid, because the temperature raising in the place of cut is higher than the melting point of the material´s matrix which causes melting of the matrix, pulling off of the fibers and filling the tool with the melted matrix material [6].

The results from milling experiments are as following. The delamination in general was lower than in drilling, however the negligible effect of cutting fluid was not so high, what more the higher cutting fluid´s pressure helps to reduce the delamination under cutting condition F 500 mm/min and 2000 mm/min. The higher delamination was observed for pressure 5 bar than for the pressure 10 bar. This effect can be explained by different kinematics of these two processes. In milling the direction of feed in not perpendicular to the direction of fibers in layers and therefore the pressure of the tool is not so high on the last layers. The higher pressure helps to reduce the delamination because its direction is perpendicular and in fact it cuts off the last layer which is better for delamination.

It can be concluded that rotary ultrasonic machining with diamond tool is suitable for fiberglass machining, however the need of cutting fluid decrease the advantage of the machining process. As was already mentioned the cutting fluid damage the material and machining without it causes melting of the material and filing the tool. Therefore the disadvantages exceed the benefits of the technology. The solution may be ultrasonic machining with standard tool with cutting edge with defined geometry, which is the topic for next research [7].

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Original Scientific Paper

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APPLICATION OF NEURAL NETWORKS FOR PREDICTING CHARACTERISTICS OF ELASTIC SUPPORTS TO PRODUCTION MACHINES

Received: 1 July 2012 / Accepted: 7 August 2012

Abstract: *Vibration and noise are unavoidable in the operation of variety of technological equipment (machines, appliances, transportation and other mobile devices). Effective contribution to solving these problems provides the application of elastic supports. This paper presents the idea of applying neural networks (whose architecture is created based on table 2) in the process of defining the static characteristics of support. As a result of analysis of many different architectures applied on the results obtained by the measurement,the most favourable architecture of predictive model of neural network is presented. Deformation assessment of supports can significantly facilitate the work for people involved in the design of technology foundation.*
Key words: *neural networks, modeling, supports, vibroisolation*

Predviđanje karakteristika elastičnog oslonca mašine primenom neuronskih mreža. *Vibracija i buka su neizbežni u radu razne tehnološke opreme (mašine, aparati, transport i drugi mobilni uređaji). Efektivni doprinos rešavanja ovih problema obezbeđuje primena elastičnih oslonaca. Ovaj rad predstavlja ideju primene neuronske mreže (čije arhitektura je kreirana na osnovu tabele 2) u procesu definisanja statičkih karakteristika oslonca. Kao rezultat analize različitih arhitektura primenjuju se na rezultatima dobijenih merenjem pa je najpovoljnija arhitektura prediktivnog modela neuronske mreže predstavljena. Određivanje deformacije nosača može značajno olakšati rad ljudima pri dizajniranju.*
Ključne reči: *neuronske mreže, modelovanje, oslonac, vibroizolacija*

1. INTRODUCTION

Foundation of machines should damped vibrations and shocks that are transmitted from technological equipment on the environment, or from the environment to technological equipment. In such conditions, machine as technological equipment and the system of elastic supports constitute an oscillatory system, which can be viewed as a dynamic model with one (Fig. 1) or more degrees of freedom (Fig. 2.) of movements which differ in place of the malfunctions.

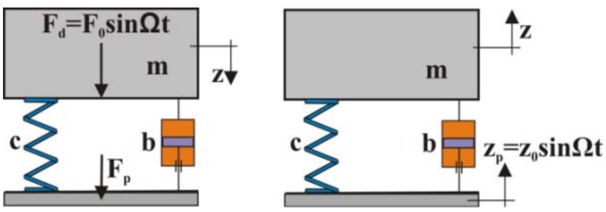

Fig. 1. Dynamic model of founded machine modeled by one degree of freedom

Vibroisolation can be active and passive. Active izloacija - a malfunction occurs in the work process of a machine that is the object of foundation. Passive izloacija - malfunction comes from the surrounding technological equipment and it is transferred to the machine over the place of reliance.

Differential equation of oscillations of the system with one degree of freedom in active isolation of vibration is given by equation (1), and in passive vibration isolation by equation (2):

$$m\ddot{z} + b\dot{z} + cz = F_d \qquad (1)$$

$$m\ddot{z} + b(z - \ddot{z}_p) + c(z - \ddot{z}_p) = F_d \qquad (2)$$

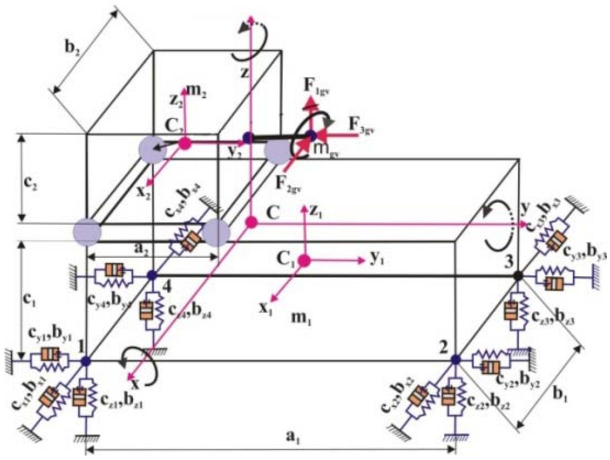

Fig. 2. Dynamic model of founded machine modeled by several degrees of freedom in active isolation of vibrations

For the case of dynamic system with n - degrees of freedom of movements of differential equation of oscillations are given with system equation (3):

$$[M]\{\ddot{\delta}\} + [B]\{\dot{\delta}\} + [K]\{\delta\} = \{F(t)\} \qquad (3)$$

where:: $[M]$ - matrix of mass system, $[B]$ - matrix of system damping, $[K]$ - matrix of system stiffness, $\{F(t)\}$ - vector of malfunctions, $\{\ddot{\delta}\}, \{\dot{\delta}\}, \{\delta\}$ - vector of acceleration, speed and movements.

An important feature of the elastic supports is stiffness that depends both on the type and form of elasto-viscose element and in most cases is a non-linear characteristics. In such cases it is necessary to define the stiffness and muffling of the elastic support as very important quantity in identification of system dynamics by given equations (1), (2) and (3), based on loads and corresponding deformation of elasto-viscose element.

2. MEASUREMENT METHODOLOGY

To make the neural network model that provides reliable estimates of supports deformations, appropriate measurements related to the static tests of elastic supports were carried out. Supports, type A and type B (Fig. 3.), different hardness, are exposed to the effects of force in the vertical direction (Fig. 4).

Fig. 3. Supports: type A and type B

Load of supports is performed by using hydraulic pumps (1), with the cylinder (2) through a dynamometer (3) on which the value of static force F is read. Static force is, through the frame (4) transferred to mat examined (6) which is mounted on a stand of the device (5), while the deformation of h mat under load and relief, is read on measurement clock (7).

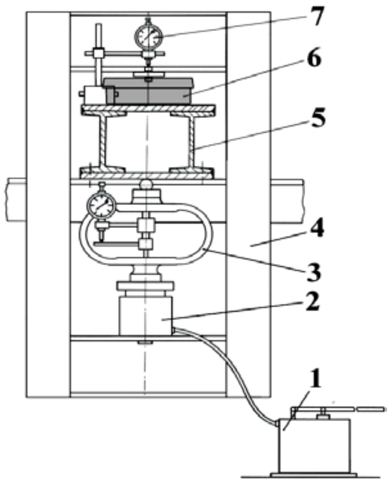

Fig. 4. Device for static examination of supports in vertical direction

3. PREDICTION OF SUPPORT DEFORMATION BY USE OF NEURAL NETWORK

Neural networks are complex systems consisting of neurons, interconnected by respective links, where the knowledge of the network is stored [1]. The neural network is characterized by its architecture, the weight vectors, and transfer functions used in hidden and output layers of the network. Neurons in the input layer receive the input data. Each neuron sums inputs and one input per neuron in the input layer, but more inputs per neuron in the hidden layer. Information between neurons in different layers are transmitted using the transfer function. Due to the different weights of connections, neurons receive different signals. The output of each neuron in the output layer is compared to the desired output. In order to minimize the difference between these two outputs, weight adjustment between neurons is performed [2].

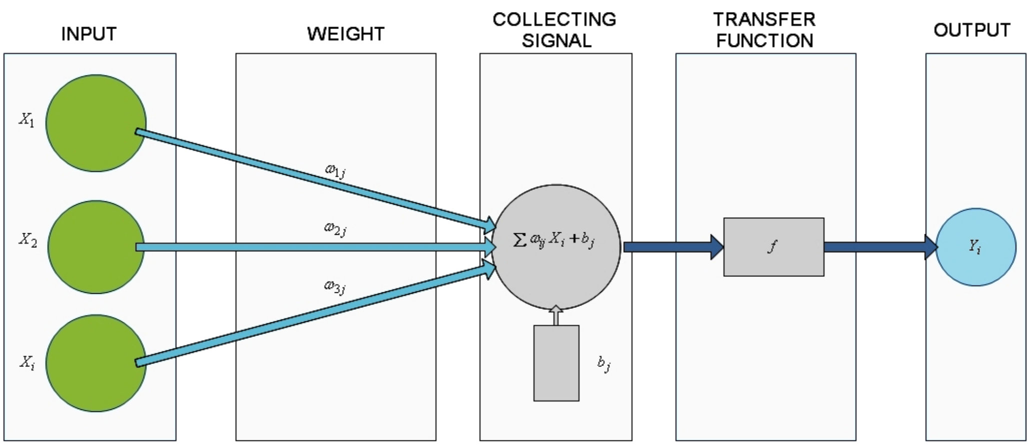

Fig. 5. Structure of artificial neuron

The most commonly used neural networks are multilayer perception networks trained by algorithm with back propagation [3]. Networks of this type are general-purpose models with good generalization ability and are relatively simple for practical use. For training the neural network that uses algorithm with back propagation, learning process implies that data set for training is available [4]. Each element of this set is defined by the input vector $x^{(k)} = [x_1^{(k)}, x_2^{(k)}, \dots x_i^{(k)}]$ and desired output vector $t^{(k)} = [t_1^{(k)}, t_2^{(k)}, \dots t_i^{(k)}]$. Learning objective is to determine the network parameters (connection weight and threshold of activation b_j) such that $t^{(k)} = [t_1^{(k)}, t_2^{(k)}, \dots t_i^{(k)}]$ is equal to $y^{(k)} = [y_1^{(k)}, y_2^{(k)}, ... y_i^{(k)}]$. Criterion function, which describes how the actual output of the network differs from the desired is given by (4):

$$E = \frac{1}{2}\sum_{i=1}^{s}(t_i - y_i)^2 \qquad (4)$$

When k sample of data set for training is led to the input, function has the following form [4]:

$$E^{(k)} = \frac{1}{2}\sum_{i=1}^{s}\left(t_i^{(k)} - y_i^{(k)}\right)^2 \qquad (5)$$

An error in this type of network spreads backwards through the network to the input layer where according to the desired output values of neural network connection weights in the network are set. Adaptation of the connection weights $\omega_{i,j}$ and threshold of activation of neurons b_j is determined from the condition that the function (5) is minimal. Parameters of the n +1 step are determined as follows [5]:

$$b_{j(l)}(n+1) = b_{j(l)}(n) - \eta\frac{\partial E^{(k)}}{\partial b_{j(l)}} \qquad (6)$$

$$\omega_{i,j(l)}(n+1) = \omega_{i,j(l)}(n) - \eta\frac{\partial E^{(k)}}{\partial \omega_{i,j(l)}}$$

where: l – mark for neuron layer, η – learning coefficient.

The set of input data includes: x_1 = load $F[N]$, x_2 = type of support, x_3 = hardness $[Sh]$, and set of output data consists of: y_1 = deformation in case of load and y_2 = deformations in case of relief. Set of input and output data defined the architecture of network (Fig. 6.) in the aspect of number of neurons in input layer and output layer.

Number	Input quantity	Bottom value	Top value
1.	Load $[N]$	250	30000
2.	Hardness $[Sh]$	45	75
3.	Type of support	1	2

Table 1. Input quantities with values

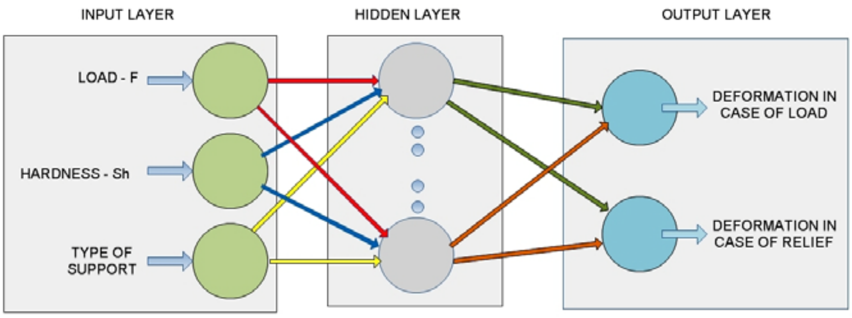

Fig. 6. Architecture of neural network for prediction of the deformations of support

Three-layer neural network has the following architecture: the input layer - three neurons to represent the load, type of supports and hardness, one hidden layer, output layer - two neurons to calculate deformations during loading and unloading. The data are divided into three groups: data for network training, data validation and data for network testing. The training sample (60 data) was presented to the network during training, and the network was adjusted according to its error. The validation sample (20 data) was used to measure network generalisation, and to halt training when generalisation stopped improving. Finally, the testing sample (20 data) had no effect on training and so provided an independent measure of network performance during and after training. Modeling was performed in the MATLAB software system [6]. The parameters of the network architecture are given in Table 2. MATLAB code created based on the parameters given provides a satisfactory response whose evaluations confirm high accuracy of this model.

Correlation coefficient is R= 0.99758, and mean absolute percentage error in case of predicting the deformations occurred by loading is 1.81%, while in case of predictions caused by unloading its value is 2.08%. Fig. 7 presents the overview of mean square error of model created. MATLAB code created based on the parameters given provides a satisfactory response whose evaluations confirm high accuracy of this model. Correlation coefficient is R= 0.99758, and mean absolute percentage error in case of predicting the deformations occurred by loading is 1.81%, while in case of predictions caused by unloading its value is 2.08%. Fig. 7 presents the overview of mean square error of model created.

No.	Parameter name	Value
1.	Input number of neurons	3
2.	Output number of neurons	2
3.	Nuber of neurons in hidden layer	12
4.	Transfer function in hiden layer	Tansig
5.	Transfer function in output layer	Purelin
6.	Learning function	Trainlm
7.	Number of epochs that is presented	300
8.	Number of epochs	10000
9.	Momentum	0.9
10.	Learning coefficient	0.05
11.	Training error	0.001

Table 2. Parameters of architecture that has provided the best results

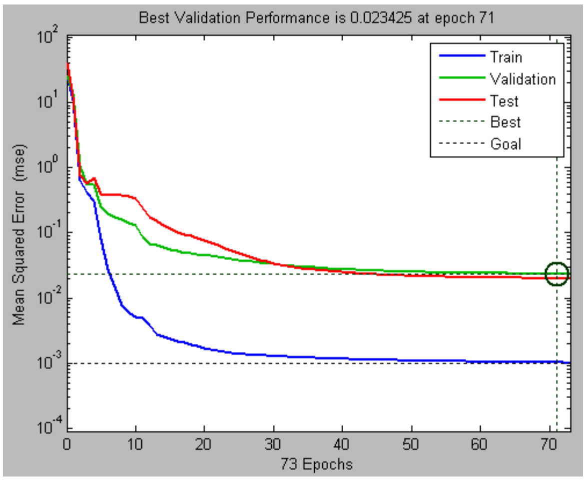

Fig. 7. Mean square error of the model created

Performances of neural network for prediction of deformations of supports occurred by loading and unloading are given in Fig. 8. and Fig. 9.

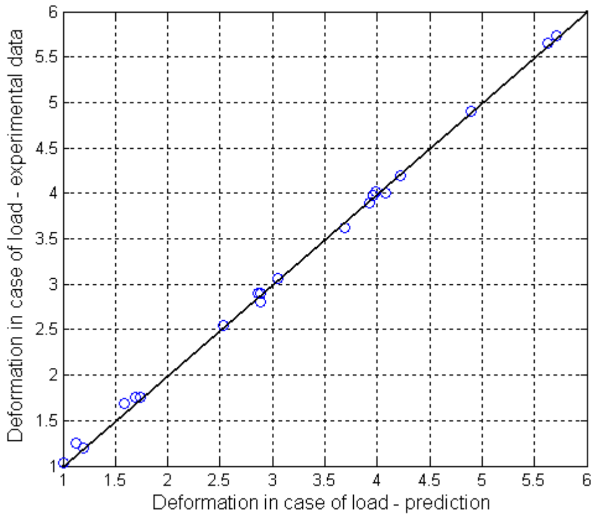

Fig. 8. Performances of neural network for prediction of support deformations occurred by load

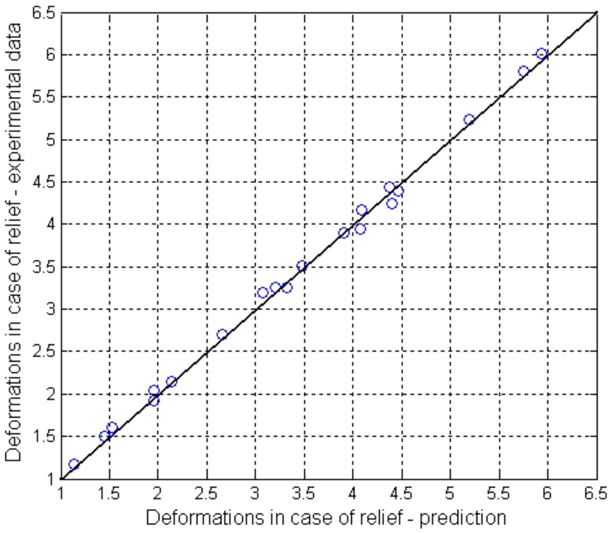

Fig. 9. Performances of neural network for prediction of support deformations occurred by unloading

4. CONCLUSION

Main concept of neural network with back propagation is presented in this paper and the results of its application in estimation of mat deformations made under the effect of load in vertical direction are described. Having in mind that vibrations of elastically relied technological equipment are executed around the position of stable balance and that those are small oscillations, such approach when defining static characteristics of elastic supports gives great contribution to further successful analysis of system's dynamics.

5. ACKNOWLEDGEMENT

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SOME CHARACTERISTICAL ASPECTS REGARDING CNC GRINDING OF SPUR GEARS

Received: 18 July 2012 / Accepted: 29 2012

Abstract: *In this paper we will present some theoretical and practical aspects of CNC grinding of cylindrical gears with different profile modification. Also in this paper, there will be presented some concrete practical results and measurement diagrams.*
Key words: *gears, CNC grinding, profile modification, involute curves*

Karakteristični aspekti CNC brušenja zupčanika sa pravim zubima. *U ovom radu ćemo predstaviti neke teorijske i praktične aspekte CNC brušenja cilindričnih zupčanika različitih profila modifikacije. Takođe, u ovom radu, biće predstavljeni neki konkretni praktični rezultati i merenja.*
Ključne reči: *zupčanici, CNC brušenje, modifikacija profila, evolventa*

1. INTRODUCTION

For a lot of new gear industrial application (precision devices, measurement apparatus, wind turbines, vehicles, etc.) is needed high precision and very different gear tooth profile modifications. In order to can manufacture these gears our team in collaboration with EMSIL TEHTRANS from Oradea and UNIO companies from Satu Mare (Romania) developed one special CNC grinding machine equipped with FANUC numerical control equipment. For obtaining the multitude necessary parameters for programming different grinding process phases, it was necessary to develop a series of mathematical algorithms that hold in to about not only the teeth geometrical characteristics, but also the machine movement command possibilities. The experimental testing and industrial application was at UNIO Company, where we had also the possibilities for high precision measurement of realized gears. In this paper we will present the main aspect of our theoretical and practical results [1, 2, 3].

2. THE DEVELOPED CNC GEAR GRINDING MACHINE

As we mentioned in the introduction the machine was developed by modernizing a NILES type machine. The necessary movements for manufacturing and coordinate axis orientation can be seen in Fig. 1.

For involute spur gear profiles' grinding it is necessary to have a numerical commanded **B** and **Z** axis. For involute helical gear grinding it is necessary to have a numerical commanded for **Z** and **A** axis. In case of modified profile gears, the teeth sections are realized by involute curves with different parameters. At the machine programming we must introduce the effective value of the distance that has to be covered on the **B** and **Z** axis directions [4, 5].

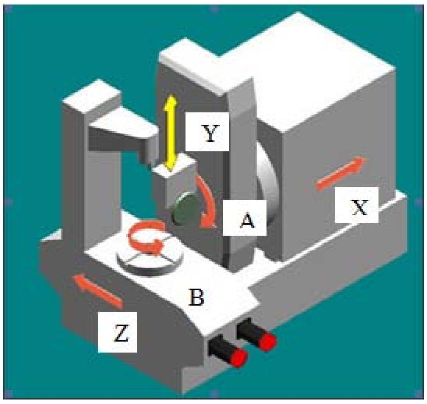


Fig.1. CNC gear grinding machine and axis orientation

Taking into account the diversity of gears that had to be grinded it was necessary to elaborate a set of mathematical and kinematical algorithms,
For all algorithms it was applied the version of grinding with different type of angles with the same grinding wheel [6, 7]. From lack of space in this paper we will present only the main parts of the A1 algorithm.

3. THE ALGORITHM. THE DETERMINATION OF CNC PROGRAMMING PARAMETERS FOR THE CNC SPUR OR HELICAL GEAR GRINDING MACHINE, FOR GEARS WITH PROFILE MODIFICATION REGARDFUL OF THOSE GEARS THAT SATISFY THE FOLLOWING CONDITION $R_f \le R_b \cdot \cos\alpha_t$,

The developed algorithm is part of a series of algorithms :

- A1 algorithm: for spur gears with $R_f \le R_b \cdot \cos\alpha_t$;
- A2 algorithm: for spur gears with $R_f \ge R_b \cos\alpha_t$;
- A3 algorithm: for gears with tip profile modifications;

- A4 algorithm: for gears with foot profile modifications;
- A5 algorithm: for gears with tip and foot profile modifications;
- B1 algorithm: for with right-hand helical teeth gears;
- B2 algorithm: for gears with left-hand helical teeth right-hand helical teeth;

In Fig. 2 we can see the graphical representation of the relative position between the left flank of the gear teeth space and the double conical grinding wheel, corresponding to the relative position at the beginning and the ending position of the grinding process. Also in the figure it is represented a general case when the profile angle α_{st} of the tool is different from the frontal gearing angle α_t. Thus the algorithm gives the possibility of grinding gears with different types of gearing angles with the same grinding wheel. As it canbe observed from the figure above the grinding starts in the point T_s and ends in the point A_s, for moving into position these two elements it is necessary to make a rotation of the gear with the angle ϕ and a translation along the axis Z with b. According to the figure we can write the following expressions [8, 9]:

$$b = \frac{\sqrt{R_{ws}^2 - R_b^2}}{\cos \alpha_{st}} - y \qquad (1)$$

where: R_{ws} – technological gearings rolling radius, R_b – base circle radius. The y parameter is calculated with the following equation:

$$y = \frac{R_b}{\cos \alpha_{st}} \cdot [(tg\alpha_{st} - tg\alpha_t) + \frac{1}{R}\left(\frac{\pi m_t}{4} - x \cdot m_n \cdot tg\alpha_t\right) + (\alpha_t - \alpha_{st})] \qquad (2)$$

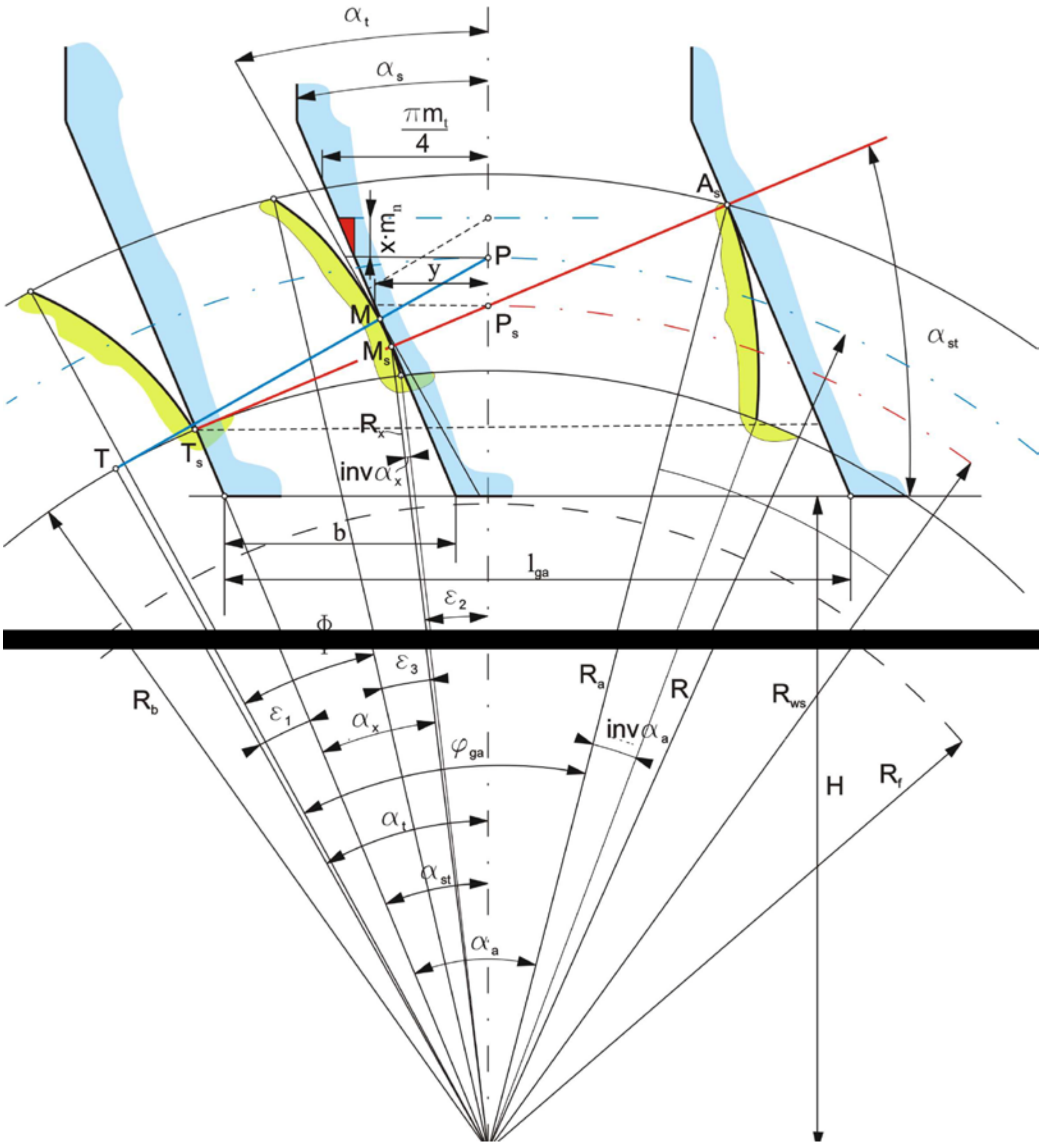


Fig.2. The graphical representation of the relative position between the technologic systems elements at the left tooth gap flank grinding

For the next parameters, after a series of calculations we obtained:

$$\phi = \frac{\sqrt{R_x^2 - R_b^2}}{R} \qquad (3)$$

$$b = \frac{\sqrt{R_{ws}^2 - R_b^2}}{\cos\alpha_{st}} - y \qquad (4)$$

$$\varphi_{ga} = \frac{\sqrt{R_a^2 - R_b^2}}{R_b} \qquad (5)$$

$$l_{ga} = -\left(\frac{\sqrt{R_a^2 - R_b^2}}{\cos\alpha_{st}}\right) \qquad (6)$$

$$R_a = m_n\left(\frac{z}{2\cos\beta} + x + 1 - k\right) \qquad (8)$$

$R_a = OA_S$ defines the distance of the final tangent point between the tools flank and the tooth flank and it is given by the expression (8)

$R_b = OT_s$ defines the distance of the starting tangent point between the tools flank and the tooth flank, located on the base circle radius [10, 11].

The A_sT_s segment represents the trajectory of the contact point tools flank and the tooth flank.

4. GEAR MEASUREMENT AND CONTROL

The measurement and control of the gears manufactured using the deloped technology, was done on the CNC measuring center GHIBLI-TRAX (Fig.3.). The measureing equipement has a special software module for gear measuring and control.

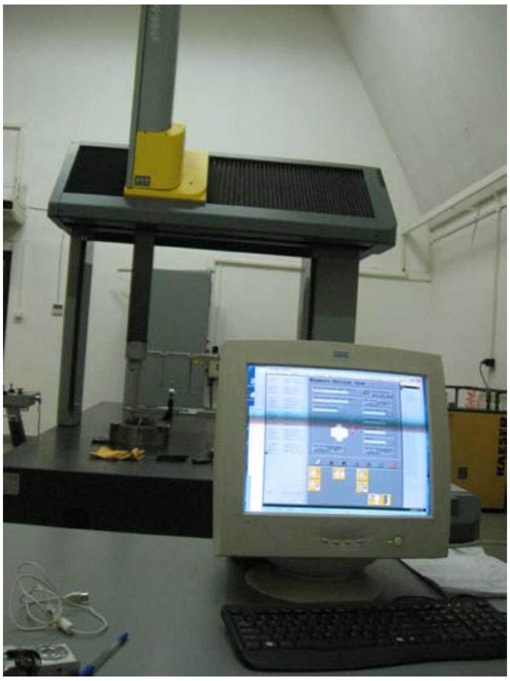
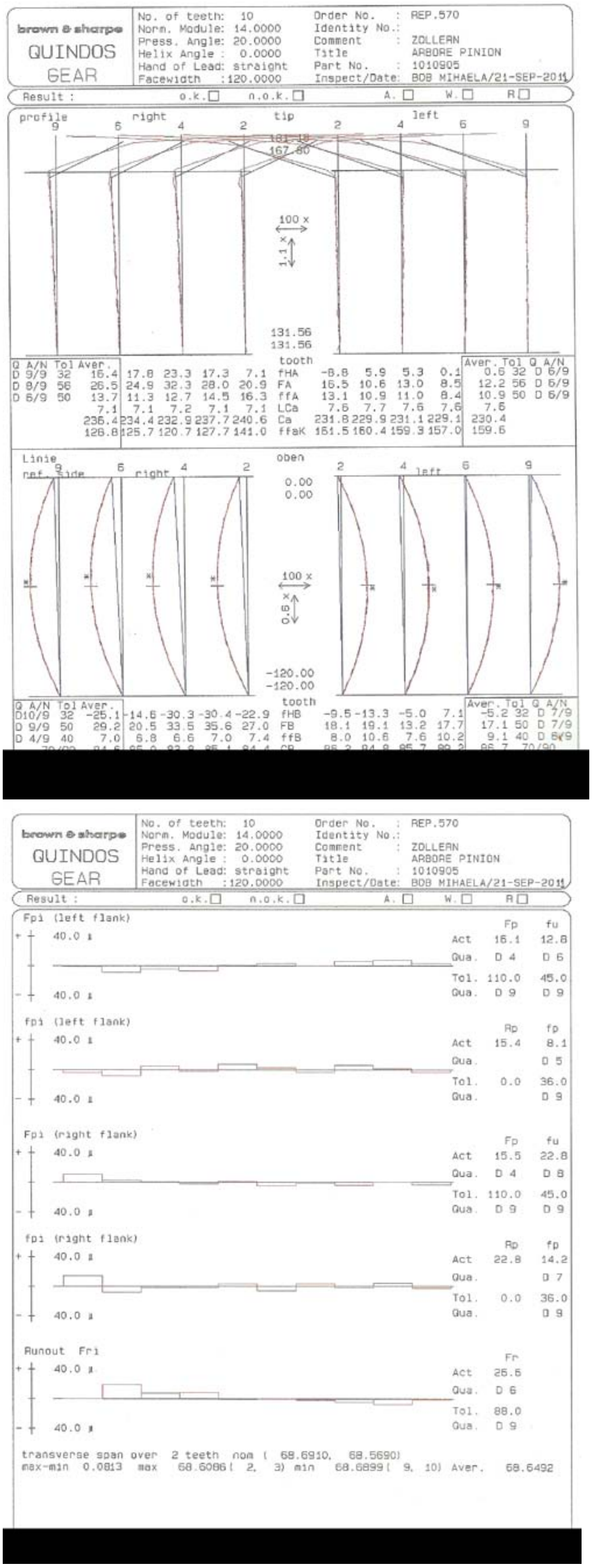


Fig.3. CNC measuring center GHIBLI-TRAX



[redacted]

[redacted]

Fig.4. Gear profile measuring diagrams of a machined gear

From the two measuring diagrams (fig. 4.), we can conclude that the gears manufactured on the CNC machine (fig.1.) are situated between 7 – 8 precision classes, for both profile and pitch precision.

For achieving higher precision classes it is necessary to purchase a higher precision grinding machine that can be equipped with the same numerical command equipment and work programs.

5. CONCLUSIONS

With the presented algorithm we can determine very precise the values of the parameters necessary for programming of gear grinding, determined after different standards (STAS, DIN, AGMA, etc.). The large number of experimental results has highlighted the faultlessness of the method. After the measurements was found that the gears which have been manufactured using the elaborated method are included in the range of precision classes 5...7. Also another positive aspect of this research is that old machines can be upgraded at a lower cost instead of disposing them and buying new expensive equipments.

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SELECTION AND CONFIGURATION OF MODULAR COMPONENTS FOR MODULAR FIXTURE DESIGN

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Abstract: *This paper presents a module for automation the design phase of modular fixture which is related to the selection and configuration of modular components. Methodology of selection and configuration of the modular components are based on production rules, classification numbers, geometrical and topological information of the workpiece, with contributing of the SolidWorks software system, API and object-oriented programming. Databases and knowledge bases are designed as an integral part of the module for the selection and configuration of modular components. Verification of this module is done by selecting and configuration of modular components in functional modular units, which are necessary for positioning and clamping of the hydraulic cylinder.*
Key words: *Modular components, modular functional units, automation*

Izbor i konfiguracija komponenti pri modelarnom projektovanju pribora. *Ovaj rad predstavlja modul za automatsko projektovanje modularnog pribora koji se odnosi na izbor i konfiguraciju modularnih komponenti. Metodologija izbora i konfiguracije modularnih komponenti zasnovani su na proizvodnim pravilima, klasifikacioni brojevima, geometrijskim i topografskim informacijama radnog komada, sa podrškom SolidWorks softverskog sistema, API objektno orijentisang programiranja. Baze podataka i baze znanja su dizajnirane kao sastavni deo modula za izbor i konfiguraciju modularnih komponenti. Izborom i konfiguracijom modularnih komponnata u funkcionalnim modularnim jedinicama izvršena je verifikacija modula, koja je neophodna za pozicioniranje i stezanje hidrauličkog cilindra.*
Ključne reči: *modularne komponente, modularne funkcionalne jedinice, automatizacija*

1. INTRODUCTION

Automation of modular fixture design is a very important link in the chain of full automation of the process planning design [1], [2]. From many types of fixtures, an increasingly important role in the production process has a modular or aggregate fixture. Because of its modular structure and concept, this type of fixtures is suitable for automation design [3]. The problem of time consumption has a significant impact in the fixture design, because process of fixture design generally can only begin after a complete definition of the process planning. It is estimated that the total time that the designer has available for process planning design, an average of 25% makes the fixture design [4]. Previously exposed facts define evidences that the automation of the modular fixture design increases the level of automation design of process planning. Thus, it is very important to introduce new technologies to the modular fixture design in the phase of selection and configuration of modular components [5] .

2. SELECTION AND CONFIGURATION OF MODULAR FIXTURE COMPONENTS

Through preliminary performed analysis of the faces for positioning and clamping, and through the overall analysis of the object, it was generated information for the purpose of selection and configuration of modular fixture components. The above analysis is performed using the program application for determining the functionality of the workpiece faces, the general geometric analysis of the workpiece using the developed algorithms and adopted typical schemas and models for positioning and clamping of the workpiece [6]. The most important information resulting from the above mentioned analysis of the objects are:

- Type and number of faces for positioning and clamping;
- The surface quality of the selected face;
- The size of each selected face (the dimensional values and values in square mm);
- Accessibility of each face from the point of view of possibility for placing of modular fixture components;
- The overall dimensions of the workpiece;
- The existence of through holes in the workpiece;

Knowing the above mentioned information about the workpiece, and applying the typical schemas and models for positioning and clamping, it is executed a selection and configuration of modular fixture components for positioning and clamping of the workpiece.

2.1 Selection of modular fixture components

Selection of modular fixture components was carried out based on previously developed production rule and logic of reasoning procedure, which is associated with a unique classification number of modular fixture component. Classification number of modular fixture component is the holder of the geometrical and structural information about the component. Classification number consists of 10 elements of which the first seven encoded according to Table 1., while the last three digits are used as a statement of the amount of the active height of component, which is also shown in this table. The system of classification, with appropriate meanings of each of the elements is shown in Fig. 1.

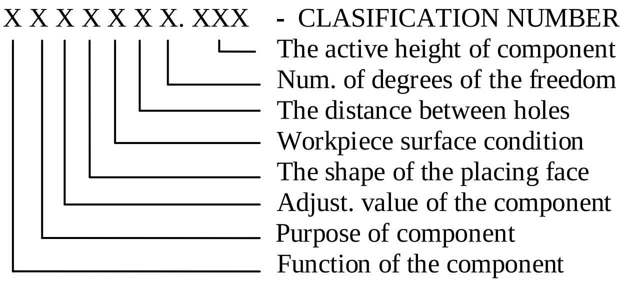


Fig.1. Component classification number [6]

Mark	Values
Function of component	1 - for positioning 2 - for clamping 3 - general component
Purpose of component	1 - basic (contact) 2 - auxiliary (lifting) 3 - additional (screws, etc)
Adjustment of component	1 - non-adjustable 2 - adjustable
Shape of component	1- prismatic 2 - cylindrical 3 - angled
Surface finish of workpiece face	1 - for all surfaces 2 - for un-machined surf. 3 - for rough surfaces 4 - for fine surfaces
Distance between screws	1- point (one screw) 2- serial 3 - diagonal
Degrees of freedom	0-0; 1- 1; 2-2; 3-3;4-4
Max. active height	20; 30; 50; 100; 120

Table 1. Defining the code of the classification number

After analysis of the workpiece, the classification of components and assigning unique classification number to each of the modular fixture components, it is executed a selection of the appropriate components according to block diagram of module for the selection and configuration of the modular fixture components (Fig. 2).

Selection of modular fixture components is divided into three levels. The first level is selection of components for bottom positioning of workpiece; the second-level is selection of components for side positioning and the third level is selection of components for clamping. All three levels are associated with a database of 3D models of modular fixture components. The database, along with algorithmic data flow is associated with a knowledge base which containing production rules as means of the selection process of modular fixtures components. The process of selecting modular fixture components was carried out on the basis of production rules [7] of the following type:

if

TSB = TSB1
PSTR1=1
$100 \leq PAV1 \leq 110$
$50 < AmaxPSTR1 \leq 150mm$
KVALP1 =BO

then

KBP = 1 x 1213130.55
1 x 1111211.20
1 x 3211130.50

Production rules which were developed for selection of modular fixture components, as input information use information obtained from the analysis of the workpiece and defined typical schemes of positioning. Process of selection of modular components is done using production rules that generate the classification number of modular fixture component.

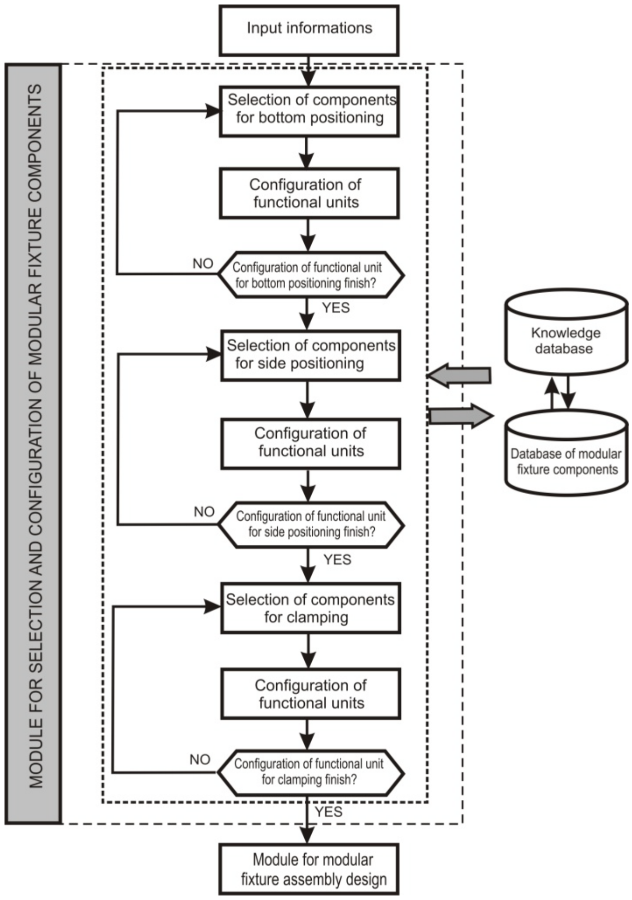


Fig.2. Block diagram of the module for the selection and configuration modular fixture components [6]

2.2 Configuration of modular fixture components

By selecting the modular fixture components, it is provided the configuration process of modular fixture components in modular configure units. Modular configure units are a set of one or more modular fixture components, that performs a unique function of positioning or clamping of the workpiece. The configuration process of modular fixture components is shown in Fig. 3, in the form of sub-module for the configuration of the modular fixture components, which is the part of the module for the selection of modular fixture components, which together with it make a unit in overall automated system for modular fixture design. Configuration process of modular fixture components starts if in the process of selection of modular fixture components appears at least one auxiliary or raise component, next to the executive (contact) component.

Modular fixture components are previously defined in terms of additional information that is later used in the software configuration process. In addition to the classification number, which is located within the name of the components, in modular fixture components have been added extra information about reference mating cases.

Name of Mate Referenc	Mate Reference
RAVAN1	coincident
RAVAN2	coincident
CILINDAR1	concentric
CILINDAR2	concentric
CILINDAR3	concentric
CILINDAR4a	concentric
CILINDAR4b	concentric

Table 2. Additional information for components

Additional information, as shown in Table 2, were assigned to modular fixture components using the SW tools Mate Reference and stored in such a way as additional information of modular fixture components. This information is a relatively easy identify by programs and processes which were used for the configuration of modular fixture components.

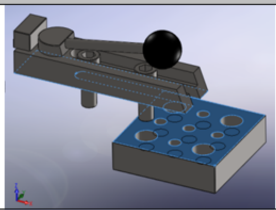
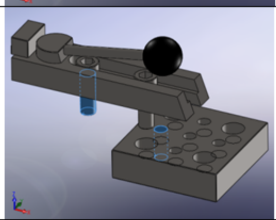
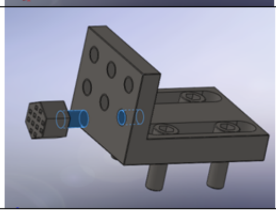
Configuration case	Description	Figure
RAVAN2 with RAVAN1	Configuration process with object RAVAN2 of one component and object RAVAN1 from other component in relationship coincident	
CILINDAR2 with CILINDAR2	Configuration process with object CILINDAR2 of one component and object CILINDAR2 from other component in relationship concentric	
CILINDAR1 with CILINDAR4a	Configuration process with object CILINDAR1 of one component and object CILINDAR4a from other component in relationship concentric	

Table 3. Some of the cases for configuration of modular fixture components

Previously predefined configuration cases of modular fixture components are not the only possible cases of configuration components, because it is possible to expand the configuration cases of modular fixture components.

The process of configuration of modular fixture components is performed for a set of modular fixture components for each of the previously selected faces for positioning and clamping. According to the module for configuration of modular fixture components, as shown in Figure 3, the configuration process begins by searching the general components of modular fixtures from the set of selected components. If the module identifies the general component, it opens in a 3D environment of the program system SolidWorks. Then the search is continuing and if the next general component was find it is also placed in same 3D environment and process of configuration of these two components is executed. If no general components (or the next general component), the process of configuring of the modular fixtures components continues searching for the lifting/rising components. If lifting component is identify it is placed in 3D environment and configured with the general component. The same process is repeated for the next lifting component, if it exists.

If there is no next lifting component, the contact component is placed in same 3D environment of program system and its configuration is done with one of the pre-configured components. If there is no general, no lifting component in the set of selected components, process of generation of the contact component were executed. Adjustment of the modular configuration unit or just contact component is the final process in the module for configuration of modular fixture components.

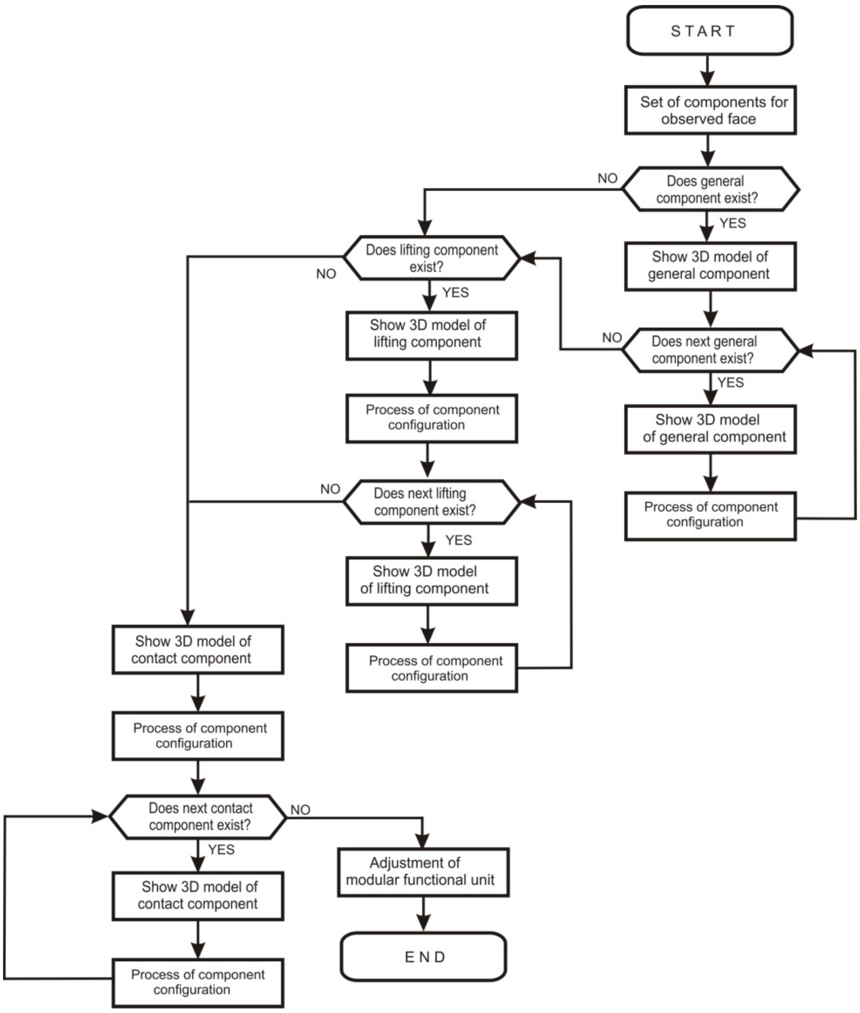


Fig. 3. Algorithmic data flow of sub-module for the configuration of the modular fixture components [6]

Adjustment of the modular fixture components or functional modular units is made regarding the value of active height of component that needs to take in order to perform a proper positioning or clamping of workpiece.

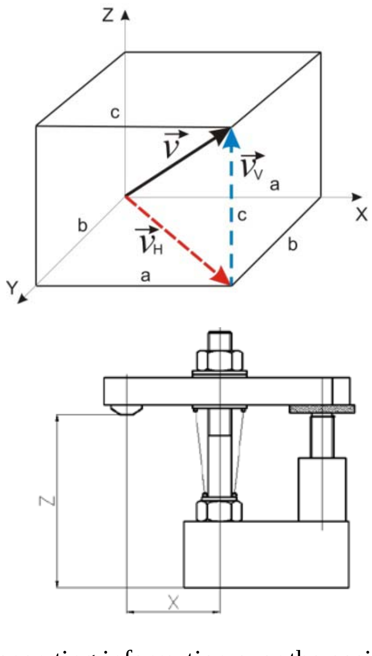


Fig. 4. Generating information over the position vector

Adjustment of modular fixture components and functional modular units is based on previous analysis of the workpiece and the existing information in the form of distribution of holes in the baseplate of the modular fixture. Fig. 4a shows the general case of generating information over the position vector V. Thus, if we look at modular component shown in Fig. 4b the distance X must be set to the value of V_H and Z value to value V_V. In this way it is generating information that is used during configuring of modular fixture components, while the process of adjustment of the components executed at program manner, by using the SW tools Advanced Mates - Distance.

3. VERIFICATION OF MODULE FOR SELECTION AND CONFIGURATION OF MODULAR FIXTURE COMPONENTS

Verification of module for selection and configuration of modular fixture components is performed on the example of a hydraulic cylinder which solid model is the shown in Fig. 5.

Selection of modular fixture components was carried out in an automated way based on production rules that take into account the previously selected standard scheme for positioning and clamping, classification numbers of modular fixture components, as well as the geometric parameters obtained by analysis of accessibility of functional faces. For hydraulic cylinder it is executed a selection of modular fixture components for the purpose of positioning and clamping, as shown in Table 4.

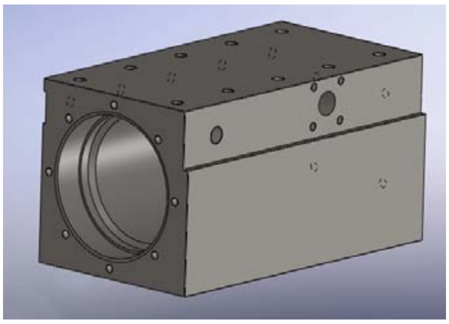


Fig. 5. Solid model of the hydraulic cylinder

After the selection of modular fixture components, the configuration process of modular fixture components for the hydraulic cylinder is executed. The configuration of modular components is performed in a fully automated manner, based on a developed algorithmic data flow and rules as set out in chapter 2 of this paper. The outputs from the process configuration of modular fixture components are functional modular units, which are shown in Figure 6 for the example of hydraulic cylinder. Adjustment the functional modular units were made on the basis of functional analysis of faces and information about position of hydraulic cylinder in relation to the baseplate of the modular fixture.

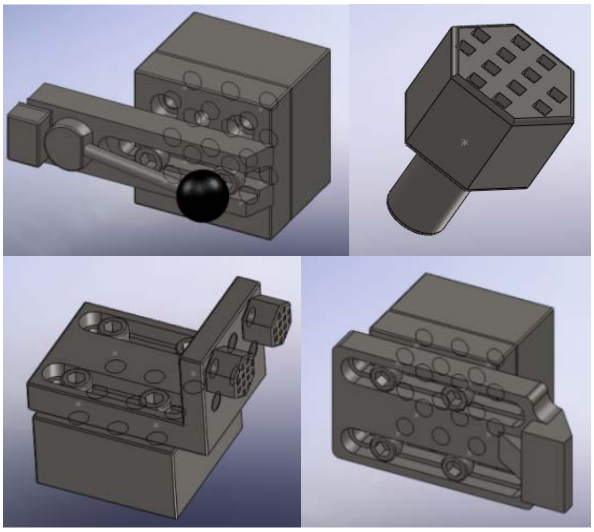


Fig. 6. Functional modular units for positioning and clamping of hydraulic cylinder

Num.	Face ID of hydraulic cylinder	Mark of functional modular unit	Mark of modular fixture component	Normal vector of observed face	Adjustable values	Coordinates of modular unit in assembly
0	10	10_1	1111211.2	(0.00, 0.00, 1.00)	0	(-125, -75)
1	10	10_2	1111211.2	(0.00, 0.00, 1.00)	0	(-125, 25)
2	10	10_3	1111211.2	(0.00, 0.00, 1.00)	0	(75, -75)
3	6	6_1	3211130.5 1113331.3 3211130.25	(1.00, 0.00, 0.00)	104	(-300, -100)
4	6	6_2	3211130.5 1113331.3 3211130.25	(1.00, 0.00, 0.00)	104	(-300, 50)
5	11	11_1	3211130.5 1213130.55 1111211.2 1111211.2	(0.00, 1.00, 0.00)	79	(-100, -200)
6	11	11_2	3211130.5 1213130.55 1111211.2 1111211.2	(0.00, 1.00, 0.00)	79	(50, -200)
7	9	9_1	2113121.35 3211130.5 3211130.25	(0.00,-1.00, 0.00)	129	(-100, 200)
8	9	9_2	2113121.35 3211130.5 3211130.25	(0.00,-1.00, 0.00)	129	(100, 200)
9	1	1_1	2113121.35 3211130.5 3211130.25	(-1.00, 0.00, 0.00)	104	(250, -100)
10	1	1_2	2113121.35 3211130.5 3211130.25	(-1.00, 0.00, 0.00)	104	(250, 50)

Table 4. List of the modular fixture components with additional information

List of the modular fixture components with additional information in the form of classification number, the required number of modular fixture components, which are used during the implementation of automation of the modular fixture design for the hydraulic cylinder, markings of selected modular fixture components, and the positions of functional modular units with orientation defined by the normal vector, are given in Table 4., as a output result of verification of the module for the selection and configuration of modular fixture components.

4. CONCLUSION

Based on the developed algorithms, production rules, using the previously generated geometric and topological information about the workpiece, it is possible to automate the process of selection and configuration of the modular fixture components in purpose of overall automation of modular fixture design. Figure 8 shows the assembly of the modular fixture for the hydraulic cylinder which automated modular fixture design is supported with module for selection and configuration of modular fixture components, presented in this paper.

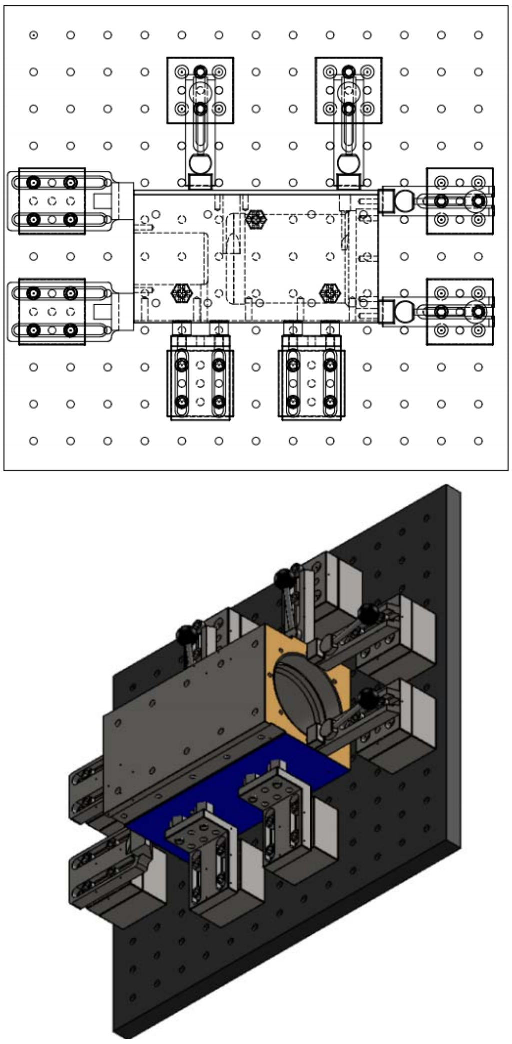


Fig. 7. Final assembly of modular fixture design for hydraulic cylinder

Phase of selection and configuration of modular fixture components, in the process of automated modular fixture design, can be realized with the support of the new CAD technology and object-oriented programming. The automation of this phase of modular fixture design reduces the total time for the modular fixture design, which increases the level of automation of process planning design.

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USE OF VIRTUAL AND ACTUAL VIBRO-DIAGNOSTICS FOR BETTER CONDITION MONITORING

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Abstract: *An intensive development of microprocessors and digital signal processing, made an outstanding impact on vibrodiagnostics and promoted it into the most exploited and reliable method of technical diagnostics. Through an innovative engineering work on development of a new vibro-diagnostics device, based on LabVIEW application, a vast of dynamic measurements were conducted and some of them are deployed in this paper. Data analysis is performed on the records collected with piezoelectric sensor of high sensitivity. The designed instrumentation underwent a true verification in harsh industrial conditions, on actual machinery, in parallel with an appropriate brand name measuring device.*
Key words: *Vibro-diagnostics, Condition Monitoring, Vibration Measurement.*

Upotreba virtuelnih i stvarnih vibro-dijagnostičkuh sistema za bolje praćenje stanja. *Intenzivan razvoj mikroprocesora i digitalne obrade signala, napravio je izuzetan uticaj na vibrodijagnostiku i promovisao ga u većini eksploatisane i pouzdane metode tehničke dijagnostike. Kroz inovativan inženjerski rad na izradi novog vibro - dijagnostičkog uređaja , zasnovana na LabVIEV aplikaciji, sprovedena su velika dinamička merenja i neka od njih su prikazana u ovom radu. Analiza podataka se vrši na osnovu evidencije prikupljenih podataka pomoću piezoelektričnog senzora visoke osetljivosti. Dizajnirana instrumentacija doživela pravu proveru u teškim industrijskim uslovima, na stvarnim mašinama, paralelno sa odgovarajućom mernom mašinom.*
Ključne reči: *vibro-dijagnostika, praćenje stanja, merenje vibracija*

1. INTRODUCTION

Technical diagnostics is undergoing rapid development and increasing implementation in real time system monitoring. In order to maximize the operational reliability and efficiency, virtual diagnostics is used for system health assessment and machinery failure prediction [1]. Market research showed the lack of powerful yet affordable multifunctional multi channel device for signal analysis. For that purpose a kind of vibro-diagnostic instrument was developed and this paper shows vibration severity measurement results.

Data sets were collected under laboratory conditions, also within industrial environment. The device architecture is based on dedicated signal conditioning module and National Institute data acquisition board. Data measurement and true vibration analysis were carried out with the application software, developed in LabVIEW graphical environment. This multichannel signal analyzer was designed to monitor a cluster of accelerometer signals in order to determine:

- Vibration severity
- Peak tones of spectrum (FFT)
- Time graph of signal trends

The device also provides options to display/store measurement data and input measurement parameters via conventional communication ports and protocols.

2. HARDWARE DESCRIPTION

This concept of multichannel portable device for signal analysis comprises (Fig. 1):

- Set of accelerometer inputs (2-8 channels; 100 mV/g)
- Sophisticated touch screen HMI
- NI cRIO specialized PLC
- Signal conditioning system
- Signal acquisition system (0-6 current inputs 4-20 mA; 1-4 impulse digital inputs 0-5 V) (Fig. 2) [2].

Fig. 1. Measurement device Micro Mon Rotech

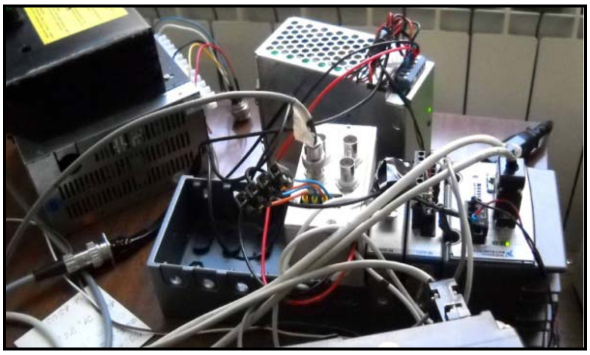


Fig. 2. Signal acquisition system

The role of NI cRIO is to accept analog and digital signals, scan, convert and deliver appropriate data package back to HMI with a strictly defined timing. On the other hand, HMI should receive/display data from PLC and send back input parameters. The measurement performs continually with frequent results refresh rate. The results are arranged in priority descending order. Additional options are accessible through HMI, such as:

- Peak tones of spectrum (FFT)
- Time graph of signal trends
- START UP/COAST DOWN measurements
- Insight balancing [3].

3. SOFTWARE DESCRIPTION

Device software component for vibration monitoring and analysis was developed in LabVIEW graphical environment. The main purpose of the application is data acquisition, data processing and interpretation. Data processing includes digital filtering, order analysis phase tracking, time/frequent domain analysis, ect. The most important achievement in device performance is bidirectional communication between cRIO and touch screen. Full synchronization between Master device (T.S.) and device (cRIO) was crucial for fluent operation, hence data acquisition and data analysis are performed in a strictly determined sequence.

3.1 Functions and LabVIEW modules

Functions and modules for data management and data analysis can be divided according to the sort of operation:

- Numerical/dynamical/string data basic processing
- Program course control
- Hardware/software communication.

The application has hierarchical structure (Fig. 3). User interface is in graphical environment and allows:

- Measurement process control
- Signal parameters defining
- Processed signal display.

NI cRIO controller has built-in real time operating system which is adjusted for the operation under industrial conditions. The controller provides increased durability and reliability at high performance. The device itself combines controller open architecture with industrial I/O modules. Since cRIO controller contains set of FPGA programmable input ports, part of the application is conducted on a hardware level. Due to this feature the wahole system can be used for security purposes.

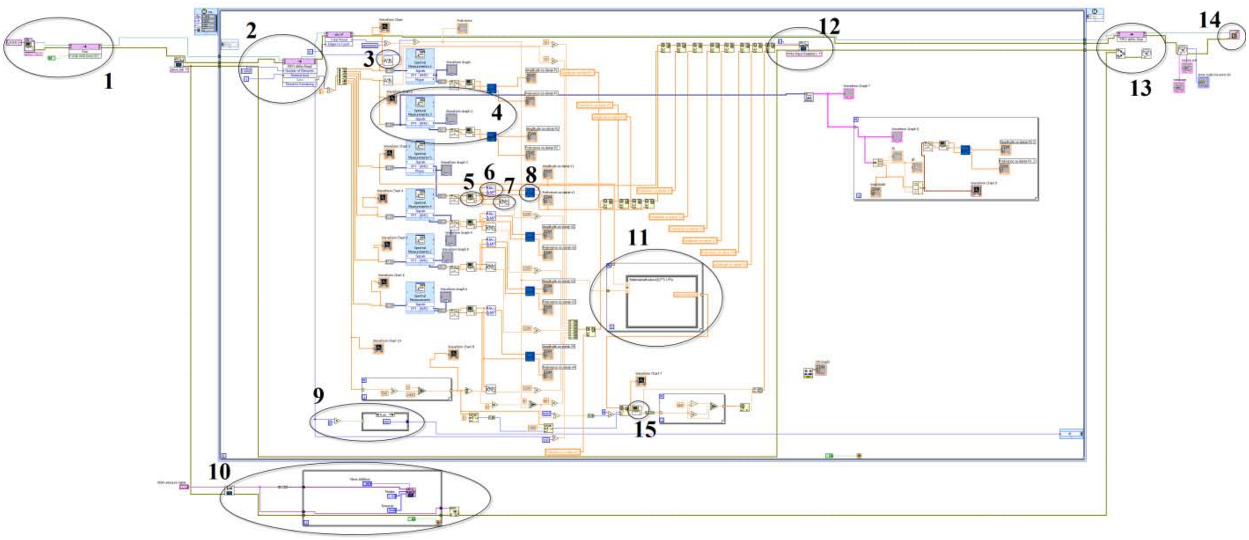


Fig. 3. Block diagram

1. Signal conditioning / process start; 2. Data recall from FPGA level; 3, 4. Signal multi-channeling, data sorting, signal graphical review before/after FFT analysis; 5, 6, 7, 8. Peak tones frequency detection / amplitudes and locations are forwarded to subprograms, for further processing; 9. Code for process quality monitoring; 10. Establishing the connection with touch panel; 11. Calculation of amplitudes; 12. Displaying results on touch panel; 13, 14. Exit FPGA level, errors display, closing the program; 15. Unbalance vector calculus program.

4. VIBRATION MEASUREMENT WITHIN INDUSTRIAL ENVIRONMENT

Experimental testing of the monitoring system was mostly conducted under laboratory conditions on an overhung rotor model. Comparison of the results, measured in accordance with ISO 10816 standard, shows high compliance with Micro Mon, or Microlog.

Testing within industrial environment was performed on steam generators turbines (Block 1) at TENT B Obrenovac under following conditions:

Measuring equipment: Micro Mon – Rotech and Microlog CMVA65 – SKF

Measured quantity: vibration acceleration

Derivate quantity: vibration velocity (RMS*)

Principal measuring axis: horizontal H; vertical V; axial A.

Selected measuring points: L_1-L_9 (Fig. 4)

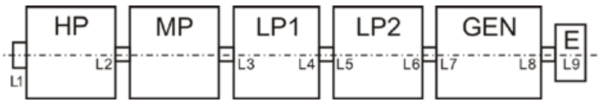


Fig. 4. Measuring points deposition (HP-turbine; MP-turbine; $LP_{1,2}$-turbine; GEN-generator; E-exciter; L_1-L_9-bearing)

Evaluation of equipment was done according to ISO 10816-2:1996 standard << *Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts» - Large land-based steam turbine generator sets in excess of 50 MW* [4, 5], under the “dynamic condition” criteria (Tab. 1)

Quality Zones	Rated speed (RPM) 1500	3000
	RMS Overall Velocity Level V_{RMS} (mm/s)	
A/B	2.8	3.8
B/C	5.3	7.5
C/D	8.5	11.8

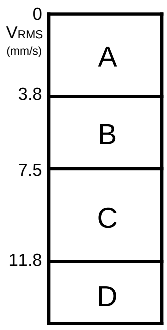


Table 1. Operating quality permissible limit according to ISO (A- newly commissioned machines; B- acceptable; C- acceptable for short term operation; D- non acceptable)

Results of vibro severity measurement on block 1 are shown in (Tab. 2,3,4.) (Microlog) and results obtained with Micro Mon (Fig. 7,8.). Outcome of the results comparison apparently shows that developed measuring device Micro Mon meets the appropriate standards.

AXIS	RMS (mm/s) L1 V_{RMS}	L1 V_i/n_i	L2 V_{RMS}	L2 V_i/n_i	L3 V_{RMS}	L3 V_i/n_i
H	1,8	1,7(1x)	1,2	0,8(1x)	4,2	4,1(1x)
						0,8(2x)
V	0,7		0,8	0,6(1x)	4,5	4,5(1x)
A	1,0	0,8(1x)	2,7	2,6(1x)	1,6	1.5(1x)

Table 2. Vibration at turbine bearings (Microlog)

AXIS	RMS (mm/s) L4 V_{RMS}	L4 V_i/n_i	L5 V_{RMS}	L5 V_i/n_i	L6 V_{RMS}	L6 V_i/n_i
H	3,0	2,9(1x)	3,2	3,1(1x)	5,6	5,6(1x)
		0,6(2x)		0,9(2x)		
V	3,8	3,7(1x)	3,5	3,4(1x)	1,4	1,3(1x)
		0,4(2x)				
A	1,4	1,0(1x)	0,5		5,2	5,1(1x)
		0,8(2x)				

Table 3. Vibration at turbine bearings (Microlog)

AXIS	RMS (mm/s) L7 V_{RMS}	L7 V_i/n_i	L8 V_{RMS}	L8 V_i/n_i	L9 V_{RMS}	L9 V_i/n_i
H	2,7	2,0(1x)	1,0	1,0(1x)	0,6	
		1,9(2x)				
V	3,0	2,1(1x)	2,3	1,3(1x)	1,4	0,9(1x)
		2,2(2x)		1,9(2x)		1,0(2x)
A	2,0	1,8(1x)	2,7	1,2(1x)	1,1	
		0,7(2x)		2,4(2x)		

Table 4. Vibration at turbine bearings (Microlog)

Figures 5 and 6 clearly show elevated level of vibration (peak) on L_3, on the basic frequency (50 Hz). Micro Mon results (Fig. 7,8.) confirm that elevated level of vibration exists on H and V axis on a basic frequency (50 Hz). Further construction analysis concluded that the cause of said vibration was a bad alignment of LP turbine axis and MP turbine axis.

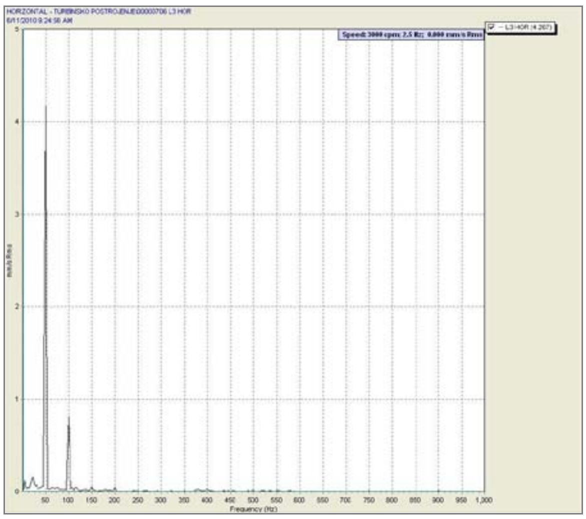


Fig. 5. FFT Spectral analysis (Microlog) (L_3/H)

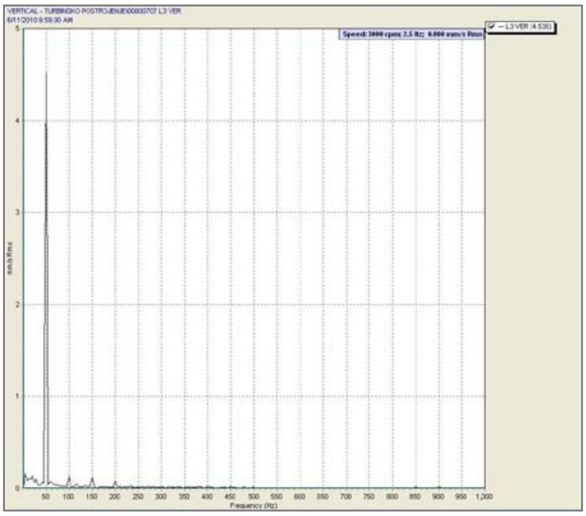
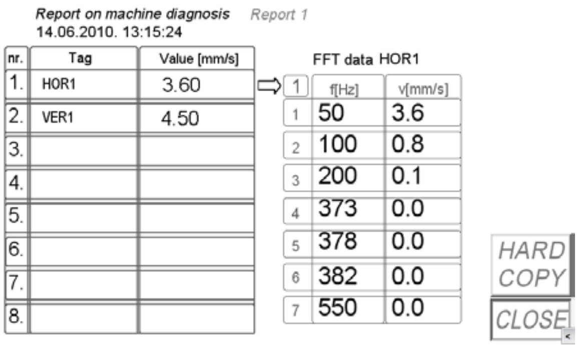


Fig. 6. FFT Spectral analysis (Microlog) (L_3/V)



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nr.	Tag	Value [mm/s]
1.	HOR1	3.60
2.	VER1	4.50
3.		
4.		
5.		
6.		
7.		
8.		

FFT data HOR1

1	f[Hz]	v[mm/s]
1	50	3.6
2	100	0.8
3	200	0.1
4	373	0.0
5	378	0.0
6	382	0.0
7	550	0.0

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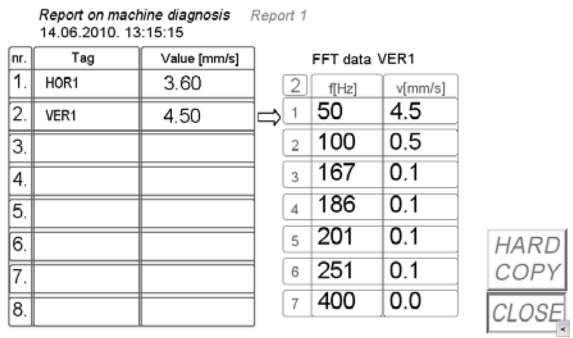
Fig. 7. Vibration at L_3, H axis



Report on machine diagnosis Report 1
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nr.	Tag	Value [mm/s]
1.	HOR1	3.60
2.	VER1	4.50
3.		
4.		
5.		
6.		
7.		
8.		

FFT data VER1

2	f[Hz]	v[mm/s]
1	50	4.5
2	100	0.5
3	167	0.1
4	186	0.1
5	201	0.1
6	251	0.1
7	400	0.0

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Fig. 8. Vibration at L_3, V axis

Based on the total measurement, the conclusion is that the block 1 vibration level is within the permissible level. On bearings L1, L2, L4, L5, L7, L8, L9 the level of vibration was within the ISO standard recommendation.

On L3 and L6 higher level of vibration was detected. L6 – on H and A axis. Primary cause: bad alignment of LP turbine axis and GEN turbine. Secondary cause: residual vibrations.

5. CONCLUSION

Based on the research exhibited in this paper, laboratory and industrial testing, a “real-time” portable vibro-diagnostic device was developed. Measurement device was verified in the real industrial conditions on turbine block.

Results were in accordance with the results obtained by SKF Microlog CMVA device, and this is an excellent indicator that the developed device is competitive on the market.

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FIXTURE ANALYSIS MODULE, AN ESSENTIAL ELEMENT OF THE INTELLIGENT FIXTURING SYSTEM

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Abstract: *This paper presents the concept of Intelligent Fixturing System (IFS) which is being developed to hold a family of thin-walled workpieces for machining operations. This is a cost-effective concept which incorporates a fixturing system, fixture analysis module, fixture stability module, clamp optimization module and clamping control system. This paper presents the development of fixture analysis module that can determine the optimal clamping force values considering the cutter location and the three cutting force components.*
Key words: *intelligent fixturing, fixture analysis.*

Analiza modula pribora, kao bitan element inteligentnog sistema pribora. *Ovaj rad predstavlja koncept inteligentnog sistema pribora (ISP), koji se razvija za stezanje tankozidnih delova pri mašinskim operacijama. To je isplativ koncept koji obuhvata sistem pribora, analizu modula, stabilnost modula, optimizaciju modula i kontrolu stezanja. Ovaj rad predstavlja razvoj analize modula pribora da bi se odredila optimalna vrednosti sile stezanja, razmatra se položaj rezanja i tri komponente sila rezanja.*
Ključne reči: *inteligentni pribori, analize pribora*

1. INTRODUCTION

In pace with automation of the work process the development and rationalization stage of fixtures becomes increasingly important and strongly influences the price of the final product. The fixing equipment is a bottleneck in production, therefore in the past decade the efforts in searching for new Intelligent Fixturing System (IFS) were increased. This paper describes the proposed IFS system, which on the basis of given workpiece geometry analyses and optimizes the magnitude/position of clamping forces. The paper is also concerned about the fixture module for the analysis and rationalization of fixtures, suitable for clamping of thin-wall products likely to undergo deformation due to clamping and cutting forces during machining. Software has been made for the evaluation of fixturing scheme, for calculation of the optimum magnitude and positioning of clamping forces, required to enable the workpiece to be safely clamped during machining. The calculation is based on the force analysis method provided with the optimization routine. Especially in cases of machining of thin-walled components, deformation can be minimised by optimizing the location and magnitude of clamping forces. Therefore, in intelligent fixturing system the clamp position and magnitude of clamping forces have to be controlled in real time [1]. More realistic and cost-effective approach is to use off-line optimisation of the clamps location and on-line adjustment of clamping force.

2. INTELLIGENT FIXTURING SYSTEM

An attempt was made to include fixture analysis module into the Intelligent Fixturing System (IFS). Proposed system is able to perform the following operations: off line optimization of clamping forces, monitor the clamping forces and adjust the clamping forces according to the change in geometry of the workpiece. The framework of the system is shown in Figure 1. It consists of the modular fixturing system, off line fixture analysis module, fixturing stability module, clamping optimization algorithm and clamping control system. At the beginning, the optimal clamping forces are determined by analysis module then the reaction forces are measured through the sensors embedded in locators. The data are sent via force monitoring module to the fixture stability model. The fixture stability module is used to monitor the fixturing stability during the entire machining operation. Once instability appears, the module sends a command to the hydraulic system to increase the corresponding clamping force. This process is repeated until the completion of the machining process. Positive reaction forces at the locators ensure that the workpiece maintains contact with all the locators from the beginning of the cut to the end. The three components of cutting forces in end-milling are predicted using the neural cutting force model developed by [2]. The clamping force optimisation algorithm determines the optimal clamping force values considering the cutter location, the three cutting force components and results of the fixture stability model. The optimal clamping forces are then applied in real-time using an electro-hydraulic clamping system. Soft PLC controls a hydraulic system to apply the required clamping forces as the cutter moves to different locations on the workpiece. The clamping forces are proportional to pressure in hydraulic cylinder.

3. FIXTURE ANALYSIS MODULE

The developed module is useful for technologist

since it can routinely determine within a short time the optimum sizes, direction and application points of clamping. The module is aimed at verifying (analysing) the obtained solution (configuration of the fixture), confirming or rejecting it, if all the set condition are not fulfilled. The worked out programme works on the PC and is programmed in the mathematical programme language MatLab. The clamping principle 3-2-1, requiring three points on the primary locating plane, two points on the second locating plane and one point on the third locating plane, was used for making the module. The clamping force must be great enough and suitable oriented so that the workpiece position during machining does not change due to cutting forces.
The clamping forces on the workpiece must not create internal stresses and must not damage or deform the workpiece surface. The objective is to minimize all the controllable and reaction forces. This is expressed as the minimization of the sum of the squares of the clamping and reaction forces.

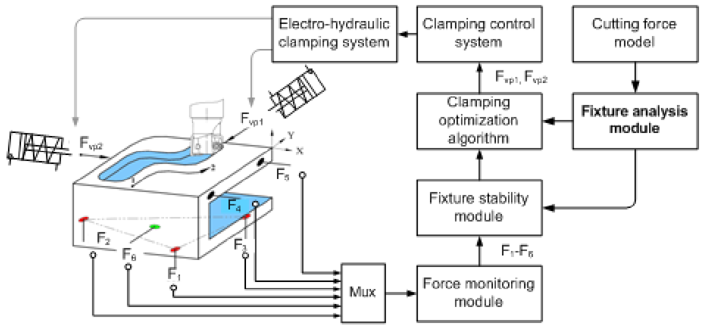

Fig. 1. Framework of the IFS system

3.1 Theoretic concept of the fixture analysis module

The workpiece is located on the six- points P_1-P_6 and is held by three clamping forces Fvp_1, Fvp_2, Fvp_3 at points P_7, P_8, P_9 (figure 2).

Where:
F_1 - F_6 - reactions acting on locating elements (*N*),
Fvp_1, Fvp_2, Fvp_3- clamping forces acting in the direction of the normal onto positioning planes (*N*),
F_t, F_a, F_f - components of cutting force F_c (*N*),
M_x, M_y, M_z - components of cutting moment M_c (*Nm*),
f_i, (i = 1...9) - friction forces in contact points (*N*),
F_g - force of workpiece weight (*N*),
μ - friction coefficient.

The resulting force of friction f_i between the locator and workpiece is $\mu \cdot F_i$ and between the fixing element and the workpiece it is $\mu \cdot F_{vpj}$, (j=1…3).

The reactions on the locating elements must be positive, because otherwise the contact between the workpiece and the fixture is lost.

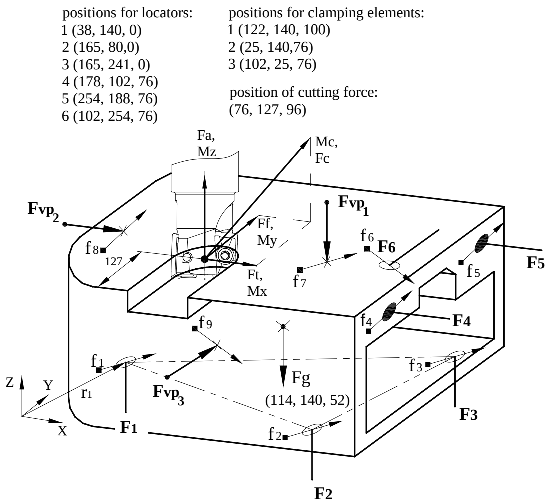

Fig. 2. Forces on a prismatic workpiece during machining of a slot

To achieve static equilibrium the resultant force and moment on the workpiece must be zero.
Because of the numerical solving of the problem the equilibrium equations are written in matrix form:

$$[A]_{lok} \cdot [F]_{lok} + [w_e] = 0 \quad (1)$$

$[A]_{lok}$ - normalized geometrical matrix.

$[F]_{lok}^{T}$ - vector of supporting forces

$[w_e]$ - vector of external forces

After entering the geometrical matrix and the vector of external forces into the equation (1) the equation (5) is obtained.

When the coefficient of the friction between the workpiece and the clamping elements is equal to zero, the equation (5) is simplified and assumed the form (6).

$$[A]_{lok} = \left[\begin{array}{cccccc} f_{1x} & f_{2x} & f_{3x} & -1 & -1 & f_{6x} \\ f_{1y} & f_{2y} & f_{3y} & f_{4y} & f_{5y} & -1 \\ 1 & 1 & 1 & -f_{4z} & -f_{5z} & -f_{6z} \\ \hdashline r_{1y} & r_{2y} & r_{3y} & \begin{pmatrix} -f_{4y} \cdot r_{4z} - \\ -f_{4y} \cdot r_{4y} \end{pmatrix} & \begin{pmatrix} -f_{5y} \cdot r_{5z} - \\ -f_{5z} \cdot r_{5y} \end{pmatrix} & \begin{pmatrix} -f_{6z} \cdot r_{6y} + \\ +r_{6z} \end{pmatrix} \\ -r_{1x} & -r_{2x} & -r_{3x} & \begin{pmatrix} -r_{4z} + \\ +f_{4z} \cdot r_{4x} \end{pmatrix} & \begin{pmatrix} -r_{5z} + \\ +f_{5z} \cdot r_{5x} \end{pmatrix} & \begin{pmatrix} f_{6x} \cdot r_{6z} + \\ +f_{6z} \cdot r_{6x} \end{pmatrix} \\ \begin{pmatrix} -f_{1x} \cdot r_{1y} + \\ +f_{1y} \cdot r_{1x} \end{pmatrix} & \begin{pmatrix} -f_{2x} \cdot r_{2y} + \\ +f_{2y} \cdot r_{2x} \end{pmatrix} & \begin{pmatrix} -f_{3x} \cdot r_{3y} + \\ +f_{3y} \cdot r_{3x} \end{pmatrix} & \begin{pmatrix} r_{4y} + \\ +f_{4y} \cdot r_{4x} \end{pmatrix} & \begin{pmatrix} r_{5y} + \\ +f_{5y} \cdot r_{5x} \end{pmatrix} & \begin{pmatrix} -r_{6x} - \\ -f_{6x} \cdot r_{6y} \end{pmatrix} \end{array}\right] \quad (2)$$

$$[F]_{lok}^{\,T} = \begin{bmatrix} F_1 & F_2 & F_3 & F_4 & F_5 & F_6 \end{bmatrix} \quad (3)$$

$$[w_e] = \begin{bmatrix} f_{7x} + f_{9x} + F_{vp_2} + R_x \\ f_{7y} + f_{8y} + F_{vp_3} + R_y \\ -f_{8z} - f_{9z} - F_g + R_z \\ -f_{7y}\cdot r_{7z} - f_{8y}\cdot r_{8z} - f_{8z}\cdot r_{8y} - f_{9z}\cdot r_{9y} - F_{vp_1}\cdot r_{7y} - F_{vp_3}\cdot r_{9z} - F_g\cdot r_{gy} + M_x \\ f_{7x}\cdot r_{7z} + f_{8z}\cdot r_{8x} + f_{9x}\cdot r_{9z} + f_{9z}\cdot r_{9x} + F_{vp_1}\cdot r_{7x} + F_{vp_2}\cdot r_{8z} + F_g\cdot r_{gx} + M_y \\ -f_{7x}\cdot r_{7y} + f_{7y}\cdot r_{7x} + f_{8y}\cdot r_{8x} - f_{9x}\cdot r_{9y} - F_{vp_2}\cdot r_{8y} + F_{vp_3}\cdot r_{9x} + M_z \end{bmatrix} \quad (4)$$

$$[F]_{lok} = -\begin{bmatrix} f_{1x} & f_{2x} & f_{3x} & -1 & -1 & f_{6x} \\ f_{1y} & f_{2y} & f_{3y} & f_{4y} & f_{5y} & -1 \\ 1 & 1 & 1 & -f_{4z} & -f_{5z} & -f_{6z} \\ \hline r_{1y} & r_{2y} & r_{3y} & \begin{pmatrix} -f_{4y}\cdot r_{4z} - \\ -f_{4y}\cdot r_{4y} \end{pmatrix} & \begin{pmatrix} -f_{5y}\cdot r_{5z} - \\ -f_{5z}\cdot r_{5y} \end{pmatrix} & \begin{pmatrix} -f_{6z}\cdot r_{6y} + \\ +r_{6z} \end{pmatrix} \\ -r_{1x} & -r_{2x} & -r_{3x} & \begin{pmatrix} -r_{4z} + \\ +f_{4z}\cdot r_{4x} \end{pmatrix} & \begin{pmatrix} -r_{5z} + \\ +f_{5z}\cdot r_{5x} \end{pmatrix} & \begin{pmatrix} f_{6x}\cdot r_{6z} + \\ +f_{6z}\cdot r_{6x} \end{pmatrix} \\ \begin{pmatrix} -f_{1x}\cdot r_{1y} + \\ +f_{1y}\cdot r_{1x} \end{pmatrix} & \begin{pmatrix} -f_{2x}\cdot r_{2y} + \\ +f_{2y}\cdot r_{2x} \end{pmatrix} & \begin{pmatrix} -f_{3x}\cdot r_{3y} + \\ +f_{3y}\cdot r_{3x} \end{pmatrix} & \begin{pmatrix} r_{4y} + \\ +f_{4y}\cdot r_{4x} \end{pmatrix} & \begin{pmatrix} r_{5y} + \\ +f_{5y}\cdot r_{5x} \end{pmatrix} & \begin{pmatrix} -r_{6x} - \\ -f_{6x}\cdot r_{6y} \end{pmatrix} \end{bmatrix}^{-1} \cdot \quad (5)$$

$$\cdot \begin{bmatrix} f_{7x} + f_{9x} + F_{vp_2} + R_x \\ f_{7y} + f_{8y} + F_{vp_3} + R_y \\ -f_{8z} - f_{9z} - F_g + R_z \\ -f_{7y}\cdot r_{7z} - f_{8y}\cdot r_{8z} - f_{8z}\cdot r_{8y} - f_{9z}\cdot r_{9y} - F_{vp_1}\cdot r_{7y} - F_{vp_3}\cdot r_{9z} - F_g\cdot r_{gy} + M_x \\ f_{7x}\cdot r_{7z} + f_{8z}\cdot r_{8x} + f_{9x}\cdot r_{9z} + f_{9z}\cdot r_{9x} + F_{vp_1}\cdot r_{7x} + F_{vp_2}\cdot r_{8z} + F_g\cdot r_{gx} + M_y \\ -f_{7x}\cdot r_{7y} + f_{7y}\cdot r_{7x} + f_{8y}\cdot r_{8x} - f_{9x}\cdot r_{9y} - F_{vp_2}\cdot r_{8y} + F_{vp_3}\cdot r_{9x} + M_z \end{bmatrix}$$

$$[F]_{lok} = \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \end{bmatrix} = -\begin{bmatrix} 0 & 0 & 0 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 \\ 1 & 1 & 1 & 0 & 0 & 0 \\ \hline r_{1y} & r_{2y} & y_{3y} & 0 & 0 & +r_{6y} \\ -r_{1x} & -r_{2x} & -r_{3x} & -r_{4z} & -r_{5z} & 0 \\ 0 & 0 & 0 & r_{4y} & r_{5y} & -r_{6x} \end{bmatrix}^{-1} \cdot \begin{bmatrix} F_{vp_2} + R_x \\ F_{vp_3} + R_y \\ F_g + R_z \\ -F_{vp_1}\cdot r_{7y} - F_{vp_3}\cdot r_{9z} - F_g\cdot r_{gy} + M_x \\ F_{vp_1}\cdot r_{7x} + F_{vp_2}\cdot r_{8z} + F_g\cdot r_{gx} + M_y \\ F_{vp_2}\cdot r_{8y} + F_{vp_3}\cdot r_{9x} + M_z \end{bmatrix} \quad (6)$$

r_i- the vectors defining the locating points, (R_x, R_y, R_z) - components of the resultant cutting force F_c

4. EXAMPLE OF FIXTURE ANALYSIS AND OPTIMIZATION

On a milling machine it is necessary to make the slot shown in figure 1. To this end we use the milling cutter of 16 mm diameter with two cutting inserts (R-216-16 03 M-M) with the following cutting conditions: cutting speed (v=25m/min), feedrate (fz=0,01mm/tooth), cutting depth (a=4mm). The values of components of cutting forces (F_a=450N, F_f=315N, F_t=810N), the tool position, the starting positions of clamping/locating elements, the friction coefficient (μ=0.4) and the workpiece weight (F_g=47N) are entered into the window for entering the input data.

Clamping is effected by the three clamping elements. With the upper clamping element the workpiece is clamped in module. the direction of the Z axis and with the two side elements it is pressed along the vertical locating plane. The equation (1) assumes the form (7). The possible solutions for Fvp_is are those that result in positive values of F_is; in other words, the workpiece will remain in contact with locators during the entire cutting process.

To solve these six linear simultaneous equilibrium equations with nine unknowns, we assume that Fvp_1, Fvp_2 and Fvp_3 have the same magnitude. Their values start from zero and are incremented by a constant value in each iteration until positive values of all F_is are achieved.

The obtained values of Fvp_1, Fvp_2 and Fvp_3, which are equal to 440N will be the first set of possible solutions, which are listed as case (1) in Table 1.

Table 1 lists the reaction forces F_i (i=1…6) on the six locators and the possible solutions for Fvp_is under different clamping conditions.

$$\begin{bmatrix} 0.373 & 0.373 & 0.373 & -1 & -1 & 0.194 \\ 0{,}145 & 0{,}145 & 0{,}145 & 0{,}229 & 0{,}229 & -1 \\ 1 & 1 & 1 & -0{,}328 & -0{,}328 & -0{,}35 \\ 5{,}512 & 1{,}496 & 9{,}488 & -2{,}002 & -3{,}112 & -0{,}505 \\ -1496 & -6{,}496 & -0{,}696 & -0{,}696 & 0{,}385 & 1{,}985 \\ -1{,}838 & 0{,}384 & -2{,}595 & 5.623 & 9{,}695 & -5{,}958 \end{bmatrix} \cdot \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \end{bmatrix} = - \begin{bmatrix} 0{,}373 \cdot F_{vp_1} + F_{vp_2} + 0{,}194 \cdot F_{vp_3} + 810 \\ 0{,}145 \cdot F_{vp_1} + 0{,}328 \cdot F_{vp_2} + F_{vp_3} + 315 \\ -0{,}459 \cdot F_{vp_2} - F_{vp_1} - 450 + 80 \\ -6.38 \cdot F_{vp_1} - 2{,}245 \cdot F_{vp_2} - 3{,}336 \cdot F_{vp_3} - 440{,}95 + 4501{,}57 \\ 7{,}034 \cdot F_{vp_1} + 3{,}218 \cdot F_{vp_2} + 1{,}985 \cdot F_{vp_3} + 6361{,}4 + 359{,}05 \\ -1{,}359 \cdot F_{vp_1} - 5{,}321 \cdot F_{vp_2} + 3{,}825 \cdot F_{vp_3} - 2910{,}63 \end{bmatrix} \quad (7)$$

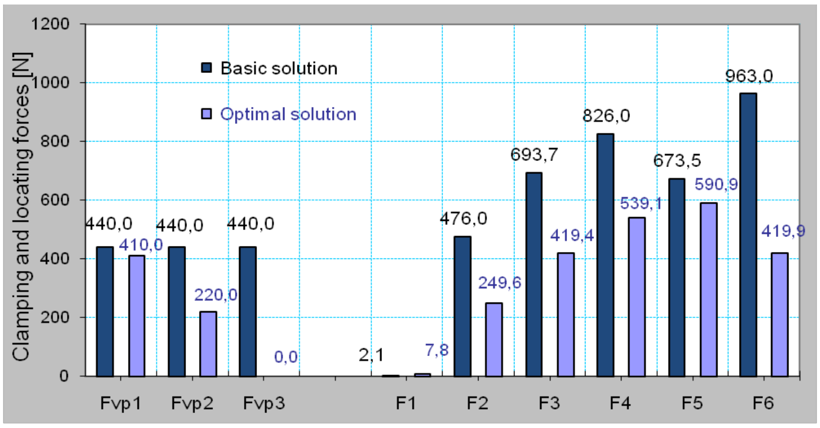

Fig. 3. Comparison of clamping cases

Forces [N]	(1) case	(2)	(3)	(4)	(5)
Fvp_1	440	430	440	410	0
Fvp_2	440	440	440	220	320
Fvp_3	440	440	0	0	0
F_1	2,14	0,967	125,57	7,808	0,44
F_2	475,9	472,12	432,77	249,644	396,842
F_3	693,7	688,765	613,25	419,354	643,647
F_4	826,0	823,769	652,30	539,109	618,558
F_5	673,5	672,009	761,73	590,891	564,291
F_6	962,9	961,526	522,97	419,862	446,534

Table 1. Reaction on the locating elements for 5 cases.

The case (1) shows the first acceptable solution where all clamping forces are equal (440N). For the other cases (case 2-3) two of the clamping forces are set to value 440N, while the value of the third clamping force is gradually increased until all F_is are positive. By such procedure the value of required clamping forces is reduced. In case (3) the clamping element 3 is not necessary, since the force acting on that element is equal to 0 (Fvp_3 =0). The software proposes the optimum solutions of the clamping configuration (case 4 and 5) between the user can choose. The critical point of the fixture is on the locating element 1. During machining the workpiece will first lose the contact with the clamping device just at that point (P_1). The fixture configuration can be improved by: placing on additional clamping element above the critical locating element 1, increasing the value of the clamping force Fvp_1 or changing position of the clamping element 7. With clamping force Fvp=0N up to Fvp=440N the clamping fixture configuration is not suitable for clamping of the workpiece in the given conditions of machining. The maximum loading of the clamping fixture occurs at the point of the locating element 6, which, during machining in the locating plane XZ, takes all loadings acting in the direction of Y axis. The proposed and analyzed clamping cases (1 and 4) are shown in figure 3.

5. CONCLUSION

A force analysis module, which is a part of the developed IFS is presented that considers the effect of frictional forces for verification, rationalization and improvement of a clamping design. A new iteration method is introduced for determining the optimal clamping and locating force. By the developed module we have significantly reduced the magnitude of clamping forces. It is possible to anticipate and prevent the defects on the workpiece during the clamping and machining process. In the research it has been found out that by taking the friction into account the value of the required clamping force as well as the number of the required clamping elements are strongly decreased.

6. REFERENCES

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EVOLUTION OF A HYBRID METHOD FOR INDUSTRIAL MANIPULATOR DESIGN OPTIMIZATION

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Abstract: *In the present paper an evolution of a hybrid optimization method is described to find the geometric design parameters and the joint angles when some end-effector poses are prescribed. The problem is solved by minimizing the sum of the deviation squares between the prescribed poses and the real poses of the considered end-effector. The evolution of the proposed algorithm is developed in MatLab software. The developed method is applied in two degrees of freedom spatial serial RR manipulator, in three numerical examples, where one, two or three end-effector poses are prescribed. Furthermore, a comparison of the results between the evolution of the method on MatLab and the initial one based on Fortran demonstrates a higher efficiency of the Matlab approach, regarding the minimum value of the fitness function as well as the computational time.*
Key words: *optimization, genetic algorithm, geometric design, robot, industrial manipulator*

Evoluciona hibridna metoda pri projektovanju postupka optimizacije industrijskog manipulatora. *U ovom radu je opisana evolucija hibridne optimizacione metode za pronalaženje geometrijskih parametra i zajedničkih uglova pri propisanim pozama hvatača. Problem je rešen minimiziranjem zbira kvadrata odstupanja između propisane i stvarne poze hvatača. Evolucija predloženog algoritma razvijena je u Matlab softveru. Razvijeni metod primenjuje se u dva stepena slobode prostornog serijskog RR manipulatora, u tri numerička primera, gde se hvatač jedan, dva ili tri propisano postavljeni. Nakon toga, ređenjem rezultata između evolucione metode u Matlab-u i početne osnove u Fortran-u, pokazuje veću efikasnost primene Matlab-a, u pogledu minimalne vrednosti fitnes funkcije, kao i računskog vremena.*
Ključne reči: *optimizacija, genetski algoritmi, geometrijsko projektovanje, robot, industrijski manipulator*

1. INTRODUCTION

The performance of a robot can be considerably improved by optimal evaluation of the robot geometric design parameters, taking into account different criteria, especially in industrial applications. During the last decades several design methodologies have been developed for spatial task oriented robotic systems. These methodologies may be classified into two categories: exact synthesis and approximate synthesis. The exact synthesis methods [1] have the advantage to find all the possible solutions, but only in few spatial manipulators the geometric design problem has been solved. So, the polynomial elimination technique is used in [2, 3] to determine the dimensions of the geometric parameters of RR and 3R manipulators are prescribed. The approximate synthesis methods, involving an optimization algorithm, are used in geometric design problems, where the precision points are less or more than the exact synthesis required points. A combination of the exact synthesis techniques with optimization methods is used in [4] to design a spatial RR chain for an arbitrary end-effector trajectory. A methodology of dimensional approximate synthesis where the problem is expressed in terms of multiobjective optimization by taking account simultaneously several criteria of performance, regarding a Delta mechanism is presented in [5].

The presented evolution of the optimization methodology, is classified in the approximate synthesis methods. This optimization method is already tested in several problems, such as optimum robot base location [6, 7], as well as geometric design optimization of 3R serial robot with geometric restrictions [8], obtaining remarkable results.

2. MATHEMATICAL FORMULATION

In this paper the manipulator is considered as an open space chain with two revolute joints (Fig. 1). A reference frame Pi attached at each link i (i=0,1,2) The relative position between two successive frames is described using the 4x4 homogeneous transformation matrices and the Denavit-Hartenberg parameters [9]. Using the homogeneous transformation matrices, the pose of the end-effector P_3 with respect to the fixed frame P_S is given by:

$$A_S^3 = A_S^0 \cdot A_0^1 \cdot A_1^2 \cdot A_2^3 \qquad (1)$$

where the matrix A_{i-1}^i describes the pose of frame i with respect to frame i-1, through the corresponding D-H parameters. The elements of the matrix A_S^3 are known since they define the position and orientation of the end-effector frame 3 at each prescribed pose, with respect to fixed frame Ps. The right side of equation (1) contains all the unknown Denavit-Hartenberg parameters that are θ_i, α_i, a_i and d_i (i=0,1,2).

In order to determine these unknown parameters the objective function is developed. This function consists of the sum of the deviations squares between the prescribed values of the elements of the matrix and the real values.

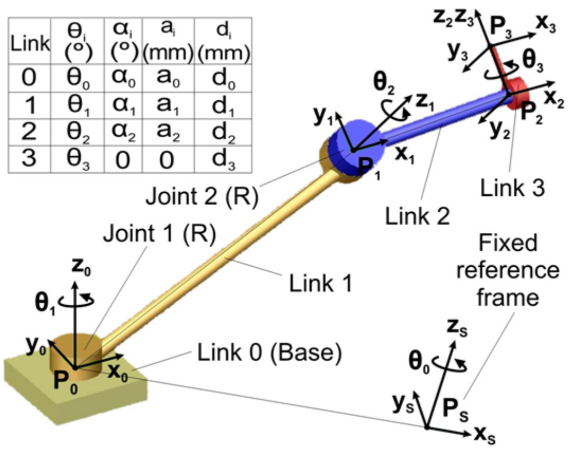

Fig. 1. 2-DOF robot and Denavit-Hartenberg params

The objective function can be described by:

$$F=\sum_{k=1}^{n}\sum_{i=1}^{3}\sum_{j=1}^{4}\left(A^3_{S\,r}(i,j)-A^3_{S\,pr}(i,j)\right)^2_k \qquad (2)$$

where n is the number of prescribed poses, $A^3_{S\,r}(i,j)$ is the real value of the element (i,j) of the A^3_S matrix and $A^3_{S\,pr}(i,j)$ is the prescribed value of the element (i,j). From the minimization of the objective function, the values of the unknown parameters occur. During the optimization procedure the imposed constraints regarding the unknown variables are described by:

$$x_{\ell\ min} < x_\ell < x_{\ell\ max} \quad \ell=1,2,\ldots m \qquad (3)$$

where m is the number of the variables and x_{imin} and x_{imax} are the lower and upper limits of the variable i.

3. PROPOSED ALGORITHM

The described mathematical model is solved with the evolution of a hybrid method [6, 7, 8] that combines a simple genetic algorithm (GA) [10], a quasi-Newton algorithm (QNA) [11] and a constraints handling method (CHM). The basic steps of the proposed algorithm are illustrated in Fig.2.

In the first loop (L1), starting populations are randomly generated to set variables values, which are used to calculate the fitness function value. Genetic algorithm [10] considering these starting populations uses selection, crossover and mutation procedures to create new generations. The optimum variables values of first loop (L1) are inserted in the QNA [11] as an initial variables vector guess. The QNA modifies the values of this vector using a finite-difference gradient method in a way that the fitness function is minimized. Afterwards these output variables values are used in the third loop (L3) to reduce the bounds of each variable, about this optimum selected one.

The minimum calculated value of the fitness function defines the optimum obtained variables values, which represent the location of robot base, the robot links geometry, as well as the robot configurations for all the prescribed end-effector poses.

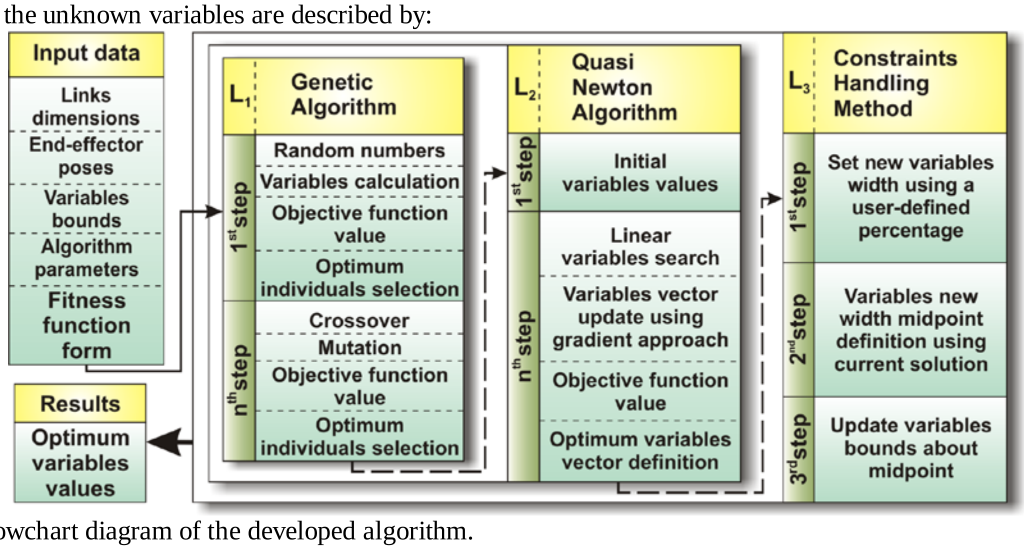

Fig. 2. Flowchart diagram of the developed algorithm.

The introduced methodology is applied in a spatial manipulator with two degrees of freedom and two revolute joints. The input data used for the algorithm are the variables bounds, the algorithm parameters and the end-effector poses. The initial applied variables limits are presented in Table.

Variables \ i	θi (o)	αi (o)	ai (mm)	di (mm)
0	0-360	0-360	0-1000	0-1000
1	0-360	0-360	0-100	0-100
2	0-360	0-360	0-100	0-100
3	0-360	-	-	0-100

Table 1. Initial variables limits.

Three numerical applications corresponding to one, two and three target points are presented. The three poses of the tool frame (T1, T2, T3) with respect to the fixed Cartesian coordinate system Ps are prescribed. Using these poses the matrices $A^3_{s\_prk}$ (k=1,2,3), of the prescribed end-effector poses are evaluated.

For each additional point, two more joints variables are used, which grow up the problem and the solution becomes slower and more difficult.

In order to make obvious the accuracy advantage of the proposed method, four different algorithms were tested in each numerical example. The first one uses only GA, the second combines the GA with the CHM, the third one uses a combination of GA with the QNA and the fourth is the proposed one. The parameters involved in all tests, mainly in GA procedure, are the same and selected as optimums through many applied tests: population of individuals=50, cross probability=70% and mutation probability=8%. All the other algorithm parameters involved in the problem are different in each case and are presented in Table 2. The loops number of GA, QNA and CHM are selected in a way that the total generations number in four tests are equal, in order to be comparable.

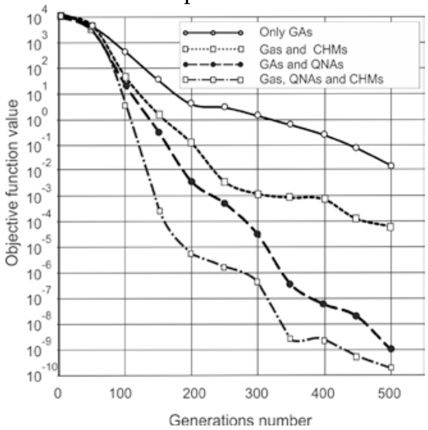

Fig.3. The evolution of the objective function value for one prescribed end-effector pose.

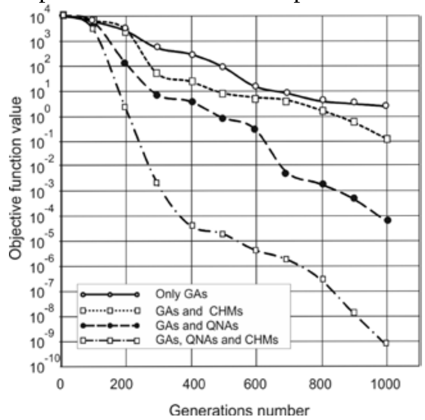

Fig.4. The evolution of the objective function value for two prescribed end-effector poses.

Fig. 3., Fig. 4. and Fig. 5. illustrate the value of the fitness function versus the generations number of the four compared methods for the first, second and third numerical example using one, two and three prescribed end-effector poses.

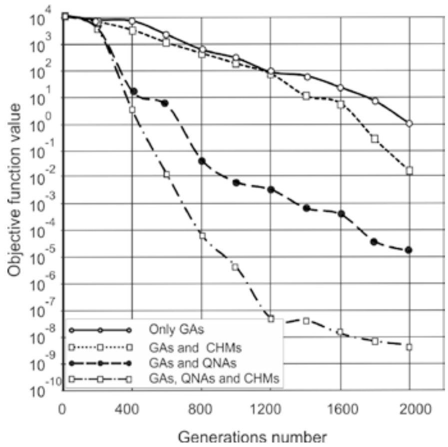

Fig. 5. The evolution of the objective function value for three prescribed end-effector poses.

As shown in these figures, the performance of the proposed algorithm is substantially better than that of the three other methods during the whole procedure both in accuracy and computational time. The obtained value of the fitness function in the three examples illustrates clearly the advantage of the proposed algorithm.

Regarding the application of the method on the Fortran environment, the comparison between the calculated elements of the matrices and the corresponding elements of the prescribed ones shows that the maximum positional deviation is lower than 0.0008 mm. The maximum deviation of orientations is lower than 0.0009 rad (0.052 degrees) in first and second example, which is insignificant value, and lower than 0.0318 rad (1.822 degrees), which is acceptable value.

On the other hand the application of the method on the Matlab environment, obtains better results than FORTRAN regarding the Fitness Function value in a lower computational time as presented in Table 2. The comparison between the calculated elements of the matrices and the corresponding elements of the prescribed ones shows that the maximum positional deviation is lower than 0.0007 mm in the three numerical examples. The maximum deviation of orientations is lower than 0.0006 rad (0.037 degrees), which is insignificant value and even lower than the Fortran approach.

Tool poses	Algorithm	Computational time	Number of loops			Range reduction	Fitness function value
			GA	QNA	CHM		
One	GA	00:35	500	-	-	-	2.10e-02
	GA+CHM	00:32	250	-	2	55%	9.24e-05
	GA+QNA	00:18	10	50	-	-	2.08e-09
	Proposed	00:08	10	10	5	85%	3.64e-10
Two	GA	00:57	1000	-	-	-	3.84e+00
	GA+CHM	01:05	250	-	4	85%	2.24e-01
	GA+QNA	00:38	10	100	-	-	1.26e-04
	Proposed	00:25	10	50	2	35%	1.66e-09
Three	GA	01:43	2000	-	-	-	1.34e+00
	GA+CHM	01:37	500	-	4	15%	2.24e-02
	GA+QNA	01:21	40	50	-	-	2.29e-05
	Proposed	01:08	10	50	4	55%	7.03e-09

Table 2. Algorithms' parameters and obtained fitness function value

Example	Poses	Parameters				FORTRAN Results		MATLAB Results	
		Number of loops			Variables range reduction	Compu-tational time	Fitness value	Compu-tational time	Fitness value
		GA	QNA	CHM					
1st	1	100	500	4	85%	0:13:04	**1.20e-09**	0:07:05	**3.47e-10**
	1	10	10	1	85%	**0:00:03**	4.73E-06	**0:00:03**	8.65e-05
2nd	2	100	500	9	65%	0:36:13	**4.33E-06**	0:12:53	**2.54e-09**
	2	100	100	4	65%	**0:02:48**	2.66E-02	**0:01:18**	4.57e-05
3rd	3	100	500	19	30%	2:44:29	**4.22E-03**	0:53:25	**3.39e-10**
	3	100	200	9	55%	**0:22:06**	1.20E-01	**0:13:18**	7.77e-07

Table 3. Fortran and MatLab approaches comparison.

In order to have a clear comparison between the solutions on FORTRAN and MATLAB environments, using the same methodology, an additional test is applied where these two approaches are compared both in accuracy and speed. The testing examples are the same with the presented in Table 2, but two variations regarding the repetitions are applied. The first test is applied using a great amount of repetitions in order to examine the efficiency of the Fortran and Matlab approaches regarding the fitness function value, without any computational time restrictions. The second test is applied using a small amount of repetitions in order to examine the efficiency of the compared approaches regarding the computational time, without any fitness function value restrictions.

The parameters of the applied tests, as well as the obtained computational time and fitness function value, are presented in Table 3. The comparison of the proposed method applied on Fortran and MatLab environment, demonstrates an advantage of MatLab approach both on computational time and fitness function value.

5. CONCLUSIONS

In the present paper a comparison between an optimization algorithm based in Fortran and an evolution approach of the same algorithm based in MatLab, to find an optimum solution in a combined problem is presented. The problem involves simultaneously the robot geometry, the robot base position and the joint angles of a 2-DOF spatial RR manipulator. The optimization is obtained through a fitness function that consists of the sum of the deviations squares between the prescribed poses and the real poses of the end-effector, taking into account the workspace restricts and variables limits.

The compared algorithms are written in MatLab and Fortran and the solid graphics are developed in Solid Works environment. Both algorithms and graphics can be modified to agree with any manipulator or problem conditions.

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Original Scientific Paper

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ADVANCED AUGMENTED REALITY APPLICATIONS IN THE PRODUCTION PROCESSES

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Abstract: *The basic aim of this paper is to introduce possibilities of production process by using special virtual tools from scientific field named Augmented Reality (AR) and their implementation on the real examples. After the introduction which sketch basic information about augmented reality, the first point quickly provides view on the current situation in AR of production processes. The following step is oriented on explanation of main philosophy of AR in order to apply their in the particular applications. The last part of paper observes real examples of possibilities to create AR, not only by commercial software but also by virtual environment which is offered by open source platform. All these mentioned possibilities and examples are implemented in the special virtual environment of the AR, where engineers can see necessary information about material, mass, special conditions etc.*
Key words: *virtual tools, virtual reality, augmented reality, production processes*

Napredna primena proširene stvarnosti u proizvodnim procesima. *Osnovni cilj ovog rada je da se uvede mogućnosti proizvodnog procesa pomoću posebnih virtuelnih alata iz naučne oblasti pod nazivom Proširena Stvarnost (PS) i njihova primena na realnim primerima. Nakon uvoda koji oslikava osnovne informacije o PR, prva tačka brzo pruža pogled na trenutnu situaciju PS u proizvodnim procesima. Sledeći korak je usmeren na objašnjenje glavne filozofije PS u cilju svoje primene u određenim aplikacijama. Poslednji deo rada posmatra realne primere i mogućnosti kreiranja PS , ne samo komercijalni softver , već i virtuelno okruženje koje je ponuđeno od open-source platforme. Sve pomenute mogućnosti i primeri su implementirani u posebnom virtuelnom okruženju PS, gde inženjeri mogu videti potrebne informacije o materijalu , masi, posebne uslove itd.*
Ključne reči: *virtualni alati, virtualna stvarnost, proširena stvarnost, proizvodni procesi*

1. INTRODUCTION

Presented paper explains main problems and structural logical concept of the production section for two kinds of the Augmented Reality (AR) applications. The AR is scientific field which interprets processes where real environment is connected together by virtual elements and this new conjunction provides the augmented tool in form of a virtual working space for user. As is mentioned in abstract, the beginning of the paper is oriented on the interpretation of basic thought of augmented reality and general logical steps which are explained by algorithm.

The second part of the paper is focused on the current situation in AR of assembling processes and gives visual imagine by enclose figures. However, it can describe advantages and disadvantages of these mentioned processes. The following step is oriented on explanation of main philosophy of AR in order to apply their in the particular applications. By means of the previous information, the last part of paper observes real examples of possibilities to create AR not only by commercial software but also by virtual environment which is offered by open source platform.

The conclusion gives a quickly recapitulation of paper steps and it is focused on the special programming packet which improves elements for the increasing entire quality of the visual area of the AR.

2. THEORY OF AUGMENTED REALITY

Augmented reality systems generate complex view where the virtual areas are covered by real environment and offer the basic working place for the engineer. Production process of AR has new special tool for the engineering area which provides strong elements and hardware components for creation of construction ideas. Final production process proposal include all functional 3D items of assembly without montage mistakes. The production application of AR was developed to determine the exact position and orientation for production process. Thanks to its possibilities if finds the utilization in many industrial spheres [1].

The problem that must be solved during this visualization step is comprised of two underling causes. The first one has explanation in transformation processes of three-dimensional environment into two-dimensional image on the display. The main task of second one is necessary to knows exact position values of real basic coordinate system of general working table. Many companies use variable devices for observing an exact position of working area. These techniques can be divided into these main groups [2]:

- Motion capture by tracking sensors.
- Motion capture by camera (markers, colour).
- Laser tracking.
- Tracking devices.

2.1 AR based on observing of marker position

VTT's Augmented Reality group started developing virtual application for AR games and entertainment applications. This mentioned engineering group provides the powerfully tool which is used for displaying assembling process of the AR [3].

The software element was designed to gives important information about assembling processes where the engineer needs to know exact position and numerical order for the single parts of the entire assembly structure. Camera provides a real video from working space and exact data about the position and orientation of the working place are obtained from markers which are on the plane of the working place.

Observing marker has its own mathematical matrix which comprise important data packet about its appearance and all variants of its rotation. Marker is made by two different colours, ordinary black and white for better comparing during the tracking process. Comparing loop takes a signal from camera in order to compare signal with marker matrix. On the Fig. 1 is basic example of marker which general structure is made by black and white colour.

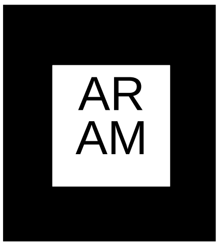

Fig. 1. The example of augmented reality marker

Software of AR has to include an augmented core and library for comparing information packet which are harvested during the observing processes of markers position. On the base of this information the application know the exact position for working area in the real time during the assembling process. VTT's Augmented Reality application for assembling process allows engineer to managed assembling process on the working table only around its own an axis of rotation. The Fig. 2 offers a view on particular example of AR where the marker situated on the desk provide position information for motion capture.

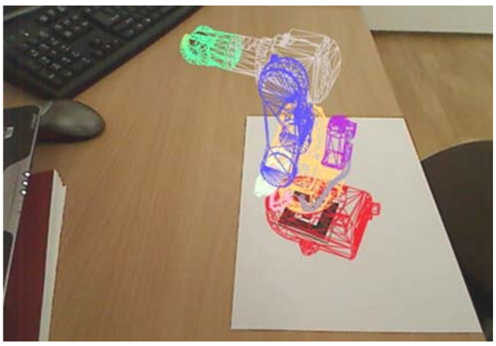

Fig. 2. Example of AR production process where virtual robot is covered by real view in the working place by marker

2.2 Laser projection technologies

Next example from industrial praxis can be found in 3D laser projection. It is accomplished by steering a single laser beam accurately through a series of specific points in space. The laser beam is directed at a pair of mirrors that are powered by a set of galvanometers called computer controlled servo motors which are capable of extremely rapid movement. The produced effect is a highly visible, glowing three dimensional template that is used as a location guide during a manufacturing process. The company Laser Projection Technologies Inc. use rapid characteristic of laser beam. Their systems replace conventional assembly methods and hard manufacturing templates in a wide variety of applications. 3D laser projectors use 3D component or part placement, paint masking and templates creating, vehicle and 3D items of assembly structure and core placement. The entire steps of this technology are described on the Fig. 3 and shows concept of method of laser projection.

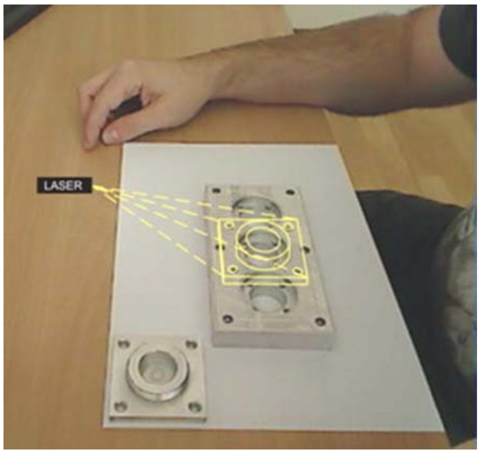

Fig. 3. The example of 3D laser projection method

3. APPLICATION OF AUGMENTED REALITY IN PRODUCTION PROCESSES

The Department of Manufacturing Technologies team created AR application intended to be used as a supporting tool in production processes but can be used also in many other application areas. Following parts of this paper describe the functional principles of this application. It is built on the mechanism that uses logical loops for realization of observation, collecting, evaluating and comparing activities and processing of all these obtained data in order to exploit them in final visualization output. Virtual environment called Virtools was used to create simply example of AR application. Working environment and its elements are based on principles of object programming, where initial conditions, actions and relations are prescribed for particular objects that according to their function change to the so called building blocks of the application (BBs). Rules and actions running between individual blocks or their sections can be graphically expressed in form of behaviour graph which at the same time serves as programming tool itself. Functionality of entire application can be then described through tasks that they are realized thanks different behaviour graphs [4].

BBs present the tool with simple graphical interface that can be used for creation of necessary logical connections defined in form of information packages. Each BBs included in virtual library has an input/output pin that can be tracked and its properties defined with respect to user orders. The environment of application that operates with special software tools offers the possibility for collection and monitoring of information about the data flow between single BBs.

Task of first behaviour graph is to fill the data array with correct values of assembly parts like information about assembly name and their initial conditions (position, geometric data and shape value). Filling process is activated by confirming message which is sent from the BG for the starting button. The first point in this process is an operation where the names of all 3D items from working environment are loaded into the exact position of the data array. This array is filled by means of adjustments of the behaviour conditions of the BBs called Iterator. By using the logical BBs called Get Position and Set Row the name of a 3D part from working environment assigns initial condition and behaviour about its position in the data array. Simple example of logical script of data array is presented on Fig. 4. This method, where the program or composition is realized by logical connection between BBs is called visual scripting.

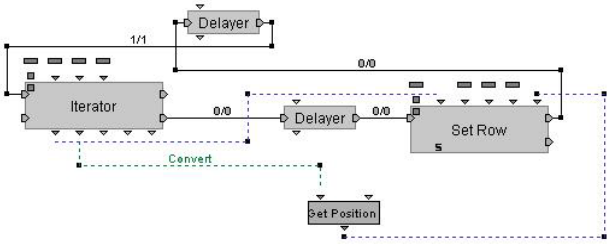

Fig. 4. The basic example of Behaviour Graph

Next part of paper investigates the establishing process of virtual tool that in its logical core utilizes an approach based on the Open Source philosophy exploited for the work with the environment of augmented reality. The goal of this part is to clarify application process for creation and development of virtual software and hardware elements that are necessary for work in the augmented reality environment. The traditional possibilities of how the engineer can use tools of augmented reality in form of normal commercial devices to collect the information about position of observed object in the working environment concern special de-vices with general structure formed by elements of motion tracking systems or technology of visual markers.

The first step in developing process was creation special device for adjusting of exact position of the operating desk in the working space. This element is described as device which gives possibilities to manage the process during the realization of whatever manufacturing situation.

This new device for augmented reality that is outlined as special positioning table which is able to adjust to an exact position of the working desk not only by using the computer interface and its own logical commands but optionally also by manual changes. Exact information about a position of the operating desk are obtained in real time during the process from special sensors that utilize the essential idea of possibility to accumulate the changes of orientation values in the real environment.

First sensor allows the collection and comparing in logical core of software in order to manage the data packets which comprise values about the spatial change of the desk position (X, Y, Z). Second one provides information about rotary motion around the main axis of rotation which is in the centre of operating desk. To simplify, base on this information about the special device and sensors elements the engineer is able to collect and explore the exact data about general movement from the real observed environment.

A process called visual scripting was used for developing procedures and programming orders for the work with logical behaviour loops in open source virtual environment. By using these tools, the application allows engineer to manage an entire data flow between different logical cores of the application (Fig. 5).

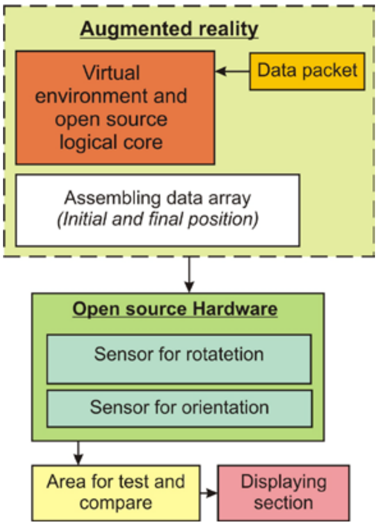

Fig. 5. Basic logical algorithm of AR application built on Open Source idea

In the following phase the general processes and logical steps of new application are described in the theoretical level. The application consists of the 4 main logical levels where the data packets come not only from inner computer elements but also from outer devices such as sensors and measuring devices [5].

First of these loops observes the button section which gives information about the confirming processes. By means of these buttons the logical loop called displaying section tarts viewing process (initial and final position).

Next loop consists of two basic areas (area for testing and comparing, area for position setting). Data packet from these mentioned areas include information about the names of all virtual items and their relevant values of initial vectors together with information about final parameters of position. Then the collected data from outer sensors are sent to the area for testing and comparing with each other and also to area for setting of position (initial, final one). On the basis of these processes, all new information of position and orientation are sent again into the logical core of the application where the newly received parameters are tested, compared and evaluated between each other. After that, the displaying section is able to see the motion process of virtual item according to its trajectory. The entire process of AR assembling is presented on the Fig. 6 and Fig. 7 where the 3D part is moved on the virtual trajectory and offers exact value about final position for each part (real and virtual part in the same environment). For better understanding the Fig. 8 gives view on improvement elements of application where each part has different colour and it allows to create assembly more clearly without mistakes [5].

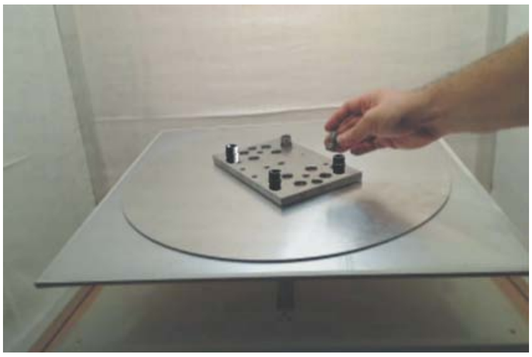

Fig. 6. AR process where the 3D part is moved on the virtual trajectory

Fig. 7. AR assembling process

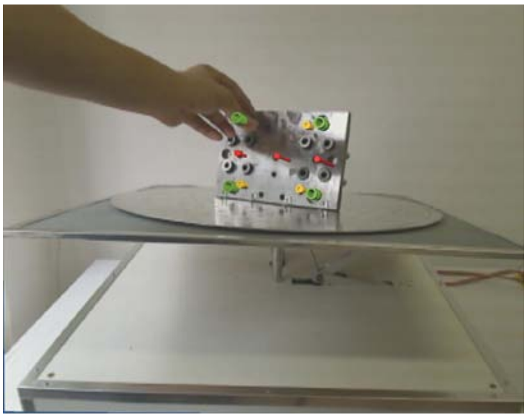

Fig. 8. Assembly process based on parts colours differences

4. CONCLUSION

This paper inform about implementation possibilities of AR for the purposes connected to the sphere of assembling structures creation. The first section presents current situation in an area of AR process. From middle to end part of article, text is focused on the real application not only from commercial side but also from Open Source platform.

It concerns software issues reflecting the model geometry (single 3D items) as well as displaying of final boundaries for all geometry shape of models of the whole structure. Created application was focused on the particular part of the problem where engineer needs to know exact positions of single 3D component of assembly structure in the real environment eventually with respect to auxiliary object. Main feature of prepared software application is utilization of motion tracking system based on the working principles of capture markers. Implementation of augmented reality elements in this manufacturing area shows that these problems are free to be developed and their solutions realized in many industrial spheres.

5. ACKNOWLEDGMENTS

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Original Scientific Paper

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CANONISATION OF ACTUATION STIFFNESS MATRIX IN KINEMATICALLY REDUNDANT INDUSTRIAL HUMANOID ROBOTS

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Abstract: *This paper presents the novel theoretical and practical approach of generalized stiffness control in industrial humanoid robots. Compliance of robot mechanism and ability of robot control system to precisely adapt the parameters of its generalized stiffness matrix is increasingly gaining in importance concerning specific requirements imposed by new production paradigm of mass customization. Precise control of generalized stiffness requires very complex actuation system, much more complex then it is present in conventional industrial robots.. This paper demonstrates practical applicability of this approach using kinematically redundant planar robot arm. Detailed analysis of its Jacobian null space which is analytically derived using analogy with four bar mechanism shows that is always possible to achieve with arbitrary precision required generalized stiffness, regardless of robot posture freely chosen within configuration space.*
Key words: *stiffness control, industrial humanoid robots, kinematically redundant planar robot arm*

Kanonizacija krutosti matrice u kinematski redundantnim industriskim humanoidnim robotima. *Ovaj rad predstavlja nov teorijski i praktični pristup kontrole generalne krutosti u industrijskim humanoidnim robotima. Usklađenost mehanizma i sposobnosti kontrolnog sistema robota da precizno prilagodi parametre opšte krutosti matrice sve više dobija na značaju u pogledu specifičnih zahteva koje nameće nova proizvodna paradigma masovnog prilagođavanja. Precizna kontrola generalne krutosti zahteva vrlo složen sistem aktiviranja, mnogo više nego kod konvencionalnih industrijskih robota. Ovaj rad pokazuje praktičnu primenu ovog pristupa korišćenjem kinematski redundantnih ruku robota. Detaljnom analizom Jakobian nultog prostora koji analitički izveden koristi analogiju sa četiri trake pokazuje mehanizam koji uvek može da se postigne zahtevane preciznosti generalne krutosti, bez obzira na slobodno izabran položaj robota u konfiguracionom prostoru.*
Ključne reči: *kontrola krutosti, industrijski humanoidni roboti, kinematski reduntantna ruka robota*

1. INTRODUCTION

Safety is the starting point of human and robot team and collaborative work. Relevant documents which regulate this field are: ISO10218-1: 2006, [1], ANSI/RIA R15.06-1986, [4], and European machinery directive 2006/42/EC. These documents recognize robots as dangerous machines, and explicitly suggest that shearing of common workspace between human workers and robots in collaborative manner of executing work tasks is not desirable and even feasible. According to [2] collaborative work of human and robot in industrial environment is allowed only if robot fulfilled at least one of three conditions: 1) TCP/terminal plate speed $\leq 0\ 25$ m/s, 2) Maximal dynamic power ≤ 80 W and 3) Maximal static force ≤ 150 N. These conditions are general and do not depend on the size or payload of the robot. Restrictivity of these requirements drastically reduces overall performances of the conventional industrial robot and therefore requires a new conceptual basis for robot design in order to solve this contradiction [3].

The essence of the problem lies in the fact that conventional industrial robots are designed based on concept that is used in machine tool design. They are designed to be accurate and fast as much as possible. This implies high stiffness of mechanical and actuation structure, which further on leads to a large mass of the robot. Conventional industrial robots are too rigid and massive to be harmless to humans even by extensive adaptation. Therefore, a fundamentally new approach to robot design was developed as response to the limitations of this type. This approach is based on the following framework:

1. Light weight and high specific load caring capacity;
2. High compliance and pliability of mechanical structure;
3. Ability to work within non-well structured environment, and capability to acquire of human behavior as well as learning through generalization.

The result is industrial humanoid robot.

Industrial humanoids are developing very fast with exponential growth in accumulation of research activities. EU FP6 projects: PHRINEDS and SMErobot, EU FP7 project: ROSETTA, and pre-commercial project of humanoid DLR/KUKA LWR IV, are typical representatives of research conducted in this area, [4]. Example of industrial humanoid FRIDA developed within FP7 project ROSETTA is given in Fig. 1. It is redundant dual-arm robot with 2 x 7 serial degrees of freedom, having proportions similar to the medium height adult male.

FRIDA (Fig. 1.) (*Friendly Robot Industrial Dual Arm*) developed within EU FP7 project ROSETTA for safe cooperative work with humans on the lightweight products assembly lines. In addition to the requirement of small mass and high specific payload, industrial humanoid robot must have the inherently controllable compliance. This means that industrial humanoid must have lightweight variable compliance actuation system, such as to provide two functions: 1) compliant response to the collisions of TCP or any part of robot kinematic mechanism and 2) to generate arbitrary generalized stiffness matrix, including isotropy.

Fig. 1. Industrial dual-arm humanoid

This paper[1] presents some results of research conducted in the field of synthesis of alternative solutions for the industrial humanoids generalized stiffness control. In particular, it shows the original approach of actuation system stiffness control using kinematic redundancy for achieving canonical form of actuation stiffness matrix.

2. GENERAIZED STIFFNESS

Generalized stiffness of manipulating robot in the task space coordinate system Q_R is defined as:

$$F = K_X(X - X_0) = K_X \delta X \qquad (1)$$

where: $F \in R^m$ – the external force acting on the robot tip TCP, $K_X = K_H \in R^{m \times m}$ – the symmetric matrix function of manipulating robot generalized stiffness, $X_0 \in R^m$ - the nominal positions vector of the robot tip, $X \in R^m$ - the actual positions vector of the robot tip, and $\delta X \in R^m$ – the vector of the robot tip displacement (response on the force F excitation).

The dominant influence to the robot generalized stiffness has compliance joint actuation system. Applying the approach given in [4] the congruent transformation of relation (1) leads to:

$$K_X \to K_q = J^T(q) K_X J(q), \; K_q \in R^{n \times n} \qquad (2)$$

where: K_q is the actuation stiffness matrix, $q \in R^n$ is the vector of generalized robot coordinates, $J(q)$ is the Jacobian matrix operator. Actuation stiffness matrix is always symmetric (congruent transformation preserves symmetry), positive definite and generally non-diagonal [5]. A key task in industrial humanoid generalized stiffness control is design of joint actuation system that always can generate stiffness matrix defined by relation (2).

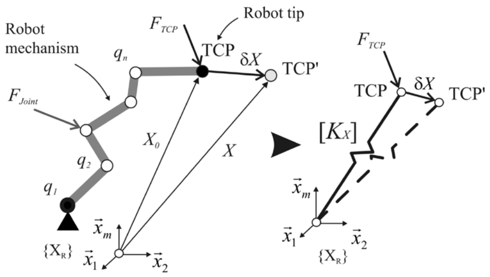

Fig. 2. Generalized stiffness model of industrial humanoid of anthropomorphic configuration.

Relation (2) is in general feasible only through the actuation and/or kinematic redundancy [4]. Actuation redundancy can generate of non-diagonal members in the matrix K_q. Actuation redundancy implies the new actuators in addition to existing non-redundant actuators. This practically means driving of two robot joints simultaneously. Redundancy of this type is shown in Fig. 3 using a simple planar robot with two degrees of freedom as an example. The third actuator, which simultaneously drives the first and second joint, is represented by non-diagonal member in actuation stiffness matrix:

$$K_q = \begin{bmatrix} k_{q1} + k_X & k_X \\ k_X & k_{q2} + k_X \end{bmatrix} \qquad (3)$$

In the way redundant actuator provides practical solution for congruent transformation (2).

Actuation redundancy of this type is widespread in biomechanical systems, and also in human's body. For example, the antagonistic muscle groups: *coracobrachialis, biceps caput longum, biceps caput breve* i *triceps brachii caput longum*, simultaneously actuate complex shoulder and elbow joints of a human arm. Application of redundant actuation in technical systems is a very delicate engineering task. Therefore this approach has very limited practical value.

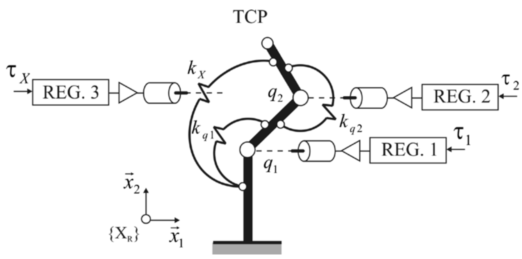

Fig. 3. An example of actuation redundancy which always satisfies relation (2).

Kinematic redundancy can be easily achieved in practice. Application of kinematic redundancy to satisfy relation (2) is based on the following hypothesis: Within the null space of kinematically redundant robot with k degrees of freedom can be simultaneously satisfied: 1) the condition of following nominal trajectory of robot's tip in the relevant task space domain, 2)the condition of nominal generalized stiffness of the robot tip K_{X0} and 3) the condition of canonical form of the actuation stiffness matrix. This

[1] This work is carried out within the project: **Smart Robotics for Customized Manufacturing**, supported by the Government of the Republic of Serbia, Ministry of Education and Sience, Grant No. TR35007.

hypothesis is based on the assumption that the increased mobility of robot can be used effectively for generation of required generalized stiffness on technically acceptable way.

The null space $\mathcal{N}(J(q))$, defined as:

$$\mathrm{N}(J(q)) = \{q : J(q) = 0\} \tag{4}$$

provides internal motions of the redundant robot mechanism that does not cause any movement of the robot tip (TCP) in the task space, [6] (Fig. 4.). Internal mobility allows finding at least one vector:

$$q^* \in N(J(q)) \tag{5}$$

that satisfies the system of following algebraic equations:

$$x_0 = f(q^*) \tag{6}$$

$$k_{q\_ij}(q^*) = 0, \ \ \forall i \neq j, \ k_{q\_ij} \in K_q(q) \tag{7a}$$

$$q^* \to \min(k_{q\_ij}(q)), \ \ \forall i \neq j, \ k_{q\_ij} \in K_q(q) \tag{7b}$$

derived from the starting hypothesis. The relation (7a) reduces *Kq* matrix to its canonical form whenever the number of redundant degrees of freedom is $k^* = n(n-1)/2$. Relation (7b) is less restrictive and matrix *Kq* is reduced to its quasi-canonical form when $k < k^*$. Less restrictive relation (7b) is the engineering solution that has greater practical value.

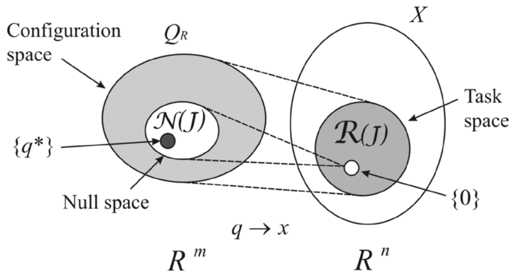

Fig. 4. The mapping of the robot configuration space into corresponding task space, and null space of kinematically redundant robot.

3. CASE STUDY

As an example of the kinematically redundant robot which is the functional equivalent of actuation redundant robot shown on Fig. 3., the planar anthropomorphic robot configuration with 3 degrees of freedom (Fig. 5) is used for the case study. In this case $k = 1 < k^* = 3$.

The redundant joint is driven by soft actuator, and together with two non-redundant joints, which is also soft driven, has the task to generate the null space where it is possible to find such a vector q^*, which simultaneously satisfies the condition (6) and (7b) and in the special case, condition (7a).

Jacobian matrix of this robot is defined by the relations 8a through 8c:

$$x_{TCP} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} l_1 c_1 & l_2 c_{12} & l_3 c_{123} \\ l_1 s_1 & l_2 s_{12} & l_3 s_{123} \end{bmatrix} \tag{8a}$$

$$J(q) = \frac{\partial x_{TCP}}{\partial q} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \end{bmatrix}$$
$$J_{11} = -l_1 s1 - l_{12} s12 - l_3 s123 \tag{8b}$$
$$J_{12} = -l_{12} s12 - l_3 s123$$

$$\begin{aligned} J_{13} &= -l_3 s123 \\ J_{21} &= -l_1 c1 - l_{12} c12 - l_3 c123 \\ J_{22} &= -l_{12} c12 - l_3 c123 \\ J_{23} &= -l_3 c123 \end{aligned} \tag{8c}$$

where for the sake of simplicity the following abbreviations are used for trigonometric functions: s(•)≡sin(•),c(•)≡cos(•) and (•)=Σ(q_i). All geometric variables and parameters are defined in Fig. 5.

Analysis of compliance actuation system is further performed in case of isotropic generalized stiffness matrix, thus the relation (2) becomes:

$$K_X = I \to K_q = J^T(q) J(q)\,, \tag{9}$$

Using relation (8b), the elements of actuation stiffness matrix defined by (9) have the following analytical form:

$$\begin{aligned} K_{q1,1} &= J_{11}^{\ 2} + J_{21}^{\ 2} \\ K_{q2,2} &= J_{12}^{\ 2} + J_{22}^{\ 2} \\ K_{q3,3} &= J_{13}^{\ 2} + J_{23}^{\ 2} \\ K_{q1,2} &= J_{11} J_{12} + J_{21} J_{22} \\ K_{q1,3} &= J_{11} J_{13} + J_{21} J_{23} \\ K_{q2,3} &= J_{12} J_{13} + J_{22} J_{23} \end{aligned} \tag{10}$$

The system of nonlinear functions (10) is visualized in Fig. 6. The robot geometry is normalized, lengths of robot links have anthropomorphic proportions: $l_1 = 1 = (7/5)l_2 = (7/5)^2 l_3$ and configuration space is defined as follows $q_1 = 0$, $q_2 = q_3 = (-\pi, \pi)$.

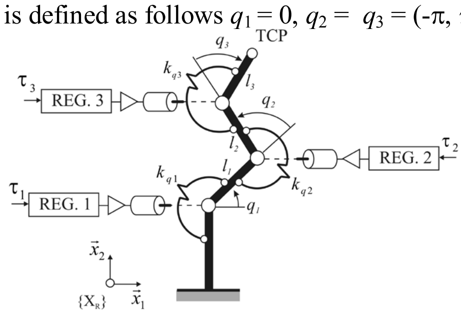

Fig. 5. Model of redundant planar robot with 3 degrees of freedom - SCARA robot with redundant soft actuation system.

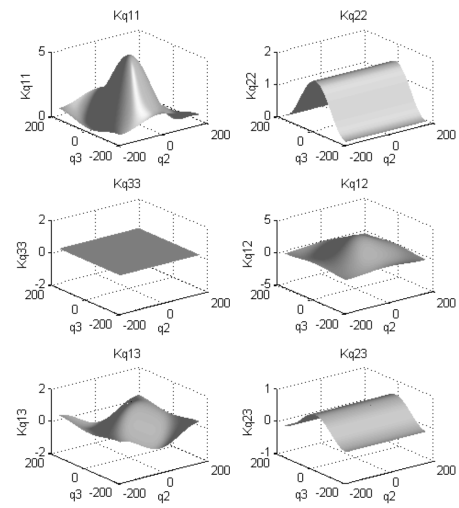

Fig. 6. Graphic representation of the elements of the stiffness actuation K_q.

The internal motion of redundant SCARA robots, or its null space, can be modeled using equivalent four-bar linkage mechanism, so that the robot tip (TCP) is represented as a virtual support that slides along the nominal trajectory. This means that the robot is reduced to an abstract closed kinematic chain with one degree of freedom. The frame of such abstract four-bar linkage is variable and can take a value in the interval which is defined as: $r_1 = (r_{1\min}, r_2+r_3+r_4)$. Angular coordinates linkage parameters of the corresponding Freudenstein's model of four-bar linkage mechanism are shown in Fig. 7., while its dimensionless analytical model [7] is defined by following relations:

$$k_1 - k_2\cos(\varphi_2) + k_3\cos(\varphi_4) = \cos(\varphi_4 - \varphi_2)$$
$$k_1 = \frac{r_1^2 + r_2^2 - r_3^2 + r_4^2}{2r_2r_4},\ k_2 = \frac{r_1}{r_4},\ k_3 = \frac{r_1}{r_2} \qquad (11)$$

Mapping between the robot generalized coordinates q and angular coordinates used in the Freudenstein's model (11) are: $q_1 = \varphi_2$, $q_2 = \varphi_2 + \varphi_3$ and $q_2 = \varphi_3 - \varphi_4$. In case that $X_U = 0$, relation between the robot coordinate system {U} and the coordinate system in the task space {X_R} is defined by the rotation matrix:

$$^{X_R}_{U}R = \begin{bmatrix} \cos(\psi) & -\sin(\psi) \\ \sin(\psi) & \cos(\psi) \end{bmatrix} \qquad (12)$$

Using the transformation matrix (12) the analytical model of robot null space given by (11) can be expressed in the robot taskspace.

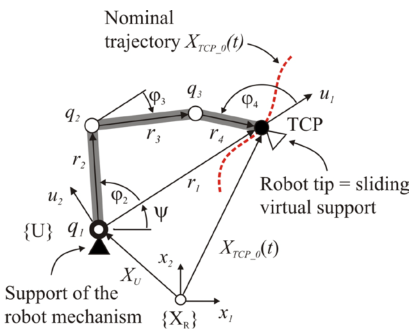

Fig. 7. Equivalent four-bar linkage that is equivalent to the null space of redundant SCARA robot.

The condition (7b) can be further relaxed by introducing Q^* region or configuration subspace robot, which quasi-canonize actuation stiffness matrix (2) for arbitrary given number ε which represents deviation of non-diagonal members from zero:

$$Q^* \to \bigcap_{\substack{i=1,n \\ j=i+1,n}} k^{bound}_{q\_ij}(q),\ \ k_{q\_ij} \in K_q(q) \qquad (13)$$

where:

$$k^{bound}_{q\_ij}(q) = \{k_{q\_ij}(q) \in K_q, \forall i \neq j : |k_{q\_ij}| < \varepsilon\} \quad (14)$$

Using relations (13), (14) and (10) two pairs of centrally symmetric region Q^*_1 and Q^*_2 are obtained, where analyzed redundant SCARA robot achieves sufficiently good mechanical isotropy (Fig. 8).

4. CONCLUSION

Industrial humanoids are a fundamentally new concept of industrial robots created as an engineering response to the radical demands of collaborative / teamwork and the capability of the acquisition of human behavior. Kinematic redundancy is physically feasible framework for generation of arbitrary generalized stiffness and mechanical impedance. The null space of kinematically redundant robot with $n=m+k$ degrees of freedom is sufficient to generate quasi-diagonal actuation stiffness matrix. Analytical experiments with redundant SCARA robot confirmed the stated hypothesis.

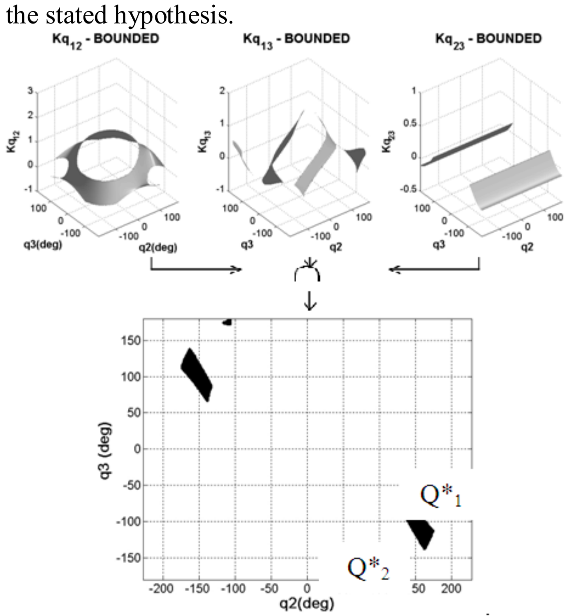

Fig. 8. The configuration subspaces Q^*_i of redundant SCARA robot which satisfy mechanical isotropy condition (7b) and (9).

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Original Scientific Paper

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MANUFACTURABILITY OF PRODUCT DESIGN REGARDING SUITABILITY FOR MANUFACTURING AND ASSEMBLY (DfMA)

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Abstract: *Manufacturability of product design significantly affect on overall quality, both in terms of functionality and utilization, so in terms of manufacturing and assembly. This paper presents systematization and analysis manufacturability of product design with a focus on DFMA methods.*
Keywords: *Manufacturability of product design, DfX, DfMA methods.*

Izrada dizajna proizvodna shodno pogodnosti za proizvodnju i montazu. *Tehnologičnost od dizajna proizvoda značajno utiče na ukupni kvalitet, kako u pogledu funkcionalnosti i korišćenja, tako i u pogledu proizvodnje i montaže. Ovaj rad predstavlja sistematizaciju i analizu tehnologičnosti pri dizajnu proizvoda sa fokusom na DFMA metode.*
Ključne reči: *tehnologičnost dizajna proizvoda, DfX, DfMA metode*

1. INTRODUCTION

Manufacturability of product design, primarily as a measure suitability for manufacturing is a very broad term and is difficult to uniquely define, because it depends on many influential elements, including the conditions in which the manufacturing process to implement.

Design of complex product is evaluated from standpoint of functionality, manufacturing, assembly, utilization and maintenance [11].

In this paper will be presented systematization of methods for analysis manufacturability of product design, with accent on manufacturability of product design regarding suitability for manufacturing and assembly (*DfMA - Design for Manufacturing and Assembly*). At the end of paper will show „DFMA“ software on one specific example.

2. SYSTEMATIZATION METHOD’S FOR ANALYSIS MANUFACTURABILITY OF PRODUCT DESIGN - DfX TOOLS

Design for eXcellence (DfX) requires taking into account of all relevant design objectives and constraints in the early stages of design. DfX is general term, where „X” may represent manufacturing, assembly, quality, etc. [3].

There are various splitting DfX methods, and here will be displayed DfX methods for scope Design for Efficiency and Green Design, Fig. 1. DfX methods using three ranges of perception: 1) product scope, 2) system scope, 3) eco-system scope [6].

Product scope includes DfM (*Design for manufacturing*), DfA (*Design for Assembly*), DfQ (*Design for Quality*), DfR (*Design for Reliability*), DfD (*Design for Disassembly*), DfMa (*Design for Maintainability*) and DfO (*Design for Obsolescence*), and system scope includes DfSC (*Design for Supply Chain*), DfL (*Design for Logistics*) and DfN (*Design for Networks*).

Green Design includes DfRe (*Design for Recycle*), DfS (*Design for Sustainability*), DfE (*Design for Environment*) and DfLC (*Design for Life Cycle*).
Eco-system scope includes DfS, DfE and DfLC, and together with product scope DfRe [6].

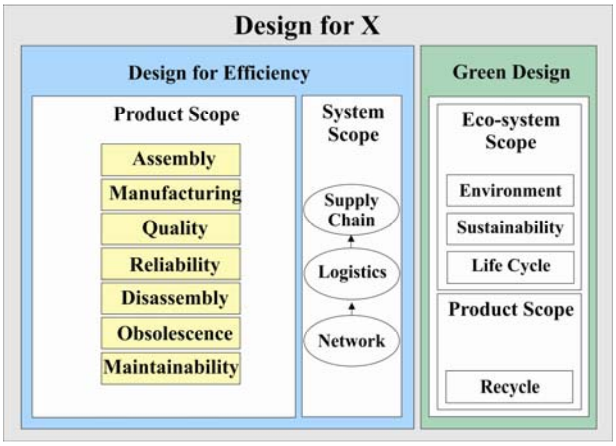

Fig. 1. Structure of DfX tools

The main purpose of design for efficiency is expressed as reducing costs and lead time of a product while sustaining or improving it’s quality. Product scope focuses on the product aspects which enable efficiencies at the shop floor, while system scope concentrates on the integration and coordination of the value chain, starting with the design stage and ending with the delivery and maintenance system.

DfX concepts and methods have role in reducing the cost items. However, the actual percentage of each DfX concept can not be precisely measured because of the variety of the product type and required production system. Fig. 2 shows the possibilities of reducing price of product considering different sources of costs.

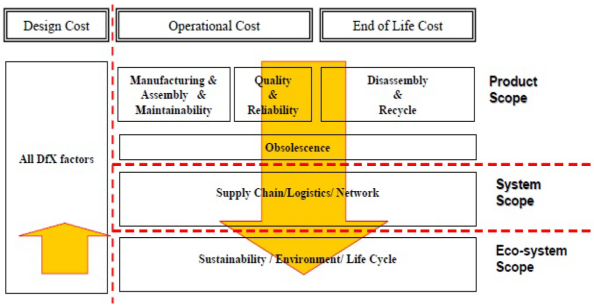

Fig. 2. The benefit of DfX factors in product costs [6]

3. DESIGN FOR MANUFACTURING AND ASSEMBLY (DfMA)

In the concept design for efficiency, design for manufacturing (DfM) and design for assembly (DfA) are methods that take into consideration first.

DfM is actually a systematic approach that allows designers to predict the costs of manufacturing in the early stages of the design process, even when it is known only approximate geometry of the product that is being developed [8].

According [4] design for manufacturing was defined as an approach for designing a product so that the design quickly transitioned into production, the product is manufactured at a minimum cost, the product is manufactured with minimum effort in terms of processing and handling requirements, and the manufactured product attains designed level of quality. Fabricius [5] proposed a procedure of seven steps for design for manufacturing to enhance linkage between design and manufacturing using a three-dimension model. Stoll [10] is described 13 DfM guidelines that are strategy-based and practice oriented. These guidelines focus on three strategies relating to modular design, multi-use parts with standardization, and easy of assembly to increase to manufacturability.

In design for assembly (DfA) estimated design of product based on quantitative charasterictis of the product. The most important indicator of efficiency of design is assembly time. Assembly time of product reflects the difficulty of assembly process such as consolidation, adjustment, and alignment. So, DfA aims consolidate the components and functions in a smaller number of components, which affects on reducing assembly time and assembly costs.

DFMA is used for three main activities [2]:

- *As the basis for concurrent engineering studies to provide guidance to the design team in simplifying the product structure, to reduce manufacturing,*
- *As a benchmarking tool to study competitors products and quantify manufacturing and assembly difficulties and*
- *As a should-cost tool to help negotiate suppliers contracts.*

Three of most common DfMA methods by which they are developed appropriate software are [7]:

- *DFMA, Boothroyd Dewhurst Inc., USA, software developed according to the methodology developed by Boothroyd i Dewhurst,*
- *TeamSET, CSC Computer Sciences Ltd, UK, software developed according to the methodology Lucas-Hull and*
- *AEM Assembly Evaluation Method, Hitachi Corp., Japan, software developed according to the methodology Miyakawa and Ohashi.*

3.1 Boothroyd-Dewhurst method

Boothroyd-Dewhurst DfMA method evaluates the product based on design efficiency. The higher design efficiency-better product. Number of parts of the product has significant effect to the design efficiency value. If the product has many parts, the assembly time will be higher. Higher assembly time means lower design of efficiency. Also, higher assembly time directly means that the assembly cost is higher. Therefore, Boothroyd-Dewhurst DfMA recommends elimination of unnecessary part and combination of many parts into fewer components to reduce the number of parts in a product [7].

DfMA is a method for evaluating the manufacturability of part design and assembly design. It is a way to identify unnecessary parts in assembly, and determine the time of manufacture and assembly costs. The steps applying DfMA methods and corresponding software are shown in Fig. 3.

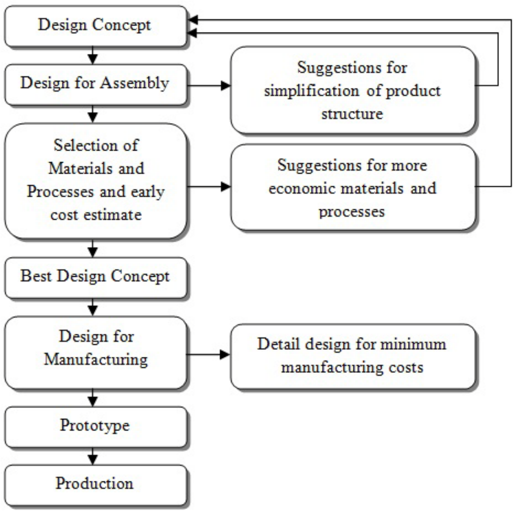

Fig. 3. The steps applying DfMA methods [6]

According Boothroyd claimed that product design for manufacture and assembly can be the key to high productivity an all manufacturing industries comparing to the automation. In his method, the concept of design for assembly was first indicated in the conceptual design phase to ensure the best design concept for materials and processes. Then, the concept was evaluated to minimize the manufacturing costs, which results in a slight increase the time in conceptual design phase. Considerable time savings would be achieved during preliminary design and detail design phases.

This method, namely software can be divided into three main stages [9]:

1) Selection of workpiece

Selection the best type of raw material or workpiece as the first step in applying DfMA depends of many *factors that affect their choice, such as:*

- *Mechanical and chemical properties of the workpiece material,*
- *Selection standard workpiece and*
- *Application of near net production technology.*

2) Selection machining processes and systems

At determining the most appropriate machining processes and systems should be taken into consideration:

- *Type of production,*
- *Type and shape of workpiece,*
- *Economically tolerance of product,*
- *Opportunities machining systems,*
- *Appropriate tools and supplies, etc.*

3) *Assembly of the product*

During assembly of product, provides the greatest possibility of applying DfMA methods. Proper use of DfMA principles allows produce a high quality products. This principles are based on:

- *Reducing the number of parts in the assembly,*
- *Implementation of symmetric parts when product design allows it,*
- *Easy design of products,*
- *Ensure self fixturing,*
- *Avoid parts that can tangle, etc.*

3.2 Lucas-Hull method

Lucas Organization and University of Hull United Kingdom are the two groups behind the development of the Lucas design for assembly (DfMA) method. Lucas DfMA evaluation method takes into consideration the crucial aspects of assemblability and component manufacture [7].
Algorithmic structure of this method is given in Fig. 4.

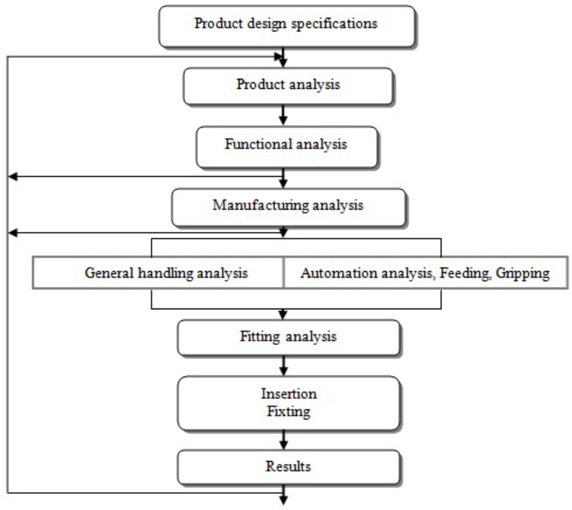

Fig. 4. Lukas-Hull DfMA method [7]

3.3 Hitachi metod (AEM)

Assemblability Evaluation Method (AEM) was developed by Hitachi in 1976 for better assemblability of product by improving design of product. AEM identifies the weakness of the design at the early stage of the design process. The design quality is being evaluated based on two indicators that are [7]:

- ‘***E’*** refers to an assemblability evaluation score ratio. It determines the difficulty of the operations and
- ‘***K***’ refers to an assembly cost ratio. It is used to project elements of assembly cost.

Description of algorithmic structure for assessing suitability for assembly by Hitachi at given in Fig. 5.

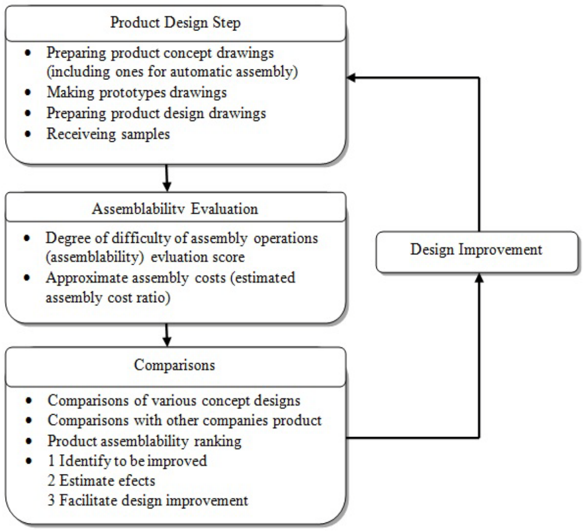

Fig. 5. Assessment of suitability for assembly and redesign [7]

4. REVIEW OF SOFTWARE SOLUTIONS

In the previous section presents the most common software for DfMA, while in this paper provides a brief overview of software *DfM Cost 2.2 i DfMA 9.4 by Boothroyd Dewhurst Inc.*, in one example. It is also important to note that this is a trial DfMA software was obtained in order to explore it’s possibilities.

It is recommended that first determine the manufacturing costs for various components using DfM aplication, and then apply DfA aplication to determine assembly costs. In Fig. 6 shown estimation of the manufacturing costs of the example of cylinder, and Fig. 7 shown estimation assembly costs for example piston assembly [1].

User interface Concurrent Cost 2.2 and Design for Assembly 9.4 consists of three areas:

1. *Tree model,*
2. *Fields to define certain data and*
3. *Fields for display estimates costs.*

In DfM aplications Concurrent Cost 2.2, under tree model are shown corresponding machining processes some parts of the product, while in the field to define the data, enter data, such as part name, part number, life volume, selection workpiece and it’s dimension, selection processes and materials, etc. Selection processes and materials (material-process or process-material) is essential. If you select material first software will show the possible processes for the selected material, and if you select process first, software will show the possible materials for the process. Fields for display estimates costs shows individual costs element, such as cost of material, cost adjustment, tooling cost, etc., and finally total cost.

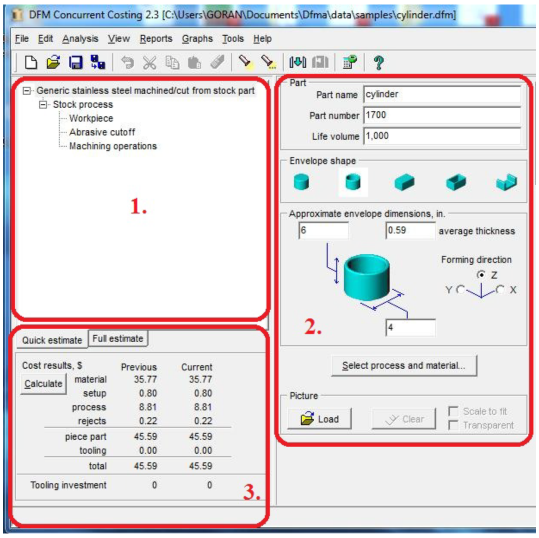

Fig. 6. Cost estimate in the example of cylinder (DfM)

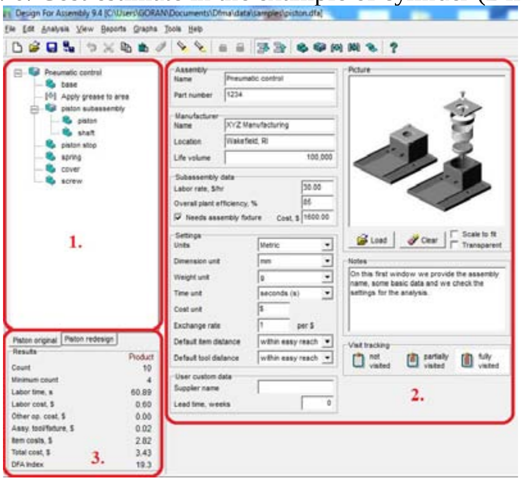

Fig. 7. Cost estimate in the example of piston assembly (DfA) [1]

In DfA aplications Design for Assembly 9.4, presents overall structure of the product or assembly, and can serve as an alternative selection for selection technical elements in the implementation of the correction on the product or assembly. In field to define certain data next to the assembly name, part number, manufacturer and life volume performed and data entry such as subassembly data and various settings that include units, dimension unit, weight unit, time unit, cost unit, etc. Field with results shows certain elements for the calculation of cost, DfA index and total cost.

After evaluation of the machining and assembly costs there is the possibility of generating reports in the form of tables or graphs with output results.

5. CONCLUSION

Costs of product design and their manufacturing process planning, participate in a small part of the total price of the product, but decisions made during this process significantly affect the overall cost of developing a new product an is essential for the market success of the product. Therefore, necessary to consider the problem of production as early as possible, even at the stage of the product design, namely, development of it's concept, because the costs of modifications of the product higher if you make changes in the later stages of product development.

In order satisfy these requirements has been developed appropriate DfX methods, whereas in the present study shown the most common methods of DfMA.

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Original Scientific Paper

Topčić, A., Cerjaković E., Herić, M.

SIMULATION OF RELOADING SEGMENTS OF INTERNAL TRANSPORTATION SYSTEMS BY ARTIFICIAL NEURAL NETWORKS

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Abstract: *Today on the market there are a number of software solutions which more or lesser fulfil the general requirements related to simulation and modelling of internal transport system, with certain restrictions regarding the implementation of some specific issues that arise within the production systems in daily practice. Therefore, in some cases, it is necessary to find other solutions and approaches for the simulation of the internal transport systems. Thanks to its characteristics Artificial Neural Networks (ANN), supported by other numerical statistical tools, enable the successful simulations of internal transport system and its individual segments, adjusted and implemented for concrete real conditions. In this paper an example of application of Artificial Neural Networks in simulation of three specific reloading segments of internal transport systems installed in various production systems – companies has presented.*

Key words: *Internal Transportation, Reloading Segments, Stochastic Processes, Simulation, Artificial Neural Networks (ANN)*

Simulacija pretovarnih segmenata u interno-transportnim sistemima pomoću veštačkih neuronskih mreža. *Danas na tržištu postoje više softverskih rešenja koje, u većoj ili manjoj meri, ispunjavaju opšte zahteve vezane za simulaciju i modelovanje interno-transportnih sistema, sa određenim ograničenjima vezanim za implementaciju nekih specifičnih faktora koji se svakodnevno javljaju u transportnim sistemima. Stoga je u nekim slučajevima neophodno naći drugačiji pristup i rešenje problema simulacije interno-transportnih sistema. Zahvaljujući svojim odlikama, veštačke neuronske mreže podržane drugim numeričko-statističkim metodama, omogućavaju uspešne simulacije interno-transportnih sistema i njihovih individualnih segmenata podešenih i implementiranih u konkretna realna rešenja. U ovom radu je prikazan primer iskorišćenja veštačkih neuronskih mreža u simuliranju tri specifična pretovarna segmenta interno-transportnih sistema montiranih u različitim proizvodnim pogonima.*

Ključne reči: *interni transport, pretovarni segmenti, stohastički procesi, simulacija, veštačke neuronske mreže*

1. INTRODUCTION

The movement of materials within the production system is the integrating factor in every manufacturing company which by adequate sizing and selection of appropriate transportation/handling devices and equipments provides opportunities for reducing of overall manufacturing costs. Internal transportation system within the company is in essence a network of transportation lines and reloading segments (points for direct linking of different transportation/production processes or phases) whose modelling and simulation is not easy due to high stochastic degree of its internal processes [1]. In principle, if the processes that occur at nodal points perceive in the long term, then the amount of material that can lead to a nodal point (Q_d) must be equal to the amount of material to be brought out of it (Q_o), Fig. 1. Otherwise, depending on the intensity of internal and external factors leads to deviations from the optimal regime of movement of material that slows/stops temporarily (creating queues) or there is a decreasing of utilization of installed transportation and production equipment.

Nodal points of the internal transportation system which, besides connecting of the individual transportation means carry out manipulative tasks of taking on and/or delivery of transportation units, with mandatory subordination to the terms of the transportation, called the reloading segment of the internal transportation systems. The entire process of arriving of transportation units to the reloading place, theirs acceptance and disposal to the provided space represents a handling process, that depending on its performance can be characterized with various indicators: the number of handling devices, the number of workers who carry out handling processes, speed of handling, queue length, waiting time on handling, duration of handling, number of failures in the handling, etc [2].

The objective of designing and developing of any kind of internal transportation system is to create a system that meets the desired functions with achieving the highest performance at lowest cost. For design and study of internal transportation systems there are and are developed numerous approaches. It is generally known the fact that modelling and simulation is one of mostly used approaches, which significantly supports decisions making process, based on the results of carried out simulation experiments. The complexity of dynamic internal transportation systems and their segments, as well as, the stochastic nature of the processes inside them, makes the behavioral modeling of these systems by analytical methods impractical and often impossible [3]. This is particularly obvious during analysis of segments of internal transportation system which are consisting from several parallel or serial connected handling devices. Therefore, simulation of internal transportation systems and their segments based on the theory of probability and statistical methods, as well as, artificial neural networks (ANN) is a good alternative for achieving satisfactory results [4].

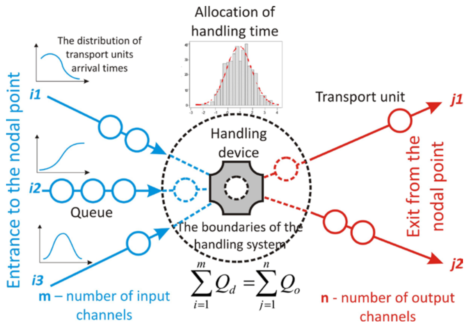


Fig. 1. Processes within nodal point of internal transportation system

2. EKSPERIMENTAL RESEARCH

As a polygon for the simulation study of reloading segments of the internal transportation system the output warehouses in three production systems are adopted: Brewery Tuzla, Salt Factory Tuzla and Detergent Factory Dita Tuzla (Fig. 2) which in essence represents the connection between internal and external transportation.

Fig. 2. Studied reloading segments of internal transportation systems

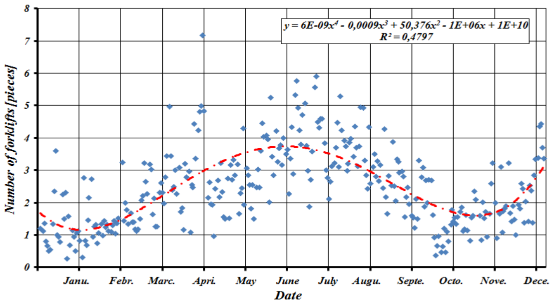


Fig. 3. Annual review of the required number of forklifts on the warehouse of Brewery Tuzla

Reloading segments that has studied are characterized by: significant intensity of the flow of materials, transfer of unit loads (pallets), periodic appearance of "impulse loads" on reloading segments, limiting of the available storage space, various external transportation devices for loading, the possibility of involvement of additional reloading equipment (forklifts) once the need arises, and the fact that all three production systems have batch production with a wide assortment of transportation units for manipulation.

For the purposes of the simulation study in all three reloading segments, monitoring of the flow of transportation units - pallets, as well as, determining the real reloading capacity of engaged forklifts for a period of three years has made (Fig. 3). The collected data were statistically processed and prepared for training of artificial neural networks. Data preparation means the execution of a series of simulation experiments based on Monte Carlo algorithm for three possible scenarios (a constant number of reloading units; a constant number of reloading units with subsequent continuous engagement of additional reloading units when a certain critical number of unloaded pallets is reached; a constant number of reloading units with subsequent engagement of additional temporary reloading units when a certain critical number of unloaded pallets is reached), Fig. 4. From all available simulation scenarios for each studied object, scenarios that provide the higher degree of efficiency of reloading units and the ability to arrange shipment of pallets in just-in-time principles has chosen. By variation of parameters of determinate statistical distribution the following data set was generated: number of intervals and the average length of the interval for primary engaged forklifts, as well as the average number of interval and average interval length of engagement for additional forklifts (Table 1).

	Brewery Tuzla	Salt Factory Tuzla	Dita Tuzla
The interval of the simulation [days]	303	338	258
No. of simulation per experiment	1000	1000	1000
The parameters of the statistical distributions	Gama α=4,00÷2,90 β=0,60÷1,00	Weibull α=1,30÷1,80 β=1,60÷2,40	Weibull α=1,55÷1,30 β=1,70÷1,85
No. constantly engaged forklifts [piece]	1 ÷ 3	1 ÷ 3	1 ÷ 2
No. temporarily engaged forklifts [piece]	1 ÷ 5	1 ÷ 4	1 ÷ 3
Limited number of pallets in queue [piece]	500 ÷ 1300	500 ÷ 2125	210 ÷ 789
Initial data set for training of ANN	Training: 2625 Validation: 657 Test: 657	Training: 2310 Validation: 578 Test: 578	Training: 1250 Validation: 280 Test: 280

Table 1. Plan of parameters variation for identified statistical distribution of the observed reloading segments

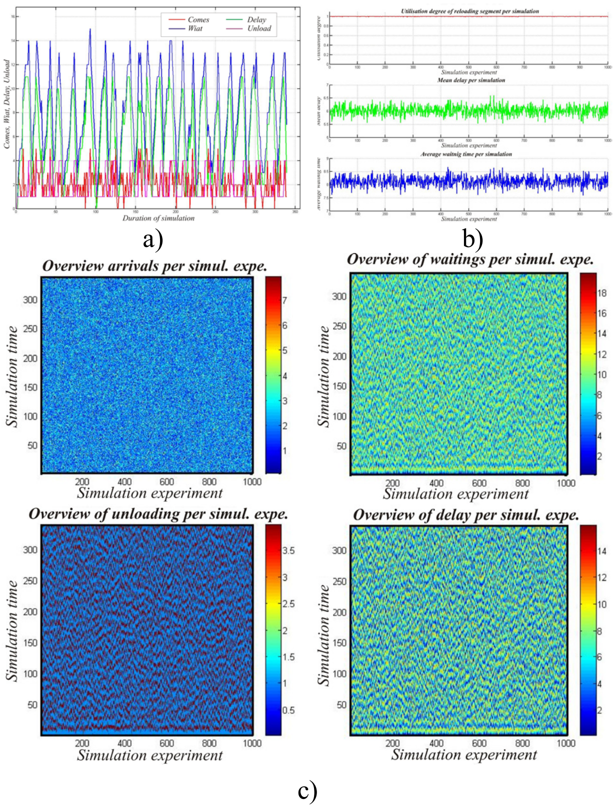


Fig. 4. Review of results for one of Monte Carlo simulation scenarios with one primary engaged and three additional engaged forklifts, and limitations on 1500 pallets in the queue in Salt Factory Tuzla: a) review of number of transportation units (pallets) on reloading segment in phase: comes, waiting, delay, unloading; b) utilisation degree of working place, mean delay, the average waiting time per simulation; c) review of results for 1000 simulation experiments

The obtained results are stored in a database which is essentially a sequence of input-output data sets for training, validation and testing of ANN, classified by usage of generator for uniformly distributed pseudo-random numbers where 1/2 set was used for training, 1/8 for validation 1/8 for testing– verification of designs for developed artificial neural networks.

According to Alexander and Morton ANN can be defined as massively parallel distributed processors that are good for the memory of experiential knowledge, and they are similar to the human brain in two aspects: knowledge is acquired through the learning process and the connections between neurons are used to store knowledge. These features allow the simulation of any system without an exact knowledge of its mathematical model, as was applied on this case.

By generating a set of series input-output data a sequence of ANN training with variable structure (different number of layers - single and dual layer, and different number of neurons per layers), based on Backpropagation (stands for Back Error Propagation, Figure 5) and Elman's training algorithm, usage of different training functions (Newton training algorithm, Powell-Beale conjugate gradient training algorithm, Polak-Ribiere conjugate gradient training algorithm, Levenberg-Marquardt training algorithm, gradient decreasing training algorithm, gradient decreasing adaptive training algorithm, etc.) was carried out.

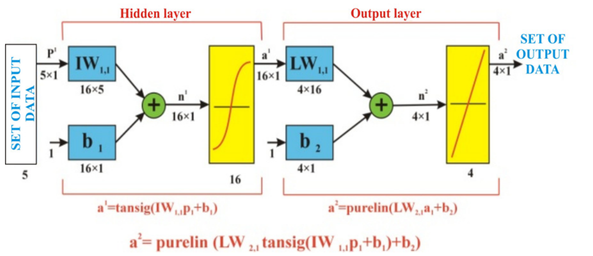


Fig. 5. Schematic review of Backpropagation -BP ANN with two hidden layers of 16 and 8 neurons, and 4 neurons in output layer

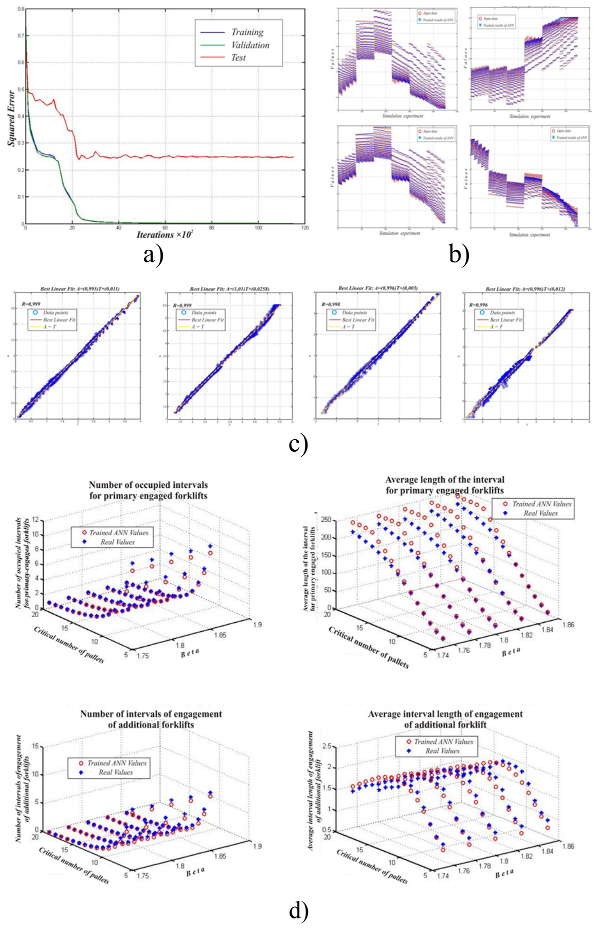
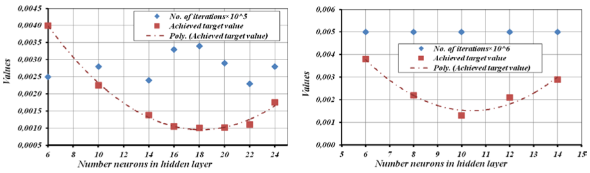


Fig. 6. a) review of accomplished training by BPANN (Powell-Beale conjugate gradient training algorithm with one hidden layer); b) comparison of training results BPANN with targeted values for: the number of occupied intervals for primary engaged forklifts, the average length of the interval for primary engaged forklifts, the number of intervals of engagement of additional forklifts, the average interval length of engagement of additional forklift; c) regression analysis of carried out BPANN training and targeted outcome values; d) results comparison of newly presented vs. test data presented to trained BPANN and targeted output values (for scenario 258-1000-1,35/1,80-2/3-210/798) on reloading segment in Detergent Factory Tuzla

In order to improve the generalization of ANN i.e. to prevent overfitting phenomenon by application of early stopping technique - stopping of training process of developed artificial neural network, preprocessing of initial data set was carried out, as follows: scaling of input and output data values, normalisation of averages values and standard deviations of training data sets and reduction of dimension of large input data vectors with redundant components.

After accomplished preparation and preprocessing of input-output data sets, forming of ANN (structures, training algorithms, etc.), and training procedures of ANN were performed. The results of one of the selected scenarios of simulation of work of reloading segments of the internal transportation systems by concrete ANN is presented at Fig. 6.

It is important to notice that the during training of developed artificial neural networks correlation between the structure and the results achieved in the case of structurally similar ANN with different number of neurons per layers with identical training functions has noted, Fig. 7.



a) b)

Fig. 7. Review of BPANN structure influence on the results achieved by the learning process in the case of reloading segment of internal transportation system: a) in Salt Factory dd Tuzla accomplished by quasi-Newton's training algorithm with one hidden layer; b) in Detergent Factory Dita Tuzla accomplished by group decreasing gradient training algorithm with one hidden layer

3. CONCLUSION

Application of ANN in simulation of reloading segments of the internal transportation systems allows obtaining results with satisfactory degree of accuracy for all considered scenarios in accordance with established criteria and without generating an exact mathematical model of the studied objects. This approach enabled realization of numerous simulation experiments that provide insights into the required number of forklift trucks at specific time intervals, thus enabling fast loading of transportation units- pallets on hold, with highest possible degree of efficiency of involved forklifts. Of course, faster loading and less waiting time is possible to achieve by involvement of larger number of additionally engaged forklifts, however, the total number of forklifts in any interval is limited by available space at the reloading site.

By analysis of results obtained by the simulation based on usage of ANN, i.e. by comparison of the values of gained targets values with the results achieved by presentation of new data to trained ANN, certain degree of deviation on the accuracy of the observed parameters was noted (Fig. 6d). The observed degree of deviation is a result of significant scatter of data input/output data sets, as well as, ways of learning of ANN based on the principles of reverse propagation of the mean squared error in the structure of ANN. In this way unequal influence of the mean square error on the input values, corresponding weights and biases has occurred.

In the development of artificial neural networks for purpose of the simulation, the analysis of the structure, architecture and various training techniques impact on the results of training achieved in terms of accuracy, generalization and speed of training was performed. Carried out analysis indicated the existence of dependence between number of neurons in the hidden layer and the architecture of ANN on the achieved results, where is for achievement of satisfactory results in cases with a high degree of dispersion of input/output data a structurally complex artificial neural networks needed to be formed. During the training of considered ANN there are clearly noted the influence of chosen training algorithm on the length of training and on the required amount of memory space, which was absolutely confirmed literature states that treat this issues.

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Original Scientific Paper

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AN APPROACH TO DEFINE OPTIMAL TECHNOLOGY PORTFOLIO OF ELV RECYCLING

Received: 7 July 2012 / Accepted: 1 August 2012

Abstract: *End of live (**ELV**) recycling is related to different technologies. Level, amount of usage and distribution of technologies could significantly influence the effectiveness of **ELV** recycling. The subject of the paper is approach to define technological portfolio, using deterministic methods and methods in case of decision under uncertainty. In this paper is presented proposed methodology.*
Key words: *Technology portfolio, End - of - Life Vehicle (ELV), recycling.*

Pristup definisanja optimalne tehnologije portfolije ELV recikliranja. *ELV (kraj životnog ciklusa) recikliranje je povezan sa različitim tehnologijama. Nivo, iznos od upotrebe do distribucije tehnologija mogu značajno da utiču na efikasnost ELV reciklaže. Tema ovog rada je pristup definisanja tehnologije portfolija, koristeći determinističke metode i metode u slučaju odluke nezavisnosti. U radu je predstavljen predlog metodologije.*
Ključne reči: *tehnologija portfolija, kraj životnog ciklusa vozila, reciklaža*

1. INTRODUCTION

ELV recycling is contemporary and sustainable answer on many different and often opposite requests, as: (1) economic growth, (2) energy saving, (3) basic material spending etc. [1,2]. ***ELV*** recycling is organizing through recycling centers, distributed on different ways [3,4]. Depend on purpose in those centers are implemented different technologies, with different levels of automatization, flexibility, effectiveness, production rate etc. [5]. That means, in some cases adequate technological solution is not appropriate and sufficient for region (Serbia) as whole. It is reason for necessity of ***ELV*** technology portfolio planning.

General approach of technology planning has four phases:

* *prioritize and quantity values,*
* *create innovative portfolio alternatives,*
* *determine and forecast relationship and*
* *find the optimal technology portfolio.*

Each of phases is very complex. An example, value of an organization is often difficult to define and access for many reasons, dominantly related to different stakeholders and problems of reliable information. Identifying the innovative solutions is connected with creativity process and depends on owners and researchers.

Problem of ***ELV*** portfolio planning could resolve using two groups of methods, deterministic and methods used for in deterministic situations. In this paper authors emphasize using of deterministic methods.

2. QUANTIFICATION OF VALUES AND RISK ATTITUDES

Each technology has different values, expressed by the characteristics or attributes of this technology that are significant and desirable for decision makers.

The characteristics have to be completely defined, measured, monitor and changed based on feedback from decision makers. For decision making is related degree of subjective preference [6, 7].

A simultaneous rating approach is the simplest method based on subjective preference of various values by the decision maker. For ***ELV*** recycling these values are:

Profitability: The amount of expected present value of net profit achieved from development or application of desired technology portfolio in next 5 years.

Quality: Technology related quality characteristics, as waste rate, reliability, mean time to failure, flexibility through faster adaptation on changes, etc.

Productivity: The amount of present worth of added value divided with total costs.

*Analytical Hierarchy Process (**AHP**)*, as second and very popular approach, starts with set up the hierarchy of values. In Fig. 1. is presented the hierarchy of values for ***ELV*** technology portfolio.

Next steps in ***AHP*** approach are:

» *set up a standard scale for pair-wise comparison,*
» *develop an comparison matrix **w** for **n** values in a hierarchy,*
» *estimate the average preferences or weights of the **n** value in a hierarchy,*
» *check matrix consistency,*
» *revise the pair-wise comparison for consistency and*
» *distribute the relative preference of a value to values through a sub-hierarchy.*

The third modern method is based on utility theory by *Neuman and Morgenson*. In area of ***ELV*** technology portfolio utility theory is related to money and risk attitude. The risk premium determines prevalent utility function (Fig. 2).

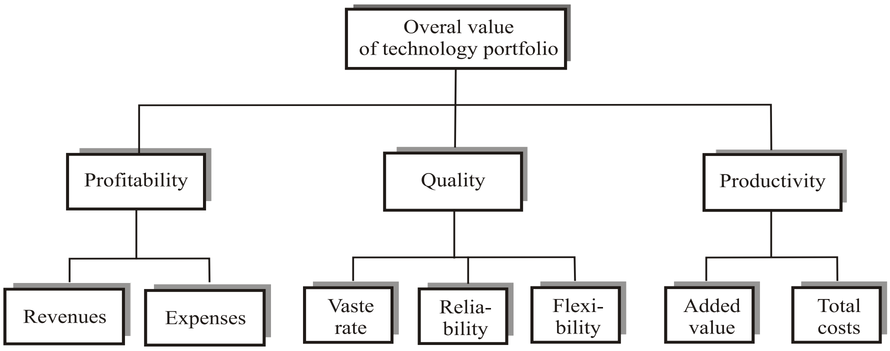


Fig. 1. The hierarchy of values for technology portfolio

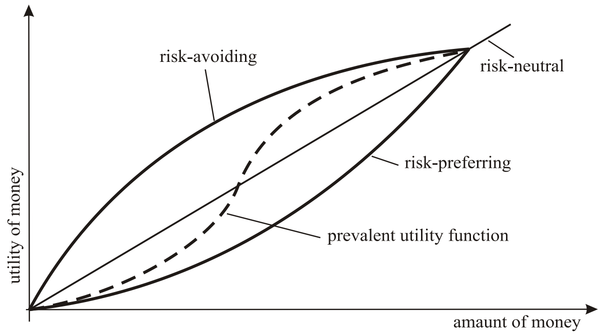


Fig. 2. Risk attitudes forwards money

3. CREATING THE INNOVATIVE PORTFOLIO ALTERNATIVES

This phase is very creative and used many techniques and tools. The most widely are: brainstorming, lateral thinking and theory of inventive problem solving.

Brainstorming purpose of ***ELV*** technology portfolio planning is conveyed in relaxed atmosphere, with no criticism and encourage for creative solution. Through two sessions are formulated three innovative portfolio alternatives:

» *redistribution of existing technologies,*
» *exchange of amount of existing technologies in* ***ELV*** *recycling centers, and*
» *introduction the new recycling technologies for:*
- recycling of electrical and electronic waste,
- displacing fluids and toxic material from ***ELV***,
- rubber recycling.

In Fig. 3. is presented forecasting of ***ELV*** recycling technologies in Serbia.

In Fig. 4. is presented risk analysis of recycling technologies in Serbia, based on expert assessment during second *Delphi session*.

Theory of Inventive Problem Solving ***(TRIZ)*** is based on 40 principles. For purpose of the paper is emphasized principle of technology evolution in combination with principle of related solution and principle of unrelated combination.

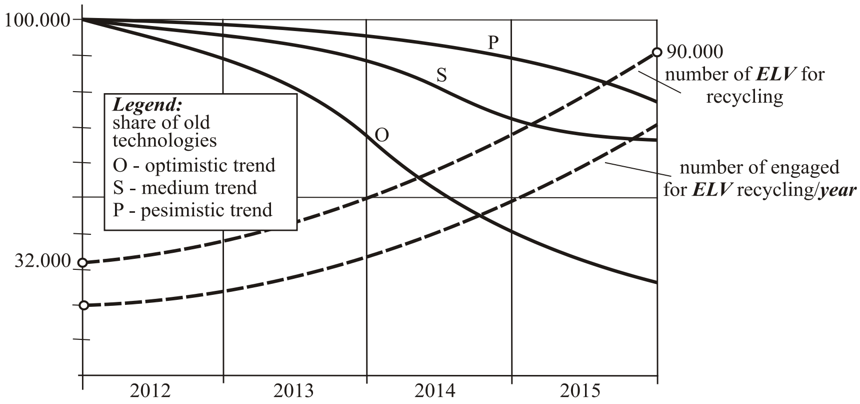


Fig. 3. Forecasting the ELV recycling technologies in Serbia

4. DETERMINATION AND FORECASTING OF ELV TECHNOLOGY USING QUALITATIVE APPROACH

For technology forecasting is used *Hierarchical Influence Tracing System* (Fig. 5).

In *figure 6* is presented analysis using ***AHP*** in area of rubber recycling technologies.

In next phase is used *Decision-Focused Scenario Analysis* as iterative process (Fig. 7).

Using this approach is determined mayor scenarios and assessed scenario implications.

Finding the optimal technology portfolio is performed using *benefit-cost* ***(B/C)*** ratio method. In Table 1 is presented preliminary results of portfolio analysis.

From those aspects is estimated as favorable technology B.

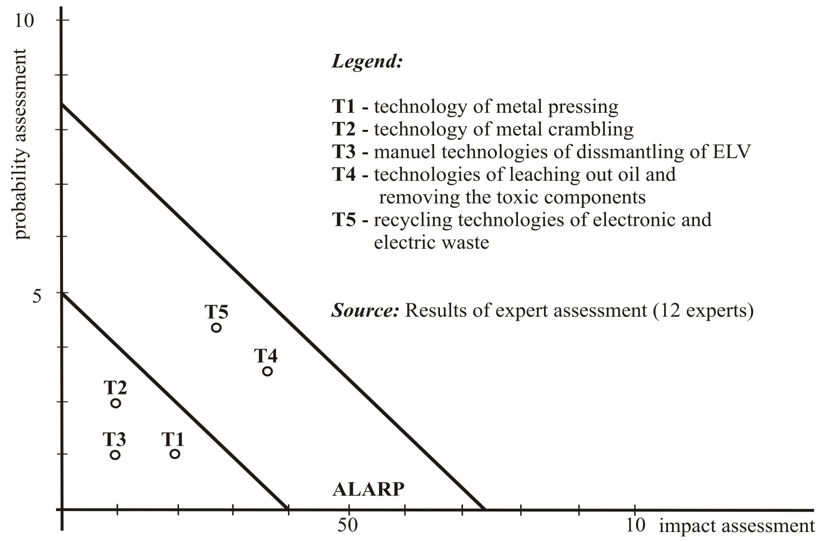


Fig. 4. Risk assessment of introduction of different recycling technologies

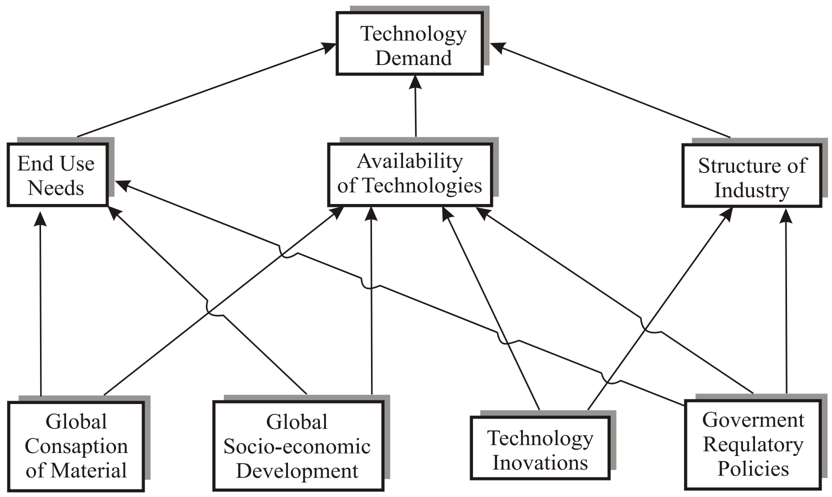
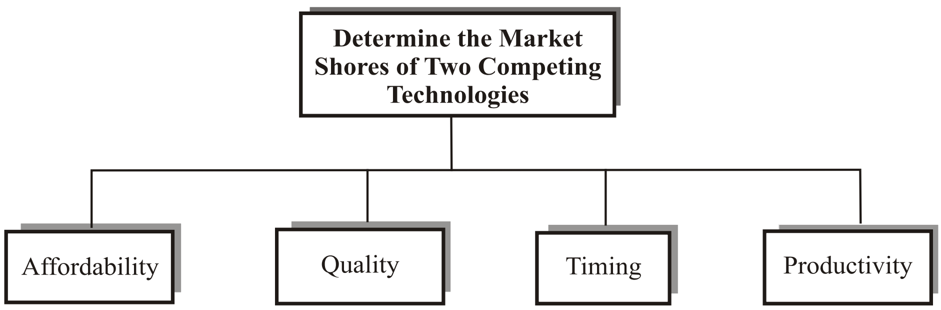


Fig. 5. Hierarchical Influence Tracing System



	Afforda-bility	Quality	Timing	Producti-vility	Sussess Probability
Weight	0.25	0.3	0.1	0.35	
Technology A	0.3	0.4	0.7	0.5	0.440
Technology B	0.4	0.3	0.5	0.4	0.380

Fig. 6. Success probability of two rubber recycling technologies

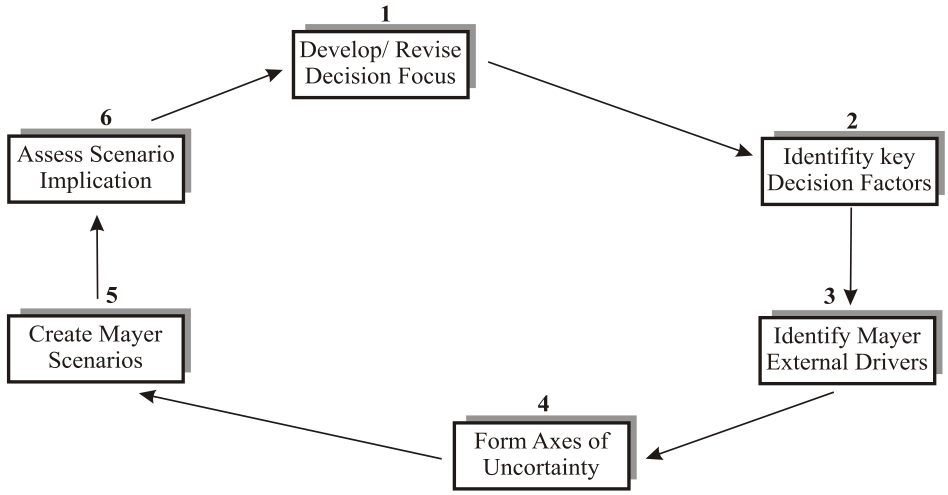


Fig. 7. Process of Scenario Development

Technology	Total benefit (€ milion)	Total costs (€ milion)	B/C
A	20	5	4.0
B	15	3	5.0
C	17	4	4.0
D	13	4	3.2
E	11	3	3.6

Table 1. B/C ratios of different rubber recycling technologies

5. CONCLUSION

From previous investigation can be concluded:

- portfolio of technology of ELV recycling is changing,
- quantification of values and risk are input for optimization of technology portfolio,
- using value and AHP approach is identified structure of values,
- using utility theory is determined prevalent utility function,
- according trend analysis of ELV technologies in Serbia are identified expanded potential for ELV recycling technologies,
- according expect assessment of risk are identified technologies related with medium risks,
- using benefit/cost method in present situation is choiced technology B for rubber recycling.

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Original Scientific Paper

Tichá, M., Budak, I.

LCA APPLICATION IN EPD AND ECO-EFFICIENCY

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Abstract: *The paper presents the possible uses of the standards of ISO 14000, Environmental management, based on Life Cycle Assessment (LCA), in the environmental practices of industrial businesses. Two studies were chosen as examples to demonstrate these possibilities. The goal of the studies was to enhance the competitiveness of products using assessment and evaluation of environmental impacts associated with product systems. EPD Czech Cement and Eco-Efficiency Carlsbad Mattoni mineral water bottled in 1.5 l PET containers followed the basic approaches and possibilities outlined in ISO standards ISO 14025 and 14045.*
Key words: *LCA, EPD, Eco-Efficiency, cement, plastic bottles*

Primena LCA u EPD i ECO-efikasnosti. *Rad predstavlja mogućnost upotrebe standarda ISO 14000, upravljanje zaštitom životne sredine, na osnovu procene životnog ciklusa (LCA), u ekološki rad industrijskih preduzeća. Dve studije su izabrane kao primer da pokažu ove mogućnosti. Cilj studije bio je da se poboljša konkurentnost proizvoda pomoću ocenjivanja i evaluacije uticaja na životnu sredinu u vezi sa proizvodnim sistemima. USD Češka cementara i Eko - Eco-Efficiency Carlsbad Mattoni pakuje mineralnu vodu u 1,5 l PET ambalažu i prati osnovne pristupe i mogućnosti navedene u ISO standardima ISO 14025 i 14045 ..*
Ključne reči: *LCA, EPD, ECO-efikasnost, cement, plastične flaše*

1. INTRODUCTION

LCA (Life Cycle Assessment) is the most significant analytical information tool, which can help to assess the impact of a selected product; specifically the effect a product's production system has on the environment during its entire lifecycle. No other tool offers such a comprehensive view of the product, which can prevent the transfer of environmental impacts from one life cycle phase to another. The growing importance of LCA shows the development of the group of standards under ISO 14000, which increasingly use LCA as a basis for other applications [1].

The two included environmental assessments of products (cement and bottled water) show the possibilities of using standards based on LCA in the practice of industrial business [2,3]. Cement was treated and certified according to ISO 14025 Type III Environmental Declarations (EPD) and bottled mineral water according to the draft standard ISO 14045 Eco-efficiency [4].

2. EPD CZECH CEMENT

ISO 14025 Type III Environmental Declaration (EPD) presents quantified environmental life cycle product information to enable comparisons between products fulfilling the same function. [5]

In the case of EPD, the scope and form of completing an LCA study follows the requirements of PCR (Product Category Rules), in this case, PCR 2010:09 Cement, version 0.1. Cement is a building block used for a variety of different purposes, which means that the treatment of cement, from the moment it leaves the factory gates, may vary significantly. LCA, in this instance, has therefore not been done from the "cradle to grave", but from the "cradle to gate". For the same reasons, a functional unit was replaced by a reference unit, i.e. 1 t of cement. Figure 1 graphically illustrates the LCA system boundaries for cement [6].

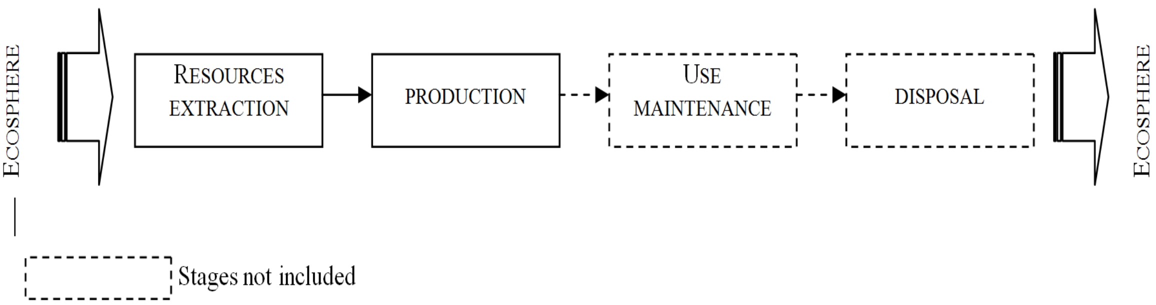

Fig. 1. System boundaries of cement

PCR also regulates the internal structure of the system, which is defined as upstream, core and downstream processes. Upstream processes include the mining and processing of raw materials, including their transport to the plant. Core processes, in this particular case, are the processes within the cement factory. Downstream processes include the use and end of life stages. In the cement example, these downstream processes were not included.

LCA study results are based on site specific data for the core processes and general data for the upstream processes, with the exception of mining limestone. The results calculated by the inventory analysis and impact categories were according to the PCR directions presented in the categories of resource consumption, hazardous and other wastes and the category of impact on global warming, ozone depletion, acidification, eutrophication and formation of photo-oxidants. The results of these categories are shown in simplified form in Tables 1, 2 and 3.

Based on the results of LCA studies, which were the basis for developing an application for certification, the Czech cement product was awarded a certificate, valid for 3 years.

RESOURCES	**Phases of a Life Cycle for a Product**		**Total**	**Unit**
	Upstream processes	**Core processes**		
Raw Materials/Materials	1,19	1865,94	1867,12	kg
Energy	1346,62	4080,04	5429,06	MJ
Water	170	170	340	1

Table 1. Resource consumption per 1000 kg of cement [7]

Impact Category	**Equivalent Category**	**Phases of a Life Cycle for a Product**		
		Upstream processes	**Core processes**	**Total**
		for 1000 kg of cement produced in Czech Republic		
Global Warming	kg CO_2 eq.	173,00	634,00	808,00
Ozone Depletion	kg CFC-11 eq.	0,000000002	0,000000124	0,000000126
Acidification	kg SO_2 eq.	1,98	1,05	3,03
Photo-oxidant Creation	kg C_2H_4 eq.	0,15	0,09	0,23
Eutrophication	kg PO_4^{3-}	0,07	0,02	0,09

Table 2. Impact Category per 1000 kg of cement [8]

	Phases of a Life Cycle for a Product		
Waste production	**Upstream processes**	**Core processes**	**Total**
Hazardous waste, kg	0,0627	0,0025	0,0653
Other waste, kg	627,03	0,49	627,52

Table 3. Hazardous and other wastes produced per 1000 kg of cement

3. ECO-EFFICIENCY OF CARLSBAD MINERAL WATER MATTONI

Eco-efficiency is a management tool that allows you to assess the environmental impact of the life cycle of a product together with the product's value. It puts into context the environmental behavior of a product system and the value of a product system [9].

The goal of the study of Mattoni mineral water bottled in 1.5 l PET containers was to provide an overview of the product system's impacts on the environment and gather data for communicating environmental performance and improved environmental profile of the Carlsbad Mattoni mineral water company.

a. Environmental impacts of a life cycle

For the purpose of calculating the eco-efficiency of the product, two LCA studies were completed looking at the development range of the bottled mineral water Mattoni manufactured and distributed in 2011 - product B and for a comparative basis the same product produced in 2001 – product A, which was used as an indicator to calculate environmental stress [10].

Comparing the results of both studies, there was a reduction of environmental impacts in almost all parameters by product B produced in 2011.

The LCA results for the product were used for calculating the environmental load indicators, which were evaluated as the most serious in terms of impact on the environment. These were:

- The total energy consumption, indicator categories - MJ (Graph 1)

- Results of impact on global warming, indicator categories - CO_2 eq.

- Results of acidification impact, indicator categories SO_2 eq.

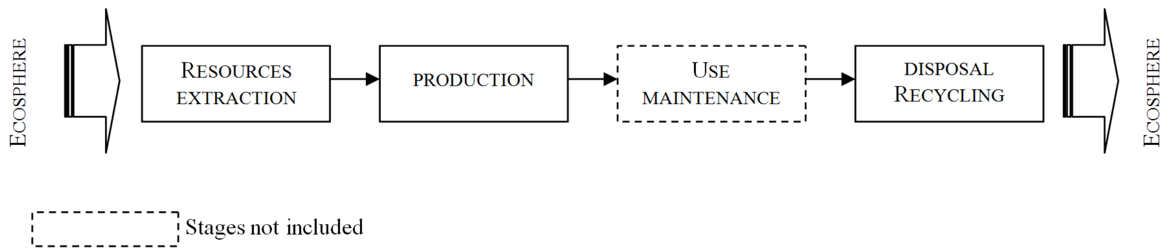

Fig. 2. System Boundaries for Carlsbad mineral water Mattoni

The LCA results were calculated and integrated as a sum of three vectors: energy, global warming and acidification (Figure 3). The resulting vector illustrates the reduction of environmental impacts.

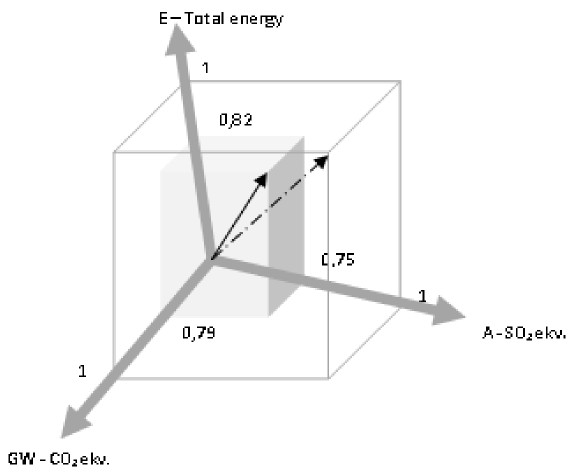

Fig. 3. Schematic representation of integration of environmental stress

b. The value of a product system

To assess the value of a product system, the characteristics of the product were evaluated based on individual customer preferences. Quantification of the functional value of a product system was expressed by using the QFD (Quality Function Deployment), which allows for determining the importance of customer requirements and the weight of their relationship. Created weighting factors were used to calculate the weighted average of product characteristics obtained from surveys. The results led to the QFD matrix calculation of the indicators of a product system that was 0.9366 for Product A in 2001 and 1.4238 for Product B in 2011 [11].

Eco-efficiency of the product system was calculated as the ratio between product value and environmental stresses of the product system. The following equation expresses the relationship [12]:

$$Eco-efficiency\ of\ \ product\ A = \frac{0{,}9366}{1{,}7321} = 0{,}54$$

$$Eco-efficiency\ of\ \ product\ B = \frac{1{,}4238}{1{,}3615} = 1{,}05$$

The basis of the eco-efficiency product of the two systems was calculated by factor X as the ratio between the eco-efficiency of product B and the eco-efficiency of product A.

$$Factor = \frac{1{,}05}{0{,}54} = 1{,}93$$

The factor value shows that the measured product, bottled natural mineral water Mattoni, produced and distributed in 2010, and specifically its product system, has 1.93 times better results than the previous product development series, which was delivered to the market in 2001.

The causes can be found not only in reducing the environmental load of product in 2010, but also in increasing the product value. A reduced bottle weight and an increased recovery of packaging material and packaging waste had an effect on reducing environmental impacts. The increase in product value was mainly due to the shape of packaging, packaging quality, weight, packaging and quality drinks.

4. CONCLUSIONS

The role of EPD and Eco-efficiency is helping to create a sustainable society. Each tool has its advantages and disadvantages.

EPD is primarily a brand of marketing that enables businesses to increase their market competitiveness. Its other advantages are the rules of PCRs), which allow you to process LCA / EPD in an exactly specified range, allowing for the easier comparison of products and its use with sub-EPD systems to build more complicated complexes, such as buildings. This environmental label but does not commit the producer to anything; it only merely states the status of the environmental stress of the products, which product and, specifically, which product system creates. Potential EPD will take full advantage of market saturation for certified products. When their number exceeds a certain threshold, the market will exhibit a preference for products with lower environmental impacts, reducing impacts on the environment throughout the production, supply and consumption cycle.

The goal of Eco-efficiency to promote the reduction of environmental burden connected with the life cycle of products with continuous customer satisfaction. This tool directly encourages businesses to think about product innovation in terms of reducing environmental burdens and increasing the product's useful properties. The method has a relatively large potential, but also a certain risk of abuse as it partially removes the requirement in the standards for assessing the eco-efficiency study by using a third party in the event that the results will be presented to the public.

The benefit, which is common to both tools, is the fact that, thanks to the LCA studies, required work in both cases, the sponsors obtained a comprehensive overview of the environmental impact connected to the product system. LCA provides a comprehensive overview of the inputs of raw materials, other materials and energy. These are items that a company has to buy. Environmental results are thus closely related to the business economy. The sponsor also receives an overview of emissions and wastes that are regulated by national rules. It is therefore in the interest of the company to not only know the extent of their portion of the life cycle of a product, but also in other phases of the range, which have environmental impacts and can involve the company.

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Original Scientific Paper

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CLINCHING IN STEEL AND RAILWAY CONSTRUCTION, SHIPBUILDING AND COMMERCIAL VEHICLES

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Abstract: *Clinching as an alternative joining technology to welding or bolting today is restricted up to circa 4mm single sheet thickness. There is no industrial experience in clinching higher sheet thickness up to 10mm. However, the branches of industry working with thick sheet metal (utility and rail vehicle engineering, shipbuilding and general structural steel engineering) represent a major potential for using this highly efficient and economic joining technology. Thus the need arises to predict the process conditions and joint quality as well by experimental and numerical analysis. This paper demonstrates investigations in both fields to understand the impact of relevant parameters and restrictions of thick sheet clinching.*
Key words: *joining, clinching, fatigue, distortion, accessibility*

Zakivanje čelika i železničke konstrukcije, brodogradnja i komercijalna vozila. *Zakivanje kao alternativna tehnologija zavarivanja i spajanjem zavrtnjima je ograničena do 4mm debljine lima. Nepoznato je industrijsko iskustvo pri zakivanju lima debljine do 10mm. Međutim, grane industrije koje rade sa debelim limom (komunalna i železnički vozila, brodogradnja i opšte čelične konstrukcije) predstavljaju veliki potencijal za korišćenje ove visoko efikasne i ekonomske tehnologije spajanja. Ukazala se potreba za predviđanjem uslova procesa i kvaliteta spoja, kao i eksperimentalne i numeričke analize. Ovaj rad pokazuje istraživanje u oba polja da bi se razumeo uticaj relevantnih parametara i ograničenja pri zakivanju lima debljine do 10 mm.*
Ključne reči: *spajanje, zakivanje, zamor, distorzija, pristupačnost*

1. INTRODUCTION

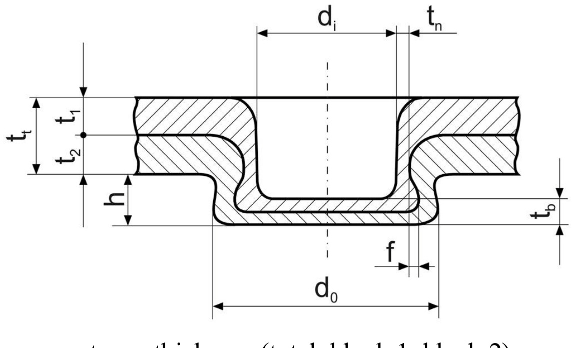
Welding as the main joining technology to connect thick sheets offers unrivalled flexibility but there are disadvantages such as processing time, fatigue weakness, thermal distortion and corrosion. Contrary clinching is not that flexible because of the necessary two side access and the restrictions in joining direction – the upper sheet should have higher strength and should be thicker than the bottom sheet. On the other hand a clinching process is very fast and accurate and the joints have a very good fatigue-potency. Due to the low variable cost using clinching this joining technology is highly efficient, especially for mass production.

Clinching is found in thin sheet applications in the range of 0.5 to 4mm single sheet thickness $t_{1,2}$ (Fig. 1), often used in the automotive industry or white goods. As already pointed out, in mass production, e.g. washer drum, the breakeven point is achieved at the fastest in comparison with other joining technologies. System suppliers like Eckold, Tox, BTM deliver the common C-frames and tools (punch, die; Fig. 2) on the basis of experience. The clinching process is dependent on knowledge – in engineering and in production process. Thick sheet clinching today is not in mass production. It is discussed recently [1,2] and is the focus of the article.

2. CLINCHING PROCESS

2.1 Principle and process parameters

The principle terms and geometry parameters of a clinched joint are shown in Fig. 1 whereas Fig. 2 shows the clinching process in three steps. There are descriptions of applications [3,4,5] and standard procedures [6,7]. Special clinching variants [8,9,10] and hybrid technologies [11,12] are described. The complexity of the clinching procedure is defined by a number of significant variables (Table 1).



$t_{t,1,2}$	thickness (total, blank 1, blank 2)
t_b	bottom thickness
t_n	neck thickness
f	undercut
h	height of joint
d_i	inner point diameter
d_0	outer point diameter

Fig. 1. Principle geometry of a crosscut

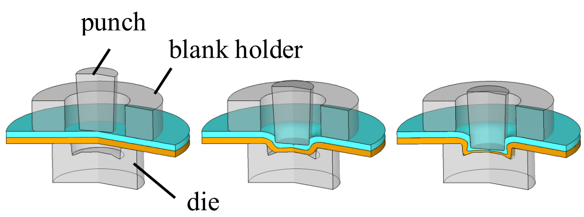


Fig. 2. Clinching process

tool parameters	process parameters	material parameters
punch: diameter, radii, angles die: diameter, depth, radii, angles	blank holder: force, spring stiffness machine: force, stiffness, velocity	thickness, flow curve, pretension (for both: upper and lower sheet)

Table 1. Principle geometry of a crosscut

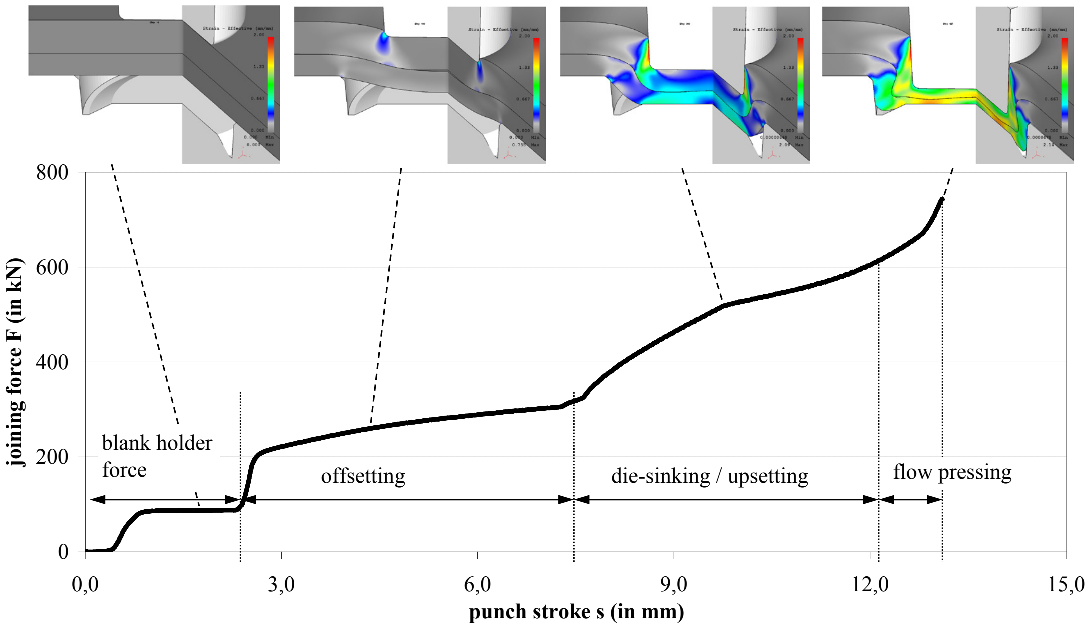
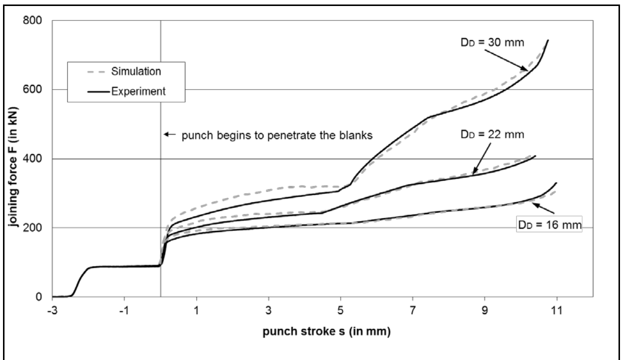


Fig. 3. Steps in the clinching process and correlation to the stroke-force-curve; S380 / S235 6+4mm; d_o: 30 mm; strain with color bar from 0 to 2

To understand the whole process detailed material flow and hardening has to be considered (Fig. 3). Before offsetting there is needed a force for fixing the sheets on the die that is applied by the blank holder. Plastifying the material in the "offsetting" step involves a substantial increase in force. The increasing material upsetting between the punch and bottom of the die causes the material to flow radial and therefore to form the undercut between the two pieces of sheet metal to be connected. The maximum force is reached at the point of the maximum punch stroke.

2.2 Predictability

Due to the large number of variables in the clinching process (Table 1) analytical methods to describe the process are limited. [13,14] use a volume based approach to define suitable tool geometries. First research in adapting existing analytical approaches for calculating the force and the stresses in the tool were done by [15]. To predict force and tool geometry as well as the final joint geometry, especially neck thickness and undercut, FE-analysis is an instrument often used [16,17,18,19,20,21,22,23,24]; also predicting process details including mathematical methods [25,26,27] or process design methods [28].



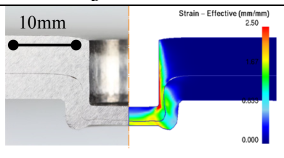
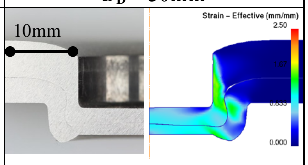
D_P = 10.0mm D_D = 16mm			D_P = 20.0mm D_D = 30mm		
 10mm			 10mm		
330	*F* in kN	306	743	*F* in kN	730
210	F_P in kN	185	623	F_P in kN	609
2.97	t_b in mm	2.97	4.25	t_b in mm	4,25
0.92	t_n in mm	0.82	2.07	t_n in mm	1,87
0.38	*f* in mm	0.31	0.41	*f* in mm	0,47

Fig. 4. Verification of simulation and experiment; S380MC – 6mm in S380MC – 4mm; die diameters D_D = 16/30mm; punch diameters D_P = 10/20mm

As a basis for numerical simulation one main parameter is the flow curve of the sheet material. Regarding the very strong deformation in the clinching process experimental data for very high values of strain are needed. This data is carried out in compression tests using round blanks. In Fig. 4 is shown the verification of simulation and experiment for the material combination S380MC (6.0mm) in S380MC (4.0mm). As to be seen, there is a quiet good correlation between the force-stroke-curves in experiment and simulation and between the geometrical data as well. The proved predictability of FE-analysis is the basis for further numerical investigations on the thick sheet clinching.

In Fig. 5 cross correlations between parameters on the basis of FE-analysis are shown for the small clinch joint with a die diameter of 16mm. The diagram illustrates the complexity of the clinching process and the effect of changed parameter values on the joint quality. In the considered room of variation the raising punch diameter leads to an increasing undercut. In contrast the effect of the die depth on the undercut is strongly nonlinear in this area and the minimum value of undercut for each punch diameter depends on the die depth. Such correlations can easy be studied in numerical analysis whereas the expenses are very high in order to describe these relationships experimentally.

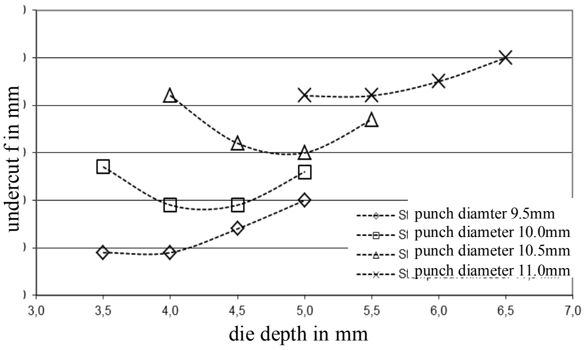


Fig. 5. Die depth and punch diameter versus undercut

3. PROPERTIES OF CLINCHING CONNECTIONS

3.1 Joint geometry

As already pointed out in chapter 2.2 the geometrical parameters of clinched connections can be identified in experimental studies and numerical analysis as well. The neck thickness t_n and the undercut f are the most important parameters regarding the joint strength whereas the bottom thickness t_b is very important for non destructive quality control. Based on a joint with known neck thickness, undercut and bottom thickness it is possible to draw conclusions from the bottom thickness to the other two parameters.

As shown in Fig. 6 the correlations between the tool parameters and the joint geometry are sometimes difficult to describe and seldom linear. Supplemental the geometry is affected by a lot of other parameters, shown in Table 1. To get information about the dimension amount of the influence on the clinch joint geometry of all these parameters sensitivity studies have to be done.

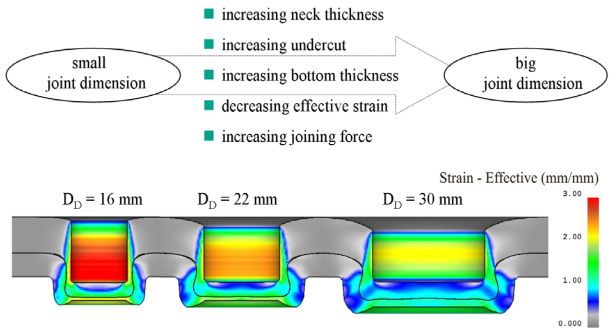


Fig. 6. Tendencies for joint dimension vs. joint geometry and force

3.2 Static and fatigue strenght

Laying-up structures is only possible with known strength values of the connections. The demand on the joints geometry is varying depending on the appearing load: shear tension, pullout or peeling load. For shear loaded joints the focus is in tendency to maximize the neck thickness. In contrast for peel loaded joints the undercut should be as large as possible.

Fig. 7 shows the force-stroke-curve for the three point (die) dimensions of 16mm, 22mm and 30mm of the material combination S380 (6mm) in S235 (4mm). The increasing point dimension has an impact on the joint strength and also on the required energy to destroy the joint.

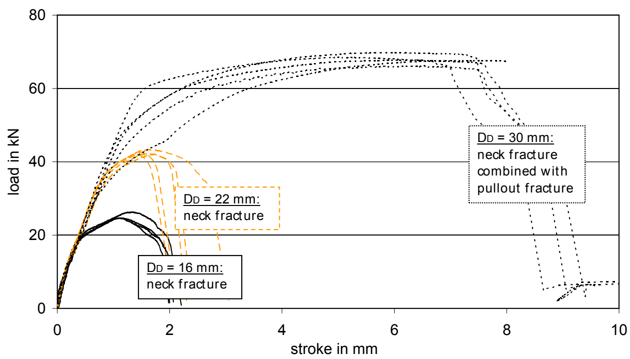


Fig. 7. Joint strength, typical curves for quasi-static testing, S380 (6mm) in S235 (4mm); Die diameters 16/22/30mm

An example for fatigue level is shown as showcase in Fig. 8 for the same material combination and the middle die dimension of 22 mm. HCF (high cycle fatigue) is on a high level compared to the quasi-static strength, about 62%. This is similar to the known level of thin sheet clinching. As to be seen in Fig. 8, the failure mode can change according to the load level. In the pictured case it changes from neck fracture for high load levels to a fracture in the sheets in / near the joint using lower load levels. Hitherto investigations show, that the failure mode has a significant influence on the fatigue strength.

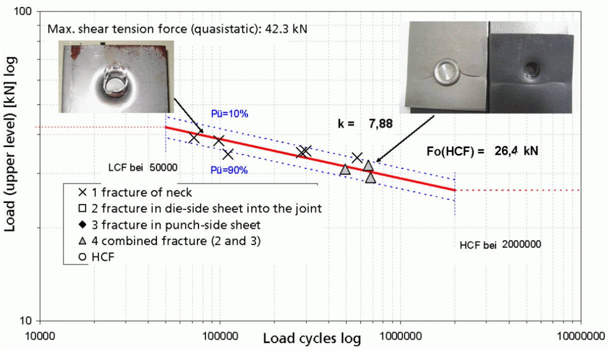


Fig. 8. Joint strength, typical fatigue curve, S380 / S235 6+4mm

Summing up the results of joint geometry and joint strength following conclusions have to be pointed out: Input parameters must be adjusted according to requirements. If small flanges or joining forces are required, small spot diameters will be selected. If high strength is required, big tool diameters will be used.

3.3 Distortion

Local radial flow inside a clinch spot is not constant over the thickness of both plates. Local strain vectors inside the spot are caused by radial and bending load to the structure. Global elastic deformation of the structure is the consequence. Blank holder force variation can minimize the bending portion of the load. To quantify the global distortion, which is induced by this local deformation, a 3.0m x 1.0m framework structure was assembled by clinching. This framework and the measured distortion of the structure are shown in Fig. 9 and 10.

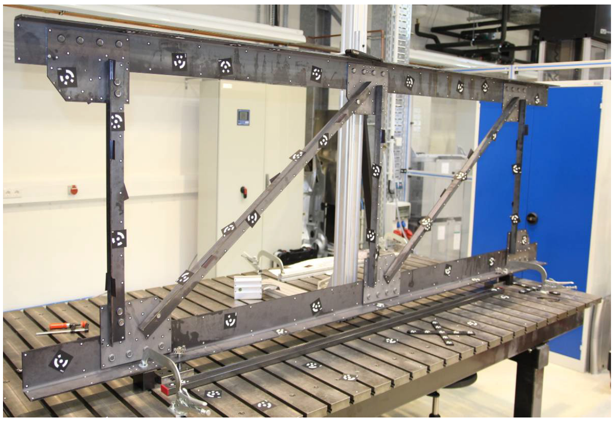


Fig. 9. Framework structure; S355MC; thickness combinations: 6mm + 6mm and 6mm + 4mm; clinching with a die diameter of 22mm

To quantify the distortion the framework was optical measured with the GOM TRITOP system. Fig. 10 shows the vector plot of distortion in y-direction comparing the framework before clinching and after clinching. The overall distortion in this direction is 5.57mm, whereas the distortion in the other two directions is nearly zero. Considering the very low stiffness in the y-direction and the length of the assembly of 3.0m this distortion is very low.

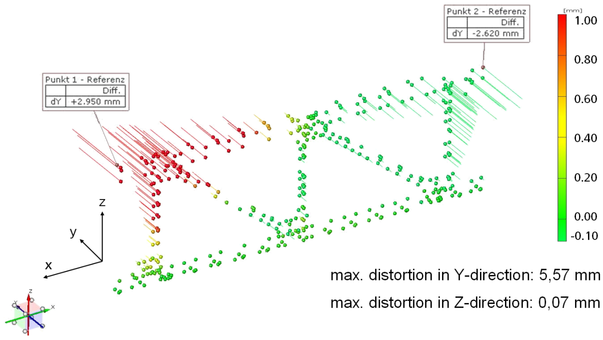


Fig. 10. Measured distortion in Y of the steel frame x: 3.0m; z: 1.0m

4. LIMITS

4.1 Joining equipment / accessibility

Standard equipment in thin sheets are C-frames with 50kN. For clinching thick sheets frames up to 1000kN are required (compare with the needed forces in Fig. 4). Next to the task (material thickness and strenght) the outer point diameter d_0 is much above all important for C-frame-force. With force and throat depth the dimension of the frame is determined and so accessability (Fig. 11). Alternatively a single or multi spot joining operation using a conventional press or press brake is conceivable. The nessesary access on both sides with a C-frame is one of the strongest limits.

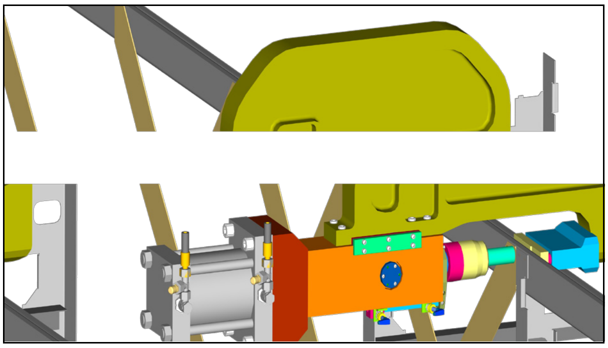


Fig. 11. Testing accessibility of a C-Frame on a clinched construction (source: Eckold GmbH)

4.2 Material restrictions

The preferred joining directions for clinching, thin sheet as well as thick sheet, are "thick to thin" and "hard to soft". If thickness or strenght of the plates are on same level or inverted ratios the joint stregth will be degrade. One further application limit regarding the material is elongation at material fracture. When using brittle or high strenth material a fracture of the neck or die side cracks may occur during the clinching process. In this case a process layout focussing low tensile stress and low deformation level in the sheets is required – best to design with numerical simulation.

5. CONCLUSION

Clinching of thick sheet with single thickness from 4mm to 10mm is possible with a performance comparable to the state-of-the-art clinched joints in thin sheet. The good numerical forecast is the basis for further numerical investigation on size effects, functional relations and sensitivity studies on the clinching process. However, general statements for tool and process design are not deliverable yet because of the complex correlations between the parameters and the clinching result and because of the changing boundary conditions for each case of application.

Main advantages are the process safety and a better ratio in price vs. strength (€ / kN) compared to welding or bolting, especially when going to mass production. The high fatigue level and the low structure distortion are further benefits of clinching in thick sheet applications. The main disadvantages are the limited accessibility with C-frames and a restriction to overlap joints with restricted thickness a limited ratio of the joined material.

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THE DUCTILE TO BRITTLE TRANSITION TEMPERATURE OF UNALLOYED ADI MATERIAL

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Abstract: *In material selection, especially in low temperature conditions, one of very important factors it is a ductile to brittle transition temperature, i.e. the temperature when material becomes too brittle to use. In this paper transition temperature determined by impact energy in temperature interval from –196 to +100°C of unalloyed austempered ductile iron with different microstructures have been studied. It was found that transition temperature is influenced by amount of retained austenite, as well as ausferrite morphology. The lowest transition temperature was obtained for ADI material austempered at 350°C for 1 hour, which possesses the most favorable combination of retained austenite volume fraction accompanied with fine acicular appearance of ausferrite. If amount of retained austenite is lower (in case of austempering at 300°C for 1 hour) or morphology is too coarse (after austempering at 400°C for 1 hour) than ductile to brittle transition temperature shifts to higher temperatures.*
Key words: *ADI material, transition temperature, microstructure, fracture mode*

Prelazna temperatura nelegiranog ADI materijala. *Pri izboru materijala, posebno kod upotrebe na niskim temperaturama, jedan od najvažnijih parametara izbora je i prelazna temperatura materijala, odnosno temperatura kada materijal postaje previše krt za upotrebu. U ovom radu, određena je prelazna temperatura u intervalu od –196 do +100°C za nelegirani ADI materijal sa različitom morfologijom mikrostrukture. Utvrđeno je da prelazna temperatura zavisi od količine zadržanog austenita, kao i od morfologije ausferita. Najniža prelazna temperatura je određena za ADI materijal izotermno transformisan na 350°C u trajanju od 1 sata (350°/1h), kod koga se javlja najoptimalnija kombinacija količine zadržanog austenita i fine acikularne morfologije ausferita. Ako je količina zadržanog austenita manja (ADI materijal transformisan na 300°C/1h) ili je morfologija ausferita grublja (ADI materijal transformisan na 400°C/1), tada se prelazna temperatura pomera ka višim temperaturama.*
Ključne reči: *ADI materijal, prelazna temperatura, mikrostruktura, karakter loma*

1. INTRODUCTION

In recent years, there has been great interest in the processing and developing of austempered ductile irons (ADI). The ADI materials possess a unique microstructure of ausferrite, produced by the heat treatment (austempering) of ductile irons. The ausferrite is a mixture of ausferritic ferrite and carbon enriched retained austenite [1, 2]. Due to this unique microstructure, the ADI materials have remarkable combination of high strength, ductility and toughness together with good wear, fatigue resistance and machinability [3]. Consequently, ADI materials are used increasingly in many wear resistant and tough engineering components in different sectors including automotive, trucks, construction, earthmoving, agricultural, railway and military [3].

During the austempering, the ADI undergoes a two stage transformation process [1-3]. In the first stage, the austenite (γ) transforms into mixture of ausferritic ferrite (α) and carbon enriched retained austenite (γ_{HC}), a product named - ausferrite. If the casting is held at the austempering temperature too long, then the carbon enriched retained austenite (γ_{HC}) further decomposes into ferrite (α) and carbides [1]. The occurrence of carbides in the microstructure makes the material brittle and therefore, that reaction should be avoided. Hence, the optimum mechanical properties of ADI material can be achieved upon completion of the first reaction, but before the second reaction starts, i.e. inside processing window.

The austempered ductile iron (ADI) materials are widely used for large parts of machinery that work in all weather conditions. In view of that, it is of a great importance to know the behavior of ADI at low temperatures [4, 5]. One very important criterion for materials selection, especially in low temperature applications, is the ductile to brittle transition temperature.

For that reason, in this paper ductile to brittle transition temperature of unalloyed austempered ductile iron have been studied.

2. EXPERIMENTAL PROCEDURE

The unalloyed ductile iron has been examined in as-cast and austempered condition. The chemical composition (in mas. %) of as-cast material was: 3.53%C, 2.53%Si, 0.347%Mn, 0.045%Cu, 0.069%Ni, 0.055%Cr, 0.031%Mg, 0.018%P and 0.042%S.

The ductile iron has been produced in commercial foundry and cast into the standard 25.4 mm (1 inch) Y-block sand molds. The samples for mechanical testing were machined from the lower parts of Y blocks in order to avoid any segregation or porosity. After machining, the samples have been heat treated to produce an ADI material. The samples were austenitized at 900°C for 2 hours in protective atmosphere of argon and then rapidly quench in salt bath at an austempering temperature of 300, 350 or 400°C. The austempering time was 1 hours in all cases. Austempering temperature and time were chosen upon literature and previous experiments [1, 4] in order to achieve different microstructure morphologies with different content of retained austenite.

To define transition temperature curves, Charpy impact test was performed in interval from –196 to +100°C. The impact energy was measured on unnotched Charpy specimens (10×10×55 mm) using a instrumented Charpy impact machine „RPSW/A“, Schenck-Treble with a maximum energy capacity of 300 J. The testing procedure was according to EN 10045. At least three specimens for each temperature were tested. In case of testing at -196, -100, -60 and -40 the specimens were cooled in a bath containing mixture of ethyl alcohol and liquid nitrogen for 10 minutes. For tests at -20, 0 and +100 an environmental chamber was used to cold or heat the specimens for 30 minutes. After the specimens have reached the required temperature, they were quickly fractured within 5 seconds time interval. According to standard EN 10045 the 5 seconds time interval is acceptable for the duration of the test and no significant temperature loss can be expected [5]. Besides the determination of impact energies at different temperatures, other mechanical properties, namely, tensile properties (EN 10002) and Vickers hardness (ISO 6507) have been determined at room temperature.

Conventional metallographic preparation technique (mechanical grinding and polishing followed by etching with nital) was applied prior to light microscopy (LM) examinations of samples cut from Charpy specimens. For microstructural characterization, a "Leitz-Orthoplan" metallographic microscope was used. The volume fraction of retained austenite in ADI material was determined by x-ray diffraction technique using "Siemens D-500" diffractometer with nickel filtered Cu Kα radiation.

3. RESULTS AND DISCUSSIONS

3.1 Microstructure

The light micrographs of the ductile iron microstructure (polished and etched surface) are given in Fig. 1. The spheroidisation of graphite in all specimens was more than 90%, with average graphite volume fraction of 10.9%, nodule size of 25 to 30 μm and nodule count of 150 to 200 per mm^2, Fig. 1a. The as-cast microstructure of ductile iron was mainly ferritic with up to 10% of pearlite, Fig. 1b.

The influence of austempering temperature on microstructure morphology of unalloyed ADI material is shown in Fig. 2. The microstructure of all samples is fully ausferritic consisting of mixture of ausferritic ferrite and carbon enriched retained austenite. However, increasing the transformation temperature from 300 to 400°C changes the ausferritic morphology, from needle-like (Fig. 2a) to more plate-like (Fig. 2c). At lower temperatures, undercooling is larger leading to a slow diffusion rate of carbon [6]. Consequently, nucleation of ausferritic ferrite plates is favorable, while their growth is delayed. In these conditions, the resultant microstructure is consisted of fine but dense ausferritic ferrite plates of acicular morphology [6, 7]. At higher austempering temperatures the carbon diffusion rate is higher and faster, promoting growth of ausferritic ferrite plates, which will be larger and coarse in nature [7]. These microstructure differences at lower and higher austempering temperatures are clearly visible in Fig. 2a to 2c.

The volume fraction of retained austenite (Vγ) for ADI material is given in Table 1. With the increase of austempering temperature, the value of retained austenite increases, also. At higher austempering temperature the diffusion of carbon is increased, growth of ausferritic ferrite plates is more favorable than nucleation and the resulting microstructure is coarse and more plate-like [7].

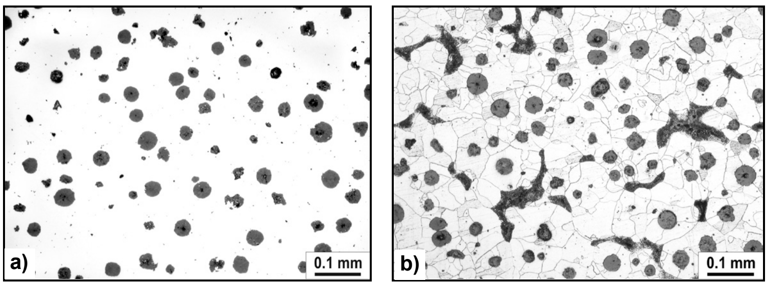

Fig. 1. Microstructure of as-cast ductile iron material: a) polished; b) etched

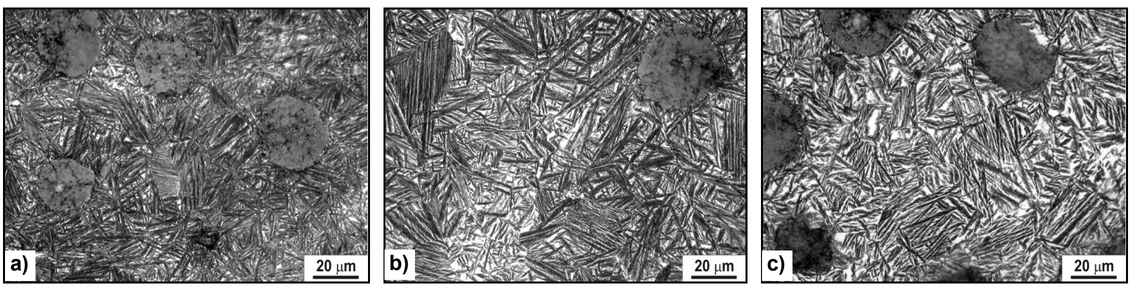

Fig. 2. Microstructure of unalloyed ADI material austempered for 1 hour at: a) 300°C; b) 350°C; c) 400°C

In these conditions, the higher volume of austenite can be enriched with carbon and stabilized, resulting in overall increase of retained austenite volume fraction (Vγ).

Austempering temperature/time	300°C/1h	350°C/1h	400°C/1h
Volume of retained austenite, Vγ (%)	16%	24.9%	31.4%

Table 1. Volume fraction of retained austenite, Vγ (%)

3.2 Mechanical properties

The mechanical properties of materials used, tested at room temperature are given in Table 2. It can be seen that the mechanical properties of ADIs after austempering are significantly increased. This is contributed to change of microstructure from ferritic/pearlitic of as-cast ductile irons to ausferritic in ADI materials. The increase of ductility at higher austempering temperatures is correlated to increase of retained volume fraction [2, 3, 8].

Material	Proof strength, $R_{p0,2\%}$ [MPa]	Tensile strength, R_m [MPa]	Elongation, A_5 [%]	Impact energy, KO [J]	Hardness HV30
As-cast	326	473	22.2	118.69	164
ADI-300°C/1h	1395	1513	3.8	64.64	460
ADI-350°C/1h	1071	1221	8.2	108.34	355
ADI-400°C/1h	759	1032	13.1	139.80	296

Table 2. Mechanical properties at room temperature

3.3 Transition temperature

The results of the Charpy impact testing in temperature interval from –196 to +100°C are given graphically in Fig. 3. It can be seen, from Fig. 3, that for each set of impact energy data there are three characteristic regions: the region of high values - upper shelf, the region of low values - lower shelf and the transition region.

That systematic variation of impact energy was fitted independently using Burr type function proposed by Todinov [9] and appropriate procedure published in literature [10]. The equation is:

$$E = E_L + (E_U - E_L)\{1 - \exp[-k(T - T_0)^m]\} \qquad (1)$$

where: E - impact energy for given temperature T, E_L - lower shelf energy, E_U - upper shelf energy, k and m - parameters determining the scale and the shape of the curve and T_0 - location parameter determining the displacement of the curve along the temperature axis.

The calculated parameters of the transition curves and the values for transition temperature - $T_{0.5}$, defined as temperature at which impact energy is average of upper and lower shelf values ($E_{0.5}$), are given in Table 3. The transition temperature ($T_{0.5}$) is used commonly, in order to describe material behavior at low temperatures and it is at the same time an engineering data for materials selection.

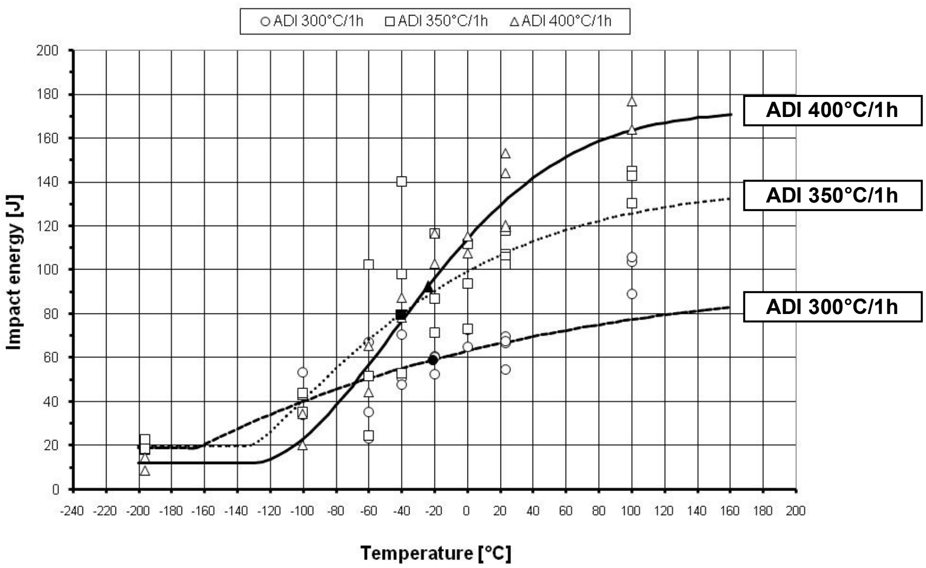

Fig. 3. The impact energies and transition temperature curves
(● - $T_{0.5}$ for ADI 300°C/1h; ■ - $T_{0.5}$ for ADI 350°C/1h; ▲ - $T_{0.5}$ for ADI 400°C/1h)

Material	Lower shelf, E_L [J]	Upper shelf, E_U [J]	T_0 [°C]	k	m	Transition	
						Energy, $E_{0.5}$ [J]	Temp., $T_{0.5}$ [°C]
ADI-300°C/1h	18.87	99.43	–165.28	4.1337×10^{-3}	1.0300	59.15	–20.84
ADI-350°C/1h	19.90	139.37	–131.70	2.8035×10^{-3}	1.2221	79.64	–40.86
ADI-400°C/1h	11.99	172.65	–131.26	1.2207×10^{-4}	1.8497	92.32	–24.20

Table 3. The parameters of the transition curve equation and transition temperature $T_{0.5}$

It is well known that materials with bcc crystal structure (like ferrite) are sensitive to low temperatures, i.e. they become suddenly brittle. On the other hand, materials with fcc crystal structure (austenite) are more stable, exhibiting only a slight change in fracture mode. Hence, the presence of retained austenite in volume fraction of 16, 24.9 and 31.4% for ADI austempered at 300°C/1h, 350°C/1h and 400°C/1h, respectively, significantly influence the behavior of ADI material at low temperatures delaying appearance of brittle fracture. The lowest transition temperature of $T_{0.5}$=-40.86°C was determined for ADI material austempered at 350°C for 1 hour, which possesses the most favorable combination of retained austenite volume fraction accompanied with fine acicular appearance of ausferrite. If amount of retained austenite is lower (in case of austempering at 300°C for 1 hour) or morphology is too coarse (after austempering at 400°C for 1 hour) than ductile to brittle transition temperature shifts to higher temperatures of $T_{0.5}$=-24.20°C and $T_{0.5}$=-20.84°C, respectively. Therefore, the transition temperature is not only determinate by amount of retained austenite but also with its refinement, i.e. with appearance of fine acicular ferrite with austenite present as film in-between the ferrite sheaves [11]. Furthermore, from Fig. 3 it might be observed that ADI material austempered at 400°C for 1h possesses highest impact energies until -32.63°C. At temperatures lower than -32.63°C the ADI austempered at 350°C for 1h have the highest impact energies, while from -101.41 to -196°C the ADI 300°C/1h exhibits highest values. It appears, that at very low temperatures the microstructure refinement (fine acicular ausferrite) has the most important influence on ductility, while at higher temperatures the amount of retained austenite is dominant factor which give high ductility.

4. CONCLUSIONS

The results obtained show that ductile to brittle transition temperature of unalloyed ADI material depends both on amount of retained austenite and microstructure morphology.

At higher temperatures, impact energies are primary influenced by amount of retained austenite, while at low temperatures the fine acicular appearance of ausferrite yields higher energies.

The lowest transition temperature of $T_{0.5}$=-40.86°C was determined for ADI 350°C/1h, whereas temperatures of $T_{0.5}$=-24.20°C and $T_{0.5}$=-20.84°C have been determined for ADI 300°C/1h and ADI 400°C/1h, respectively.

5. ACKNOWLEDGMENT

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Original Scientific Paper

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DIFFERENCES IN TIBIAL ROTATION AND TRANSLATION IN ACL DEFICIENT AND HEALTHY KNEES

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Abstract: *Anterior cruciate ligament (ACL) reconstructive surgery is used for achieving stability of the knee and normal gait pattern. Anterior – posterior translation and internal – external rotation are defined as the leading pathological parameters of the ACL deficiency. Nineteen adult men were examined in this study. Patients were walking along defined pathway at their own speed. Pathological parameters were defined based on kinematic data obtained by recording with six infrared cameras. Maximal values of the AP translation and IE rotation in early stance phase were recorded during preoperational measurement. Significiant value decrease of the AP translation and IE rotation were recorded after reconstructive ACL surgery.*
Key words: *anterior cruciate ligament, gait cycle, knee kinematic, reconstruction*

Razlike u rotaciji i translaciji ACL oštećenog i zdravog kolena. *Rekonstruktivna hirurgija prednjeg ukrštenog ligamenta (ACL) se koristi za postizanje stabilnosti kolena i normalnog hoda. Prednja – zadnja translacija i unutrašnja - spoljašnja rotacija su definisani kao vodeći nedostatak patoloških parametara ACL. Devetnaest odraslih muškarca su ispitivani u ovom radu. Pacijenti su hodali duž definisane putanje proizvoljnom brzinom. Patološki parametri su definisani na osnovu kinematskih podataka dobijenih snimanjem sa šest infracrvenih kamera. Maksimalne vrednosti AP translacije i IE rotacije u ranoj fazi zabeleženo tokom pred operativnih merenja. Značajne vrednosti smanjenja AP translacije i IE rotacije zabeleženo posle rekonstruktivne ACL operacije.*
Ključne reči: *prednji ukršteni ligamenti, kružno hodanje, kinematika kolena, rekonstrukcija*

1. INTRODUCTION

Anterior cruciate ligament (ACL) injuries are very common. Therefore, each year many people undergo ACL reconstructive surgery. Ligaments reconstruction is commonly based on using patellar tendon graft or a hamstring graft in order to resume knee stability and pain relief, and possibility of the recovery to athletic activities [1, 2].

Normal function of the knee lies in complex relationship of the movement and stability. Anterior cruciate ligaments of the knee are of the essential importance for providing passive restraint anterior – posterior knee movement. Primary function of the ACL is to prevent occurrence of the tibial translation along anterior – posterior (AP) direction, and to keep internal – external (IE) rotation in the appropriate limits [2, 3].

Purpose of this study is to present more precise and objective method for determining ACL deficient knees, and for judging the successfulness of the reconstructive surgery.

2. METHODS AND MATERIALS

2.1 Patients

Nineteen adult men with ACL deficient knees have voluntary agreed to participate in experiment of the gait analysis. Mean height of the patients is 183.33±2.24 cm, mean weight is 86±3.48kg, and mean value of the patients' age is 29.89±1.73.

Test analysis and surgery were performed at Clinical Centre Kragujevac, (Clinic for Orthopedics and Traumatology).

2.2 Instrumentation and protocol

3D kinematic data were recorded using OptiTrack (Natural Point, Inc., Oregon, www.naturalpoint.com) system with six infrared cameras (V100:R2) resolution 640x480 and software ARENA (Natural Point, Inc., Oregon, www.naturalpoint.com). On the patient's lower extremity four fluorescent markers, each 10mm in diameter, were set (Fig. 1):

- at region of the great trochanter (RGT),
- at lateral epicondyle of the femur (LEF),
- at tuberosity of the tibia (TT), and
- at the centre of the ankle joint (CAJ) .

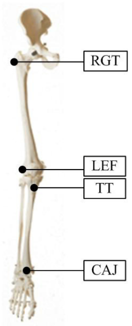


Fig. 1. Clinical positions of the leg landmarks

Patients walked 5.00m long pathway along which cameras were placed.

By protocol, patients had task to walk at their own speed. This task was performed four times. Preoperational measuring was performed the day before surgery and post operational measuring 15 days after the surgery.

2.3 Kinematic data

Movement curves were recorded in regions of the fluorescent markers' positions for the ACL deficient and healthy knees.

Patients gait were presented with a three–dimensional curves, which were exported from ARENA software in standard VICON .c3d format, and were further processed in Catia V5 (Dassault Systemes, France, www.3ds.com) and MatLab (The MathWorks, Inc., USA, www.mathworks.com).

In order to define pathological gait parameters, phases of the gait cycle were assigned on the basis of centre ankle joint curve in sagittal plane (Fig. 2) [4].

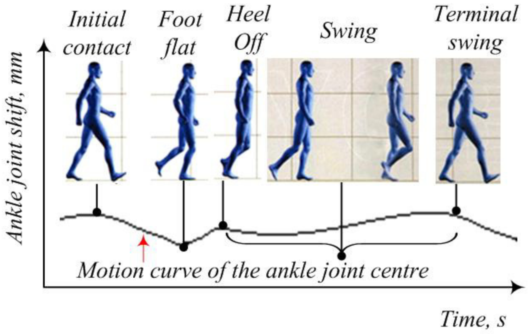


Fig. 2. Phases of the gait cycle

Gait cycle begins when one foot contacts the ground, and ends when that foot contacts the ground again. Initial contact between foot and the ground labels beginning of the ankle joint center curve descend to local minimum. Local minimum labels foot flat phase of the gait cycle. Continuous curve increase, marking heel–off and transition in swing phase. In this phase, movement curve is conditionally horizontal. Curve decrease to next local minimum labels end of the swing phase and transition in terminal swing phase which define end of the gait cycle [4].

Classification of the movement curves were performed in two groups, one group with deficient ACL knees, and another group with healthy ACL knees.

Values which define tibial shift relative to the femur are given in function of time, e.g. defined in the percentage of the gait cycle relative to time.

2.4 Data analysis

Femoral coordinate system can be considered for referent coordinate system that does not change its orientation because tibial translation and rotation (AP translation and IE rotation) relative to the femur occurs in the deficient ACL knees [4, 5, 6, 7].

If we consider tibia as rigid body, its movement can be identified with movement of the marker placed at the tuberosity of the tibia. In one moment (point TT_1), coordinate system of the tibia occupies certain position relative to the femur. In that case, it is possible to define tangent line on the movement curve t_1 and corresponding normal line n_1 at the point TT_1. In next moment (point TT_2), coordinate system of the tibia capture another position relative to the femoral coordinate system where it is possible to determine tangent line on the movement curve t_2 and corresponding normal line n_2 at the point TT_2.

Tangent and normal lines on the movement curve of the tibia will match respectively with x – axis and y – axis at any time [4]:

$$x_{ti} \perp y_{ti} \ i \ t_i \perp n_i \Rightarrow x_{ti} \parallel t_i \ i \ y_{ti} \parallel n_i \qquad (1).$$

Determination of the IE rotation angle is based on definition of the movement curve tangent line coefficient and on definition of the angle between tangent line and AP axis of the femoral coordinate system (Fig. 3) [4, 7]:

$$t = f'(x_i) = \frac{dy_i}{dx_i} \qquad (2).$$

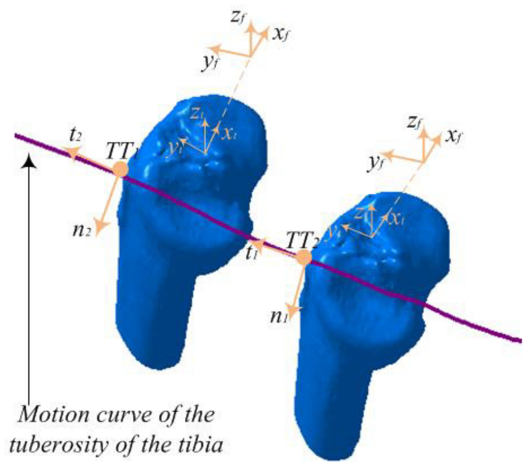


Fig. 3. Tibial translation along AP direction and IE rotation

LEGEND:
TT_1 - tuberosity of the tibia in one moment, TT_2 - tuberosity of the tibia in one moment, x_f - mediolateral axis of the femur, y_f - anteriorposterior axis of the femur, z_f - superior - inferior axis of the femur, x_t - mediolateral axis of the tibia, y_t - anteriorposterior axis of the tibia, z_t - superior - inferior axis of the tibia, t_1, t_2 - tangent line of the curve at the point TT1, e.g. TT_2, and n_1, n_2 - normal line of the curve at the point TT_1, e.g. TT_2

Value of the distance between points TT_1 and TT_2 along all directions and planes indicates possibility of the ACL deficient knees. Since displacement along inferior – superior and medial – lateral directions is negligible, determination of the tibial translation along AP direction (Fig. 3) is conducted by successive calculating the affine coordinates along AP direction [4]:

$$d_{TTAP} = (TT)_{i+1} - (TT)_i \qquad (3),$$

where is
$(TT)_i$ - tuberosity of the tibia in i - th moment, and
$(TT)_{i+1}$ - tuberosity of the tibia in i+1 - th moment.

3. RESULTS

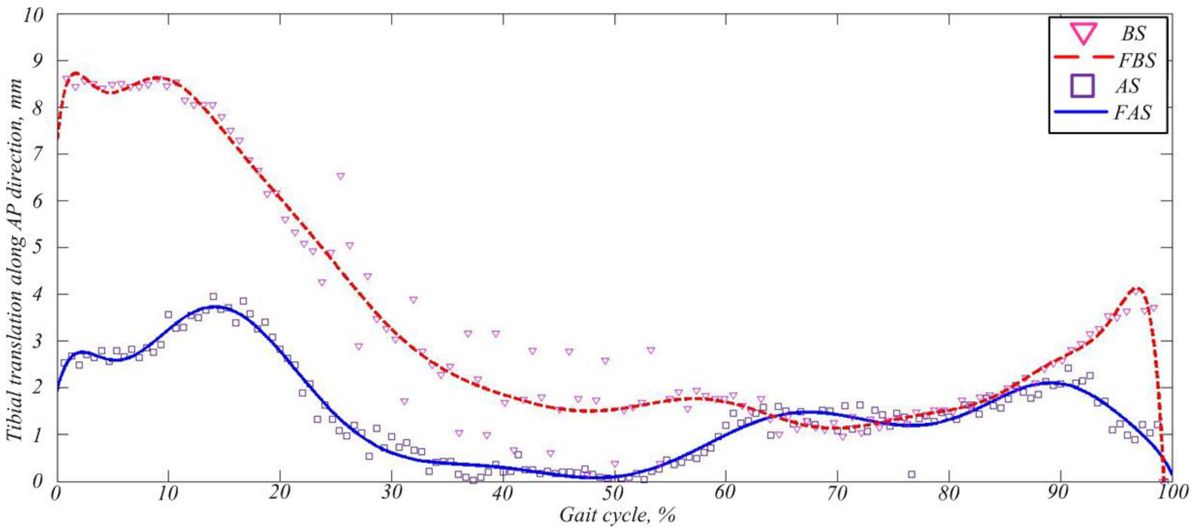
In order to obtain cuves of the AP translation and IE rotation eight order Furier approximation is applied.

The horizontal axis shows percentage distribution of the gait cycle and the vertical axis shows difference of the tibial translation changing in milimeters, e.g. difference of the IE angle rotation changing.

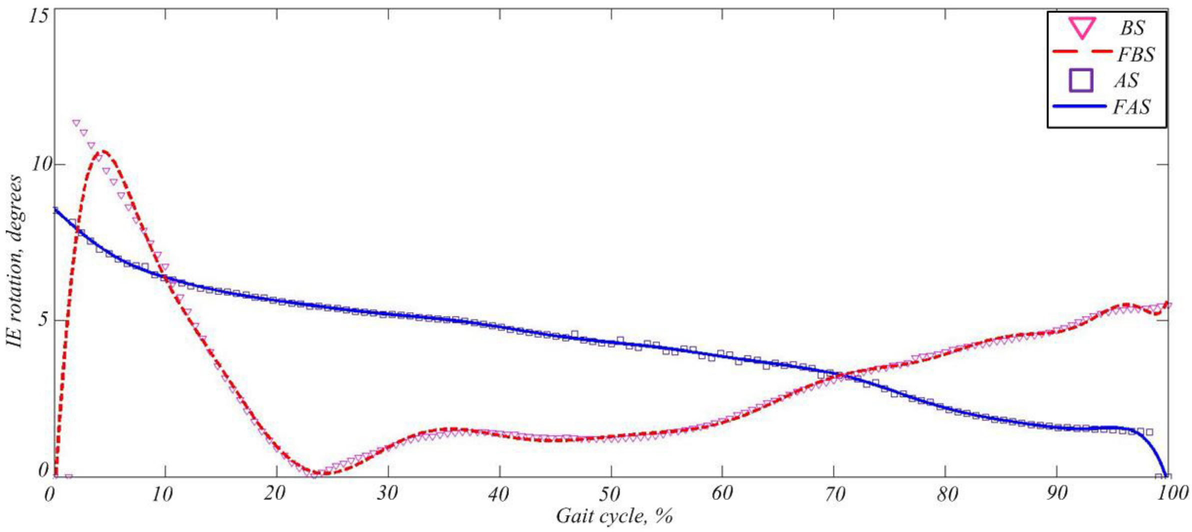
Diagrams at the Figure 4 show that these pathological parameters have the big influence on the knee stability. Measurements before operation, at the initial contact between foot and the ground which correspond to 20% of the horizontal axis, points to the high amplitudes of the AP translation, e.g. IE rotation. Before, surgery, mean value of the AP translation is 6.619±1.447mm, and for IE rotation is 6.169 ±0.711° [7].

Curves on diagrams which show patients' walk pattern after surgery has lower amplitudes, and intensity of the AP translation and IE rotation changes is decreased. Mean value along AP direction is 3.0901±0.551mm, and IE rotation is 2.382±0.477° [4].

Student t – test was used for purpose of the statistical significance of the experimental results. It can be seen that the character of the change in preoperational and post operational period is not random, but is created under the influence of the systematic or experimental factors for possible error P<0.1 and for certainty of the P>99%.



a)



b)

Fig.4. Values of the pathological parameters during gait cycle for: a) AP translation, and b) IE rotation

LEGEND:

BS - Changes of the tibial AP translation (or changes of the IE angle) before surgery, *FBS* – Fitted curve of the tibial AP translation (or changes of the IE angle) before surgery, *AS* - Changes of the tibial AP translation (or changes of the IE angle) after surgery, and *FAS* - Fitted curve of the changes tibial AP translation (or changes of the IE angle) after surgery after surgery.

4. DISCUSSION AND CONCLUSIONS

Knowing knee kinematics is of the great importance for getting relevant knee function information which can be used for improvement treatment of the knee pathology [6]. In this study inovative gait analysis technique is applied.

Stable knee joint implies small values of the AP translation and IE rotation. In order to achieve fuctional role of the ACL, gait cycle specific phases which have influence on pathological kinematic of the ACL deficient knee joint have to be determined.

Numerous reserchers have noticed tibial translation along AP direction and higher values of the IE rotation using in vitro and in vivo experiments [8, 9]. Results of this study shown in Figure 4, concides with results [3, 6]. Maximal values of the AP translation and IE rotation occur in early stance phase when heel strikes [5]. After ligament reconstruction surgery, these values decreased.

Andriacchi et al. and M. Kozanek et al. have shown that there is conection between AP translation and flexion – extension of the knee movement. At initial contact between foot and the ground, anterior position of the tibia relative to the femur is related with extensor mechanisam pulling on the tibia [2,6]. During foot flat phase tibia sliding posteriorly as the knee flexion. This is in agreement with Bergamini et al. which were shown ACL decrese during knee flexion [9]. Our results show (Fig.4) maximal values of the AP translation when knee is in extension, e.g. heel strikes.

Bull et al. in study show that there is significiant reduction of the pathological IE rotation across the whole range of the knee motion measured after ACL reconstruction surgery [10]. This correspond with results shown in Figure 6b, where maximal values of the IE rotation at the begginig of the gait cycle occurs, and after reconstruction surgery decrease [11].

Using the same clinical position of the leg landmarks, limitations of this study are minimized which are related to the measurement errors and data noise coming from skin and soft tissue motion.

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Original Scientific Paper
Puskar, T., Jevremovic, D., Eggbeer, D., Lapcevic, A., Trifkovic, B., Vukelic, D., Williams, R.J.

DETERMINATION OF CORROSION CHARACTERISTICS OF DENTAL ALLOY BY INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY

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Abstract: *Corrosion resistance is one of the characteristics that dental alloy should possess as it should be placed in the oral cavity. Adverse tissue reactions of the gingiva and the periodontium close to dental cast alloys may be caused by the effects of released metal elements. Corrosion effect of dental Co-Cr-Mo alloy was investigated by ICP MS according to the EN ISO 10271 and EN ISO 22674. Co- Cr dental alloy Remanium GM 800+ (Dentaurum Ispringen, Germany was tested in artificial saliva for 7 days at 37ºC. The released metals were detected by Nexion 300X ICP MS (Perkin Elmer, USA). The results showed that the metal release was very low for Co, Cr and Mo, far below the permitted levels. ICP-MS can be considered as very reliable method for such a research.*
Key words: *dental alloy, corrosion resistance, ICP MS*

Utvrđivanje korozionih karakteristika stomatološke legure sa induktivno spregnutim plazma masenim spektrometrom. *Otpornost na koroziju je jedna od karakteristika koju poseduju stomatološke legure koje trebaju biti postavljene u usnoj duplji. Neželjene reakcije tkiva gingive i parodoncijuma sa stomatološkim legurama može biti uzrokovano efektima oslobođenih metalnih elemenata. Efekat korozije stomatološke Co- Cr -Mo legure ispitana je ICP MS prema EN ISO 10271 i EN ISO 22674 . Co- Cr stomatološke legure Remanium GM 800 + (Dentaurum Ispringen , testirano u Nemačkoj u veštačkoj pljuvački tokom 7 dana na 37 C. Otkriveni su oslobođeni metali Nekion 300Ks ICP MS (Perkin Elmer , SAD). Rezultati su pokazali veoma slabo oslobađanje metala, Cr i Mo , daleko ispod dozvoljenih nivoa. ICP -MS može smatrati veoma pouzdan metod za ovakvo istraživanje .*
Ključne reči: *stomatološke legure, otpornost na koroziju, ICP MS*

1. INTRODUCTION

Alloys are in use for many years in dentistry as a material for fabrication of dental devices. Demands for mechanical properties as well as for the stability of dental alloys in oral environment are very high. Dental alloys should withstand high cyclic loads up to 800N per occlusal unit, high humidity, temperature changes from 0ºC to 70ºC, and acidity variations from pH 2 to pH 11 [1,2,3]. Corrosion resistance is one of the characteristics that dental alloy should possess as it should be placed in the oral cavity. The release of metallic ions from the alloy into saliva should be as low as possible, because they could diffuse in mucosae tissue or they could be ingested, transported and accumulated in distant parts of the organism [4,5]. Many studies have reported toxic and carcinogenic effects induced when humans and animals are exposed to certain metals [4,5,6,7]. Adverse tissue reactions of the gingiva and the periodontium close to dental cast alloys may be caused by the effects of released metal elements. Tissue reactions depend upon the amounts of elements available which are a function of corrosion rates [8]. All previously mentioned indicate that the investigation of potential release of metals from dental alloys in oral environment is necessary step in testing new products before they are allowed to be introduced in clinical practice and in controlling products that are in use for many years.

The insight that we have on stability of the alloy and the safety for use are strongly dependent on the tools available which allow us to perform our investigation. The detection and analysis of the released metals at the trace level poses a number of challenges to the analyst [9]. In previous investigations besides atomic absorption spectrophotometry (AAS) nuclear corrosion monitoring (NCM), electron microscopy (ESCA), microphotography and SEM were used [5,10,11,12,13] . All of the mentioned methods have their limitations, for example AAS has limited linearity and therefore is recommended for low-level analytes.

ICP MS offers the capability of specification with multi-element detection, of isotope measurements to improve precision and accuracy excellent sensitivity and detection limits and wide dynamic range [14]. ICP-MS is suitable for analyzes that are requiring the lowest detection limits and the greatest level of productivity.

Favourable characteristics of ICP-MS can be summarized in a few points:

- Instrument detection limits are at or below the single part per trillion (ppt) level for much of the periodic table;
- Analytical working range is nine orders of magnitude;
- Productivity is unsurpassed by any other technique and
- Isotopic analysis can be achieved readily [15].

The principal of ICP MS function is that samples are introduced into argon plasma as aerosol droplets. The plasma dries the aerosol, dissociates the molecules and then removes an electron from the components, thereby forming singly-charged ions, which are directed into a mass filtering device known as the mass spectrometer [16]. Most commercial ICP-MS systems employ a quadruple mass spectrometer which rapidly scans the mass range. Upon exiting the mass spectrometer, ions strike the first dynode of an electron multiplier, which serves as a detector [16]. The impact of the ions releases a cascade of electrons, which are amplified until they become a measureable pulse. The software compares the intensities of the measured pulses to those from standards, which make up the calibration curve, to determine the concentration of the element [16]. For each element measured, it is typically necessary to measure just one isotope, since the ratio of the isotopes, or natural abundance, is fixed in nature [16]. ICP-MS can be used to measure the individual isotopes of each element; this capability brings value to investigations interested in one specific isotope of an element or in the ratio between two isotopes of an element.

2. MATERIALS AND METHOD

Corrosion effect of dental Co-Cr-Mo alloy was investigated by ICP MS according to the EN ISO 10271 and EN ISO 22674 [16,17]. A rectangular plate sample of 34mm x 13mm x 1.5mm of dental Co-Cr-Mo alloy was made according to the standard technological procedure that was common in today dental laboratory using lost wax technique. Non precious Co-Cr alloy Remanium GM 800 + (Dentaurum Ispringen, Germany) was used. The composition of the alloy is given in Table 1. First, wax model was made. It was invested in Rema dynamic investment and vacuum casted in Nautilus CC system (Bego, Germany). After casting the sample was divested, blasted and polished. The sample was fixed with nylon thread and immersed in glass container with artificial saliva with pH=6.8 [18]. It was held for 7 days (+/- 0.1) at 37°C. After that the sample of artificial saliva was taken and was analyzed in Nexion 300X ICP-MS (Perkin Elmer, USA) (Fig. 1).

Chemical composition (in mass %)	Co	Cr	Mo	Si
	63.3	30	5	1
Others less than 1%: Mn, N, C				

Table 1. Chemical Composition of Remanium GM800+ (Dentaurum Ispringen, Germany) dental alloy according to the manufacturer

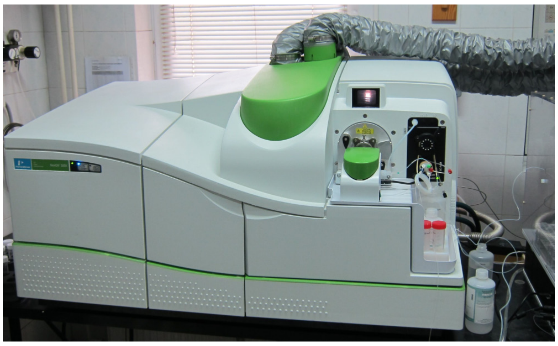

Fig. 1. Nexion 300X ICP-MS

An ICP-MS consists of the following components (Fig. 2):

- Sample introduction system – composed of a nebulizer and spray chamber and provides the means of getting samples into the instrument;
- ICP torch and RF coil – generates the argon plasma, which serves as the ion source of the ICP-MS;
- Interface – links the atmospheric pressure ICP ion source to the high vacuum mass spectrometer;
- Vacuum system – provides high vacuum for ion optics, quadrupole, and detector;
- Collision/reaction cell – precedes the mass spectrometer and is used to remove interferences that can degrade the detection limits achieved;
- Ion optics – guides the desired ions into the quadrupole while assuring that neutral species and photons are discarded from the ion beam;
- Mass spectrometer – acts as a mass filter to sort ions by their mass-to-charge ratio (m/z);
- Detector – counts individual ions exiting the quadrupole and
- Data handling and system controller – controls all aspects of instrument control and data handling to obtain final concentration results.

3. RESULTS

The corrosion characteristics of Co-Cr alloy was investigated by analysis of element release in artificial saliva. After the investigating period of 7 days the results of the released metals from the Co-Cr dental alloy were far under the permitted level.

According to ISO 22674 the quantity of released metal from the alloy should not exceed 200μg/cm^2 in 7 days period [17]. The results of the investigation are shown in Table 2.

4. DISCUSSION

The investigation of corrosion characteristics of dental alloy can be done by analysing the release of metal ions in electrolytic solution. Today, there are three widely accepted analytical methods for analyze of metal release: atomic absorption, atomic emission and mass spectrometry. The most common techniques in use today are:

- Flame Atomic Absorption Spectroscopy;
- Graphite Furnace Atomic Absorption Spectroscopy (GFAA);
- Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) and
- Inductively Coupled Plasma Mass Spectrometry (ICP-MS) [16].

Performing atomic absorption spectroscopy requires a primary light source, an atom source, a monochromator to isolate the specific wavelength of light to be measured, a detector to measure the light accurately, electronics to process the data signal and a data display or reporting system to show the results. Whatever the system, the atom source used must produce free analyte atoms from the sample [16]. The source of energy for free atom production is heat, most commonly in the form of an air/acetylene or nitrous-oxide/acetylene flame. The sample is introduced as an aerosol into the flame by the sample-introduction system consisting of a nebulizer and spray chamber. The burner head is aligned so that the light beam passes through the flame, where the light is absorbed. The major limitation of Flame AA is that the burner-nebulizer system is a relatively inefficient sampling device. Only a small fraction of the sample reaches the flame, and the atomized sample passes quickly through the light path. An improved sampling device would atomize the entire sample and retain the atomized sample in the light path for an extended period of time, enhancing the sensitivity of the technique [15,16]. This leads us to the next technique – electrothermal vaporization using a graphite furnace. With Graphite Furnace Atomic Absorption (GFAA), the sample is introduced directly into a graphite tube, which is then heated in a programmed series of steps to remove the solvent and major matrix components and to atomize the remaining sample [20]. Graphite Furnace analysis times are longer than those for flame sampling, and fewer elements can be determined using GFAA. However, the enhanced sensitivity of GFAA, and its ability to analyze very small samples, significantly expands the capabilities of atomic absorption.

ICP is argon plasma maintained by the interaction of an RF field and ionized argon gas [16]. The plasma can reach temperatures as high as 10 000 K, allowing the complete atomization of the elements in a sample and minimizing potential chemical interferences. Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is the measurement of the light emitted by the elements in a sample introduced into an ICP source. The measured emission intensities are then compared to the intensities of standards of known concentration to obtain the elemental concentrations in the unknown sample [16]. Sequential-type systems can select any wavelength and focus it on a single detector. However, this is done one element at a time, which can lead to longer analysis times.

With Inductively Coupled Plasma Mass Spectrometry (ICP-MS), the argon ICP generates singly charged ions from the elemental species within a sample that are directed into a mass spectrometer and separated according to their mass-to-charge ratio. Ions of the selected mass-to-charge ratio are then directed to a detector that determines the number of ions present [16]. ICP-MS combines the multi-element capabilities of ICP techniques with exceptional detection limits equivalent to or below those of GFAA. It is also one of the few analytical techniques that allows the quantification of elemental isotopic concentrations and ratios, as well as precise speciation capabilities when used in conjunction with HPLC or GC interfaces [15]. This feature enables the analytical chemist to determine the exact form of a species present – not just the total concentration. However, due to the fact that the sample components are actually introduced into the instrument, there are some limitations as to how much sample matrix can be introduced into the ICP-MS.

In addition, there are also increased maintenance requirements as compared to ICP-OES systems. Inductively coupled plasma-mass spectrometry (ICP-MS) is the method of choice for analyzing metal release from dental alloy in investigated medium because of its multi-element capability, low detection limit (ppt) and wide dynamic range (109 orders of magnitude)

Mean value of the released element (μg/l)	70.52	35.27	0.74
Volume of the artificial saliva	0.05	0.05	0.05
Dilution	1	1	1
Mean value (μg)	3.53	1.76	0.04
The surface area of the sample (mm^2)	990.09	990.09	990.09
The result of element release ($\mu g/cm^2$)	0.356	0.178	0.004

Table 2. The results of the investigation

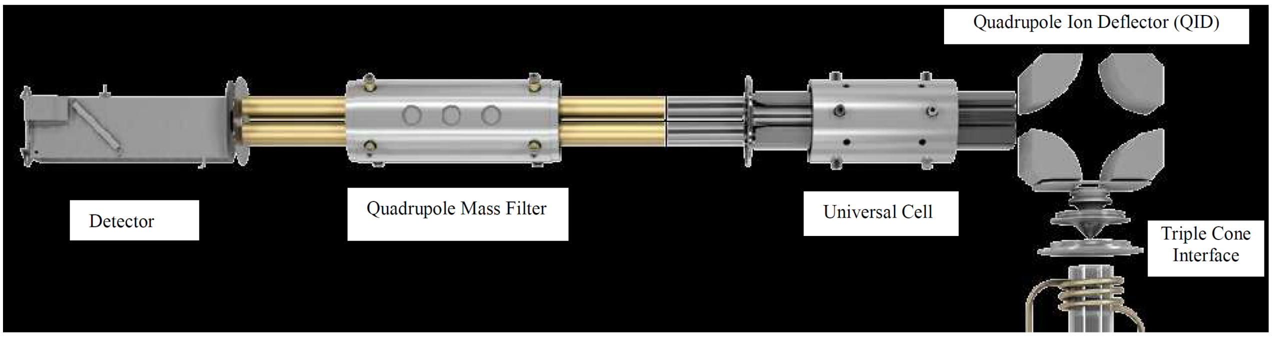

Fig. 2. The ion optic path of the PerkinElmer NexION ICP-MS

5. CONCLUSION

Although Co-Cr dental alloys are used for fabrication of dental devices for many years the research of their stability in oral environment are current. A growing amount of results provide evidence that toxic and carcinogenic metals are capable of interacting with nuclear proteins and DNA causing oxidative deterioration of biological macromolecules [4, 21]. Detailed studies in the past two decades have shown that metals like iron, copper, cadmium, chromium, mercury, nickel, vanadium possess the ability to produce reactive radicals, resulting in DNA damage, lipid peroxidation, depletetion of protein (4). Current analytical methods for analysing metals at trace levels give researchers new opportunities for detection and quantification of metals with possible new perspective on their interaction with biomolecules.

According to presented results investigated Co-Cr dental alloy Remanium GM 800 + (Dentaurum Ispringen, Germany) has good corrosion characteristics and stability in oral environment. ICP-MS can be considered as very reliable method for such a research.

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DEVELOPMENT OF THE ENDOPROSTHESIS OF THE FEMUR ACCORDING TO THE CHARACTERISTICS OF A SPECIFIC PATIENT

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Abstract: *Arthroplasty of the hip joint is one of the most widely implemented endoprothetical aids in humans. Each year, around 800,000 operations such this, are done in the world. The main factors influencing the success of the surgery are the operative procedure, the degree of adaptation elements of prosthesis to the patients, and its mechanical properties. Due to the large number of influencing factors, the best results are achieved by the development of prostheses tailored to the patient. The custom-made development of the endoprosthesis body includes four group activities as follows: data acquisition from diagnostic images and the reconstruction of the morphology of the affected elements of the skeletal system, definition of a computer model for a hip endoprosthesis, verification using the appropriate computer analysis and production by applying the NC technology. This paper describes the specific activities present in the development of hip endoprosthesis specifying their advantages and limitations. The presented results are the part of the research on development of the custom made endoprostheses at the Faculty of technical sciences.*
Key words: *custom-made endoprsthesis, hip joint, CAD, CAE*

Razvoj endoproteza femura prema karakteristikama određenog pacijenta. *Artroplastika zgloba kuka je jedan od najčešće implementiranih endoprotetičkih pomagala kod ljudi. Svake godine, oko 800.000 operacija poput ove se urade u svetu. Glavni faktori koji utiču na uspeh operacije su operativni postupak, stepen adaptacije elemenata proteza za pacijente , i njene mehaničke osobine. Zbog velikog broja uticajnih faktora , najbolji rezultati se postižu razvojem proteza kreiranih po meri pacijenta. Razvoj endoproteze po meri tela obuhvata četiri grupe aktivnosti: prikupljanje podataka sa dijagnostičkih slika i rekonstrukcija morfologije pojedinih elemenata skeletnog sistema, definicija kompjuterskog modela za endoprotezu kuka, verifikacije pomoću odgovarajuće kompjuterske analize i proizvodnja primenom NC tehnologije. Ovaj rad opisuje konkretne aktivnosti prisutne u razvoju endoproteza kuka navodeći svoje prednosti i ograničenja. Predstavljeni rezultati su deo istraživanja razvoja endoprostheses po meri na Fakultetu tehničkih nauka.*
Ključne reči: *endoproteza po meri, kuk, CAD, CAE*

1. INTRODUCTION

The intensity of life activities and illnesses occurring as a consequence have a significant impact on the elements of the locomotion system. In everyday physical activities, every person makes approximately 10,000 steps per day [1], and as the consequence, the elements of the hip and knee joints suffer the most, since they are exposed to the most intensive workloads. Due to the problems in these elements of the locomotion system, there are about 800,000 total hip replacement surgeries performed yearly worldwide [2].

According to the form and manner in functioning, the hip is a spherical joint establishing the connection between the pelvis and the femur. This joint consists of several elements, as presented in Fig. 1.

Operative treatment of replacing the natural with the artificial hip joint is generally composed of several phases: separation of the natural femoral head and the neck from the femur bone (Fig. 2a); installation of the acetabular component presenting the artificial seat of the hip joint (Fig. 2b); installation of the endoprosthesis body into the medullary channel of the femur bone with the elements replacing the natural neck (Fig. 2c); setting of the artificial head to the neck of the prosthesis body (Fig. 2d); and, connection of elements of the artificial hip joint into a unity (Fig. 2e) [2].

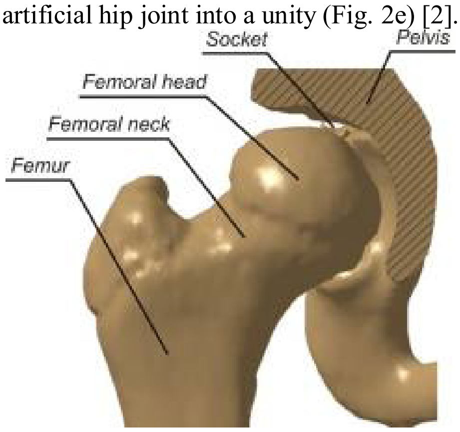
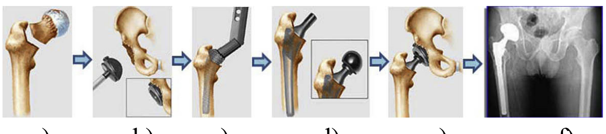


Fig. 1. Elements of the hip



a) b) c) d) e) f)

Fig. 2. Phases of the operative treatment of replacing the natural with the artificial hip joint [3]

The success of the operative treatment of replacing the natural hip joint with the artificial one is measured by the time period necessary for the recovery of the patient and the exploitation life of the prosthesis. The main factors influencing the success of the surgery are the operative procedure, the degree of adaptation of prosthesis elements to the patient, and its mechanical properties.

From the aspect of the development of the endoprosthesis, the most significant element of the artificial hip joint is the femoral stem. It provides the connection between the hip joint and the femur, and it overtakes the largest workload during the physical activities. In developing the endoprosthesis body, it is important to bear in mind that the femur is the mechanically most loaded bone in the human locomotion system.

The success of the installation of the hip joint endoprosthesis, as well as the exploitation life in the organism, depend on many factors, from which the most important one is the proper selection of the shape and the size of the endoprosthesis body. The most common method for the development of the endoprosthesis is the "methodology of the typization". Beginning with the stated methodology, the most common method is the systematization of endoprosthesis according to the type (primary, revision…), the dimensions (usually up to 10 per type), and the mode of fixing into the femur (cement, cementless). The selection of prosthesis for a particular patient, from the offered set of prosthesis, is based on the following: the complexity of the disease, patient's age and femur dimensions.

In the recent year, the research in the area of biomedical engineering has been directed towards the development and manufacture of prosthesis according to the morphological characteristics of a patient (so-called custom-made endoprosthesis). This type of endoprosthesis, apart from femur dimensions and shape, maximally considers the type and the extent of the disease [4], as well as some other parameters. The objectives in the development of the hip joint endoprosthesis tailored for a specific patient are the maximum design speed providing minimal invasiveness in the operative treatment, short recovery period and long exploitation life of the implant. This can be achieved by using the computer technologies that enable the design, analysis and simulation of the product behaviour in all developmental stages. The custom-made development of the endoprosthesis body includes three group of activities [5] as follows:

- Data acquisition from diagnostic images and the reconstruction of the morphology of the affected elements of the skeletal system;
- Definition of a computer model for a hip endoprosthesis;
- Verification using the appropriate computer analysis;

The paper describes the activities in the development of the hip joint endoprosthesis tailored for a specific patient, as well as the tendency to develop each of these based on the contemporary research in the area.

2. DATA ACQUISITION AND FEMUR MORPHOLOGY RECONSTRUCTION

Determining the properties of the diseases in the elements of the human locomotion system largely depends on the sharpness and the quality of images used in diagnostics. Furthermore, for the development of endoprosthetic implant the significant role is attributed to the recording method, recording angle and device calibration. Hence, in the past years, there has been an intensive development of the methods based on the spatial images of the diseased limb (mainly by applying tomographic recording methods) [6], which generate digital copies of the desired cross-section of the subject. In medicine, and hence in the orthopaedics as well, the most commonly used are the computerized tomography (CT) and magnetic resonance imaging (MRI). Both methods allow the generation of a series of images showing the cross section of the diseased tissue (Fig. 3).

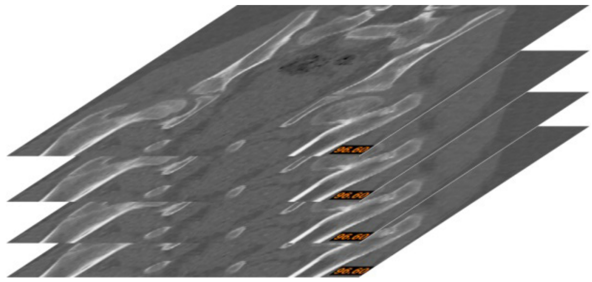


Fig. 3. CT image of the pelvis region

The application of the tomographic imaging in diagnostics enables the determination of the type and the extent of the disease, as well as the measuring of characteristic sizes of the diseased limbs [6]. This enables the possibility to define the geometric parameters of the femur [3]. In addition, the application of tomographic methods provides prerequisites for the formation of spatial computer models of the diseased limb in order to design the endoprosthesis, and in later phases, to simulate its behaviour in the exploitation conditions, as well as to simulate the surgical procedure. Modelling of the diseased femur, among others, is performed by applying specialized software systems for the reconstruction of tomographic images. This procedure consists of three following activities:

- Preparation activities;
- Manual or automated segmentation of the bone and tissue mass;
- Definition of output data in the form of a database containing the coordinates of the cloud of points or the creation of a volumetric model by introducing volume elements (voxels) between segmented image planes.

First, the preparation activity includes the processing of diagnostic images most commonly in the form of a series of image planes with the cross section of the recording object. It implies the correction of contrasts in order to segment the bone mass more easily, as well as the input into the software system for the reconstruction of the bone system morphology.

Tissue segmentation includes the identification of the image area belonging to relevant organs. This is one of the most significant steps in the reconstruction process based on the series of images, and the accuracy of the generated model highly depends on it [2]. Fig. 4. presents the diagnostic image and the segmentation of the femur bone tissue.

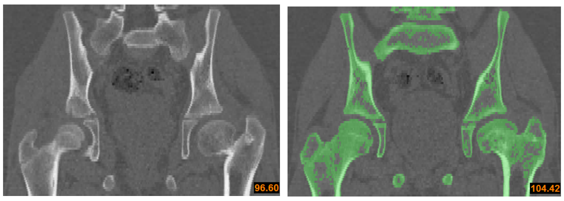


Fig. 4. Example of the hip segmentation on a diagnostic image

Further process in the organ reconstruction (in this case, femur and its medullary channel) includes the generation of the characteristic points which describe the formation of a spatial femur model. A simpler form in the femur description is the cloud of characteristic points (Fig. 5) which is suitable for further processing [7] and the reconstruction of the areas in the CAD software systems (CATIA, PTC Creo, and the like).

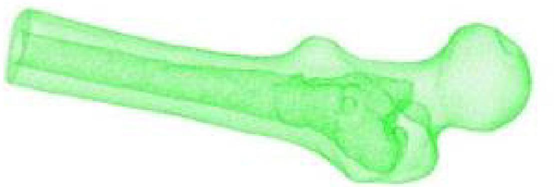


Fig. 5. Cloud of points describing the femur

The model of the affected skeleton segment can also be obtained by replacing the elementary unit (pixel) images with spatial elements (voxels), realized in the specialized software system for the reconstruction of the tomographic images (ScanIP, Mimics, etc.). As a result, the volumetric model of the reconstructed femur is obtained (Fig. 6).

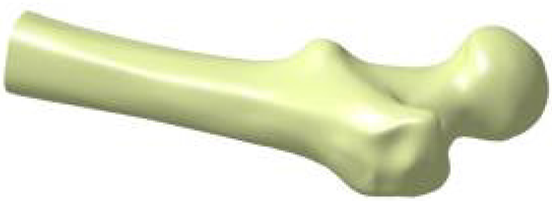


Fig. 6. Computer model of the femur

Both described procedures allow the generation of a computer model suitable both for defining the necessary parameters and for computer verification of the designed endoprosthesis body.

The reconstruction of the femur geometry implies the reconstruction of the outer and the internal geometry of the femur, i.e. medullary channel. Spatial model of the internal geometry of the femur, obtained by the reconstruction of the points of clouds, is presented in Fig. 7.

Fig. 7. Computer model of the medullary channel

3. DESIGN OF THE ENDOPROSTHESIS

Design of the endoprosthesis body tailored for a specific patient, from the application of tomographic image methods of the patient, is based on defining the following: characteristic cross sections of the endoprosthesis based on the adequate cross sections of the femur (Fig. 8a) and the properties of the medullary channel in it. The subsequent design phases for the endoprosthesis imply the formation of the geometric surface around the defined cross sections and hence the formation of the endoprosthesis body (Fig. 8b).

Fig. 8. Computer model of the femur (a) and the endoprosthesis body (b)

In order to minimize the period for designing the endoprosthesis body, there are two methods utilized for implementing the influential parameters (geometric, exploitation and operative) into the geometric form creating the computer model of the endoprosthesis body. Both methods, apart from including the existing ones, also allow for the introduction of new influential factors. These two methods are as follows:

- Method of parameter modelling, and
- Method for model definition by applying general mathematical laws (general mathematical models).

Parameter modelling is the most suitable method for creating computer models for a group of products with the similar geometry. In the case of the endoprosthesis body, it implies the typization of elements of its geometry, separate individual definitions of each element, and the definition of constraints. Geometry of the endoprosthesis body consists of a series of surface or volumetric shapes that determine the lower (distal), middle (medial) and upper (proximal) segment of the endoprosthesis. The method of parameter modelling, most common, apart from the generalized geometry defined by general sizes, also includes the application of a database containing the values of these sizes (Fig. 9).

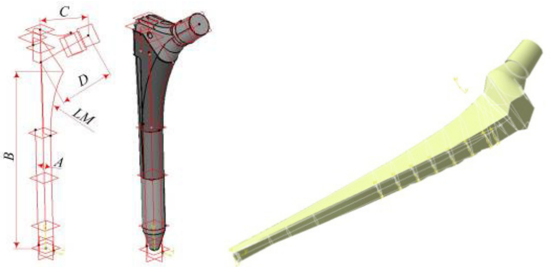


Fig. 9. Appearance of the parameter model [8,9]

The parameter modelling method is suitable for application in designing the body of the hip endoprosthesis when the Rtg method is used for diagnosing the disease. The application of the Rtg method can be used to define the limited number of geometric parameters of the femur. The advantage of this method is in the relatively simple automation of the geometric parameter input, since it is a plane imaging. Drawbacks of this method include complexity and "rigid" structure of the model. That structure disables the introduction of new geometric parameters into the design process.

Second method, in which the geometry of the endoprosthesis body is described by applying spatial generated models, is based on the application of mathematical laws made from polynom expressions. This method is suitable to describe parts of complex geometric forms [10]. This general mathematical method for describing the endoprosthesis body, due to its generalized form, has several advantages in relation to parameter modelling. They primarily include the significantly more flexible procedure for describing the geometry that can be utilized for more types of endoprosthesis, and the final model form which contains the decreased number of geometric elements. The most commonly used are polynom and rational Bezier curves[1] and similar functions. Fig. 10. shows a segment of the general model of an endoprosthesis body for a hip joint developed by applying the rational Bezier function.

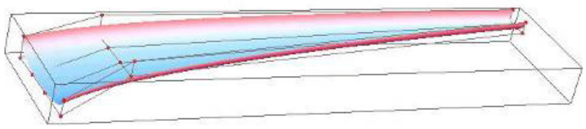


Fig. 10. Segment of a general model of anendoprosthesis body

4. VERIFICATION OF THE SOLUTION

The final phase in the development of the endoprosthesis according to the characteristics of a specific patient is the computer verification of the behaviour in exploitation conditions. Apart from defining the set of exploitation values, this is also an introduction into the optimization of the shape and the dimensions of the endoprosthesis.

Verification of the solution includes the evaluation of the endoprosthesis behaviour using the computer simulation in exploitation conditions by applying software systems for the computer model analysis with the finite element method [Heller, Weinans]. Considering the properties of tension and the conditions to which the endoprosthesis can be exposed under the transfer of the force from the leg to the pelvis and vice versa, it can be observed that the endoprosthesis and the artificial joint are exposed to constant workloads (static ones in standing and dynamic ones in motion). Behaviour analyses in static and dynamic conditions are used to evaluate the developed solutions, as well as to optimize geometric parameters of the endoprosthesis from the aspect of static, kinematic and dynamic properties. Regardless the software system that performs the verification of the endoprosthesis body and the type of analysis, the procedure itself includes the following: discretization of the developed model (Fig. 11), definitions of workload, environmental conditions and constraints, and the calculations of forces and deviations in individual model nods.

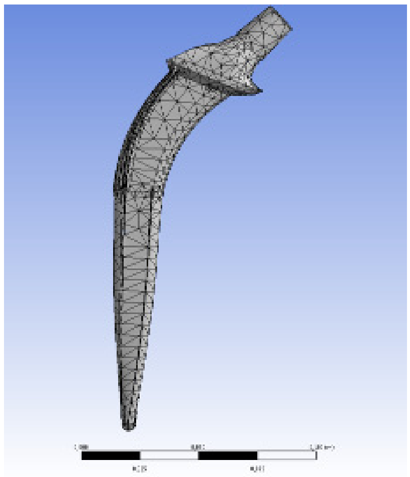


Fig. 11. Discretized model of the endoprosthesis body of the hip joint

The success in the simulation of the endoprosthesis behaviour depends on defining the forces and constraints which can be obtained by biomechanical analyses of the human locomotion system [11]. In doing so, the distal part of the prosthesis provides the positioning in medullary channel of the femur. In orthopaedic practice, the prosthesis body is placed in the femur so that the resultant force is acting at an angle of $\alpha=20°$ to the vertical plane (Fig. 12a). However, the structure of the pelvis and the operative procedure as such (Fig. 12b) can, as a consequence, also have another angle of the action of the resultant force. In order to determine the relation between the angle of the force and the behaviour and the exploitation of the endoprosthesis body in the exploitation conditions, the analyses have been performed for diverse values of this angle. Fig. 12c. shows the force angle on the discretized model of the

[1] Bezier curves were developed by Pierre Bezier for the demands of the automobile factory Renaults at the beginning of 1960s [10].

endoprosthesis.

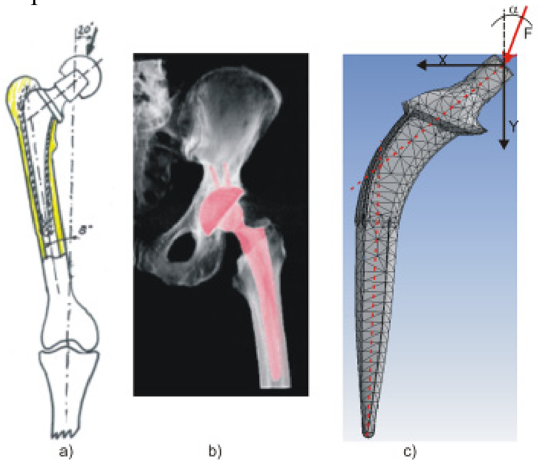
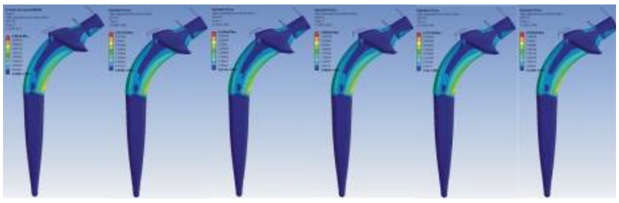


Fig. 12. Load on the endoprosthesis body of the femur: a) load angle; b) X-ray image of the implanted endoprosthesis; c) force angle on the discretized model in static analysis

4.1 Static analysis

For the analysis on the behaviour of the endoprosthesis body, in static conditions, apart from the load angle and the force intensity (4,000N), incarcerations should also be defined. Most commonly, they are defined as the fixation of a third of the height of the distal part. Fig. 13. shows graphic results, and Table 1 shows maximal values of the Van-Misses stresses depending on the load angle.



α=15° α=16° α=17° α=18° α=19° α=20°

Fig. 13. Graphic presentation of the equivalent Van Misses stresses

Load angle [α°]	Maximal equivalent Von-Misses stress σ_{ekv} [MPa]
15	449.5
16	431.7
17	413.8
18	395.8
19	377.7
20	359.4

Table 1. Maximal equivalent Van-Misses stresses

4.2 Analyses on the exploitation life of the endoprosthesis body

On the other hand, the main objective of implementing the endoprosthesis is the return of the function of the diseased organ for a longer period of time. Therefore, the development of the endoprosthesis for a specific patient must also include the analysis on the exploitation life in the organism. Based on the biomechanical researches, it has been concluded that the twenty-year-long life span of the endoprosthesis implies $N=2*10^8$ cycles [12]. Table 2 presents the life span of the endoprosthesis and the minimal safety factor obtained for the model of total endoprosthesis for the hip joint tailored for a specific patient (in Fig. 14. it is presented within the reconstructed model of the femur).

[α°]	Min. safety factor	Life of failure x 10^8 cycles
15	1.08	0.9
16	1.18	1.3
17	1.34	1.5
18	1.67	1.7
19	1.98	1.9
20	2.01	2.3

Table 2. Minimal safety factor and life of failure shown in cycles for different load angles

Fig. 14. Connection of endoprosthesis and femur

5. FINAL CONSIDERATIONS

Based on the analyses of papers in the field of designing endoprosthetic implants, acquisition of diagnostic images and biomechanics of the locomotion system, it can be concluded that the future of the endoprosthetics, among others, implies the development of endoprosthetic implants tailored for a specific patient. The reasons include a significantly longer exploitation life of the endoprosthesis designed for a specific patient, shorter post-operative recovery, less invasiveness of the operative procedure, etc.

Further research in the field of medical prosthetics follows the direction of lowering the costs of implants by shortening and partially automating the development of an endoprosthesis. Furthermore, new research is being performed in the direction of including a greater number of geometric and exploitation parameters used for defining the shape and the dimensions of an implant.

The procedure for developing an endoprosthesis body described in this paper contains a combination of three group activities (bone reconstruction based on tomographic images, endoprosthesis design and verification using the FEM methods) which are being developed independently. Hence, the directions of future researches can be observed through their individual development.

Geometric reconstruction of the femur (and other elements of the skeletal system), as well as the definitions of their geometric properties, present a series of standardized activities which can almost entirely be automated by applying adequate software technologies (as well as additional libraries of classes, such as VTK library) [13].

Defining the computer based model of the endoprosthesis based on the general mathematical models and the integration of methods for defining the characteristic parameters (position of individual anatomic surfaces on the femur) can also be automated to a larger degree. Hence, the designer is left with only the key decisions related to the character of the disease and the implementation procedure of the endoprosthesis.

Software systems for computer verification enable the automation of the shape and mass optimization for the endoprosthesis by correcting the adequate parameters on a geometric model of the endoprosthesis prior to its production.

Further improvement and automation of individual designing phases can greatly shorten the time for the development and the production of an endoprosthesis tailored for a specific patient, which would be a justification for the high price for this type of implant.

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Preliminary Note

Senderská, K., Lešková, A., Mareš, A.

DESIGN CHARACTERISTICS OF MANUAL ASSEMBLY WORKSTATION SYSTEM IN THE LEAN PRODUCTION STRUCTURES

Received: 17 January 2013 / Accepted: 25 February 2013

Abstract: *The presented article focuses on the design characteristics of lean workstations with a modular design structure. The specification of basics Lean Production principles, that should help to design of flexible manual workstations, as continuous flow, simplicity, workplace organization, parts presentation, re-configurability, product quality, maintainability, ease of access, and ergonomics are discussed in the first part of this paper. Presented principles are applied in the new designed laboratory manual assembly workstations. The closing section of the article provides the specification of the Lean Assembly Laboratory project with some selected methods and tools supporting.*
Key words: Lean Production, manual workstation, design characteristics

Dizajn karakteristike ručnog montažnog sistema u Lean Production strukturama. *Predstavljen rad se fokusira na dizajn karakteristike "lean" radnih stanica sa modularnom dizajn strukturom. U prvom delu rada je opisana specifikacija osnovnih Lean Production principa koji bi trebalo da pomognu u dizajnu fleksibilnih ručnih montažnih stanica kao kontinuirani tok, jednostavnosti, oragnizacije rada, prezentacije delova, rekonfiguracije, kvaliteta proizvoda, mogućnosti održavanja, jednostavnosti pristupa i ergonomije. Ovi principi se primjenuju u novo predloženim ručnim montažnim laboratorijskim stanicama. Završni deo rada specificira projekat Lean Assembly Laboratory s podrškom izabranih metoda i alata.*
***Ključne* reči:** *Lean Production, ručna montažna stanica, dizajn karakteristike*

1. INTRODUCTION

The management techniques Lean production and continuous improvement of processes aims to simplify workplace layout and assists with the reduction of wastage. Identifying the potential for waste and transfer it into facility design considerations is the essence of lean workstations design. Properly designed lean workstation is flexible, low cost, and efficient. Flexibility is the ability to adjust and easily to change. This applies to changes at the individual workstation, as well as changes in the process flow or work cell layout. Modular systems are inherently more flexible than stand-alone units and in this regard they are characterized by sharing of structural components and the ability to create different layouts. The modular structure allows an individual and flexible adaptation of workstations to varying requirements, particularly in regard to ergonomics parameters.

2. LEAN PRODUCTION BACKROUND

Lean Manufacturing or Lean Production, derived from the Toyota Production System, [8] is an approach based on the effort to maximal satisfaction of the customer requirements. At the same time there is an effort to achieve low costs and minimal time without product quality reduction. These goals are primarily achieved by waste eliminating. The following basic types of waste were identified by Lean approach: transport, overproduction, waiting, quality, motion, over processing and inventory. To eliminating these sources of waste can be applied a lot of techniques and tools.

2.1 Lean assembly

The same principles of waste eliminating as in the manufacturing can be applied also in the assembly. The assembly [15, 16] is an integral part of the production processes and have these specific characteristics:

- assembly process is organized and synchronized, in relation to the parts, which the production is carried out at different times and in different places,
- in the assembly process, very often, are exploited the manual operations because the automation of some operations required too complicated and expensive devices,
- the assembly process is usually the last production process in which manifests the term and qualitative irregularities from the previous phases and processes,
- some operations occasionally are repeated and they can be realized also parallel,
- usually the subassembly process is separated from the final assembly.

2.2 Principles of the lean assembly workstation design

Focusing on a group of seven main areas of waste in the assembly processes means, among other things, involve these principles into actual design of the assembly workstation or to the technical design of structural elements of the workplace. Next section of the article presents some design characteristics of assembly workstations that support shape generalized lean concept.

Flexible workstation layout

Optimal workstation's layout, respectively the possibility of a change, is an important aspect that results from the possibility of convert the assembly procedures, respectively from the work organization changes at the workstation. The flexible layout is a feature that enables to modify the assembly task and to adjust the material flow according to changed conditions. Significant floor space may be saved by properly sizing workstations. To save on cost, as well as to minimize the operational complications related to disposing of inflexible welded steel structures, preference should be given to material and joining technology that is reconfigurable and reusable. For example, the modular characteristics of extruded aluminum profiles and bolt-together systems make them perfect for the implementation of lean manufacturing concepts; lightweight aluminum structures are easier to move when re-configuration is necessary.
A properly designed lean workcell must be easy to reconfigurable or even moved to accommodate assembly of a new product. An adequate modification allows the working table to be integrated easily into existing assembly lines. Bolt-together modular framing is the key to workstation´s flexibility - when new products call for line changes, it can be quickly reconfigure, add to, or re-purpose.

Using module and adjustable components for design

The design principle applied to proposing of assembly workstation's structure, is usually modular what means, that from the existing modules can be the workstation planned according to the customer requirements. The producers of assembly means and equipments offers own reference solutions, so besides the modular concept insures also complexity of accessories. For that reason it is possible to build complete workstation from components, offered by one producer of modular units kit. Stability of presented standardized components then allows expandability or supplement of workstation. Re-configurability of workstation, respectively re-configurability of its elements, offers ability to adapt workstation according to assembly tasks requirements, also according to employee need.
So, the modular structure allows an individual and flexible adaptation of workstations to varying requirements and modular construction permits complete freedom in system configurations. Based on easy-to-reconfigure framing system, modular set let to build an extremely flexible lean manufacturing system with workstations for variable production conditions. Sit-down or stand-up assembly workstations provide an optimum basis for work without fatigue and can be adjusted to the needs of individual employees.

Continuous material flow and transport

Uninterrupted flow of completed workpieces is the desired result of a properly designed lean workcell.
Optimized solution of material flow [2] is a core task mainly because this is source of potential time - saving and also because to achieve the main goal - be "lean" is the need to minimize inventory in the workplace as

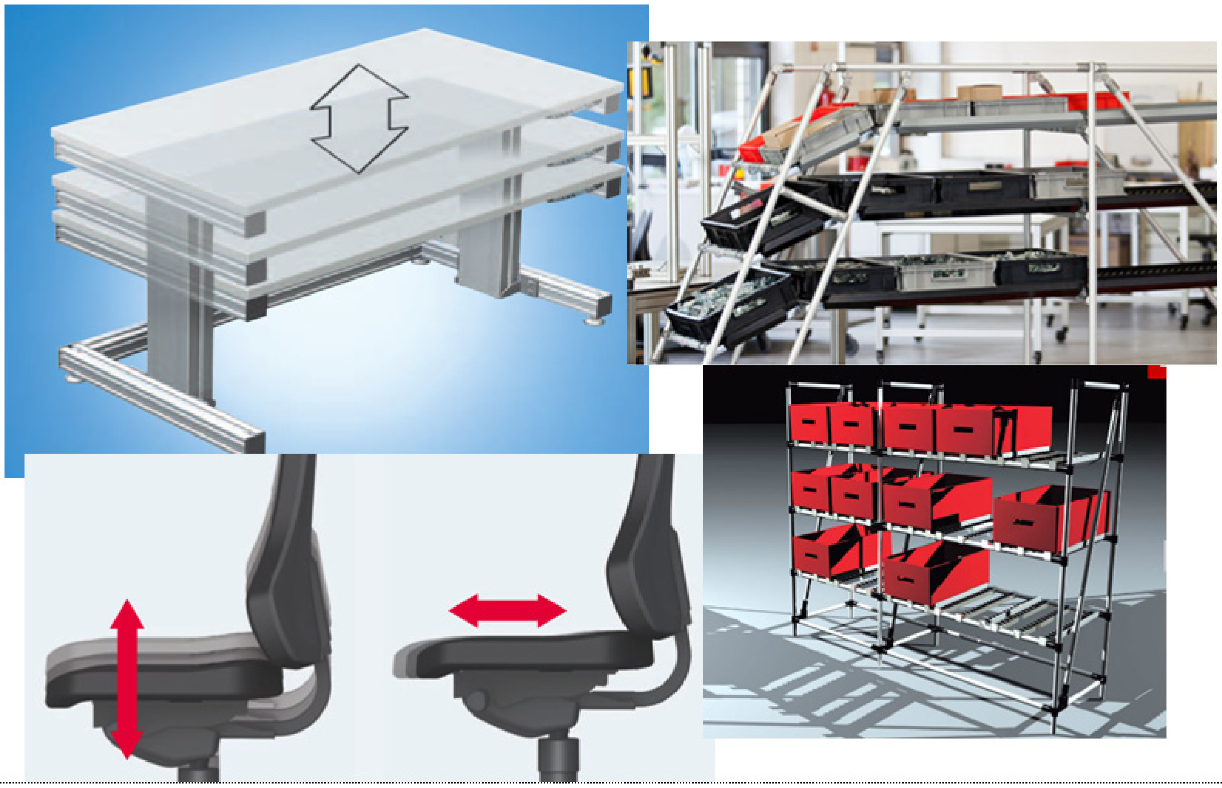

Fig. 1. Examples of adjustable work table, work chair [4] and shelf [5], [6]

well as in stores, and synchronize the transport of parts and workpieces between workcells. The current offered solutions include automatic guided vehicles (Fig. 2) or different types of conveyors.

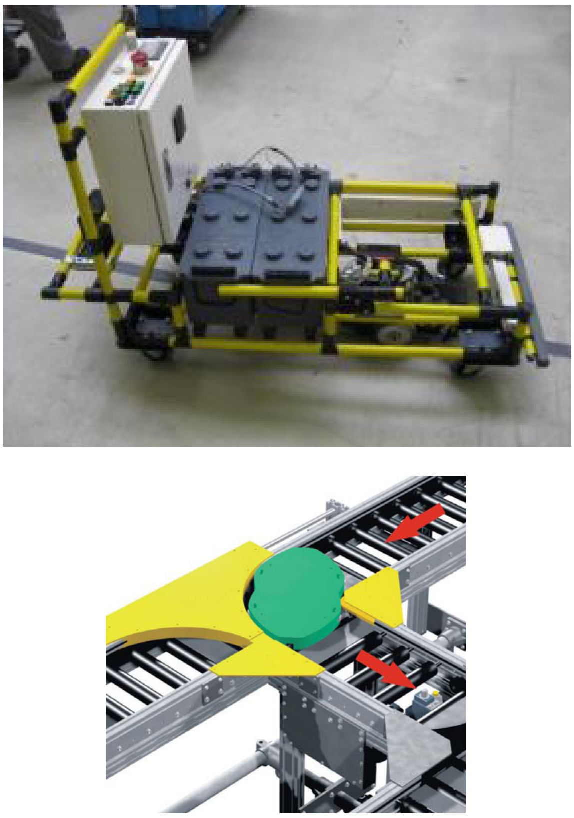

Fig. 2. Automatic guided vehicle [5] and modular transfer system [7]

Optimal storage

System of storage of components, parts and prepared sub-assemblies is one of the important tasks and, in principle, it is possible to identify store space in the workplace, or storage among workplaces directly on the production area, which create stock of supplied parts between assembly stations (Fig. 3). In doing so, it is important to achieve synergies with the transport system and central storage.

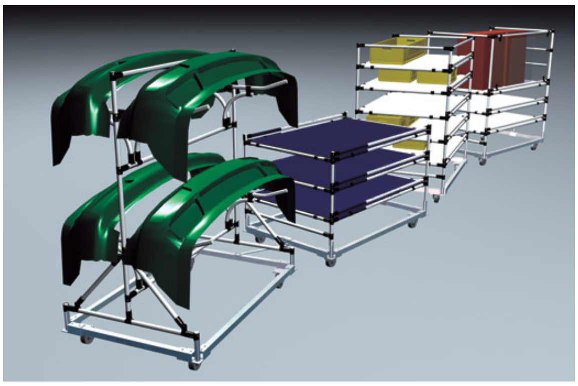

Fig. 3. Example of shelf system for storage and transfer parts from firm Trilogiq [5]

Quality assurance

The final product quality assurance process should be an integral part of the assembly process, started by quality control of parts and components, through the control during the assembly process to the testing and inspection of the final product at the end of assembly cycle. During assembly workplace design, this requirement is reflected mainly in construction of the fixtures and equipment, in the control of the assembly process by means of application the sensors and also in implementation of POKA-YOKE principles. As an example, it is possible to exemplify the solution in Fig. 4, where the manual assembly operations are controlled by sensors and give notice to worker, for example in case of part absence and do not allow to proceed in assembly process until everything is done correctly.
If each part is produced, visual inspection by the worker can verify that it is correctly assembled.

Fig. 4. View at manual assembly workplace, equipped with sensors to control assembly process [1]

Accessible tools

Lean workstation must be comfortable for the operator, and include the tools and supplies necessary to complete the manufacturing process. All tools used at a workstation should have their own holder. Using a modular tool holder system with a specific holder for each tool is ideal - if holders can easily be added to (or taken away from) a workstation, this simply adds to the flexibility of the workstation and increases its usefulness in a lean manufacturing process. Handy accessories are necessary addition to perfect design on optimal workplace. Of maximum benefit are tool holding structures that allow tools to be swung or slid into the workspace and easily returned to the storage position when no longer needed. The tools an operator is going to use every cycle should be located the closest.
Use of tools in the assembly can have an impact on a number of monitored factors, such as the time, ergonomic comfort, respectively quality. Their accessibility, arrangement, respectively good to grasp position are key factors. In Fig. 5 is the example of suspension mechanism [6].

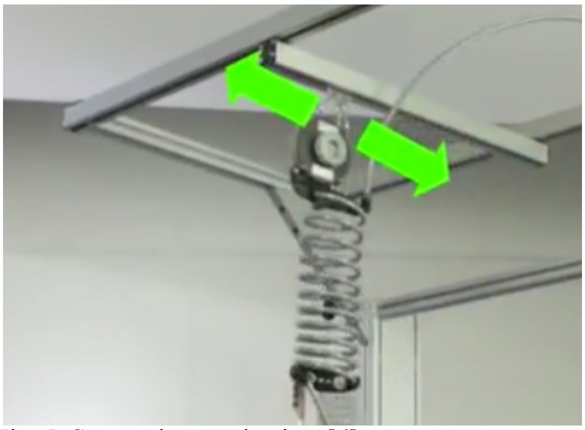

Fig. 5. Suspension mechanism [6]

Part feeding

Supply of components and parts on assembly site is also possible to realize by various ways. In manual assembly there are often used simple hoppers for small parts and worker removes parts from them. Although the choice of container type, combined with the characteristics of taken away components may impact on the various monitored parameters such as time or the need to fill the container. At Fig. 6 is the example of modeling the impact of the type of container to the time required to take away components. Although at first look it may seem that time differences are very small, it should be noted that these operations are often repetitive.

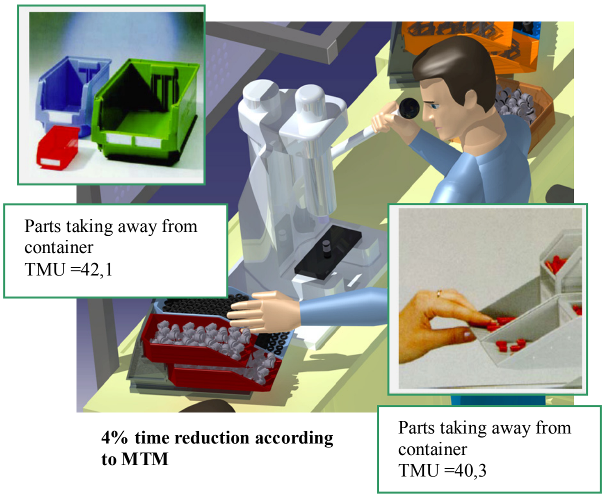

Fig. 6. Time reduction caused by different type of container using [4]

Ergonomics

From an ergonomic aspect, the main focus is on the worker, workstations are designed to fit each employee and this reduces waste during production. The adjustment to meet ergonomic requirements may be achieved, for example, with height-adjustable chairs and footrests or by using case lifters, to move containers into more convenient positions for employees. Ergonomic simulation can be used to evaluate a work cell to reviewing the interaction between the human model and the work environment (such as e.g. reach analysis or posture requirements). A wide range of manikins can be used in the simulation to determine how different types of people will interact with the assembly workstations.

3. DESIGN OF THE LEAN MANUAL ASSEMBLY WORKSTATIONS

3.1. Concept of Lean Assembly Laboratory

Within the scope of the international project LEAN LAB HUSK was proposed a concept of the assembly laboratory for the Lean Manufacturing approach application and verification.

According to specification, the laboratory will consist from 4 workstations intended to the assembly of defined product group such as brake cylinder, pump, ventilation grid, oil filter and so on.
In this context, it is essential not only this, that the actual workplaces were created by using the Lean Manufacturing approach, but also that in the assembly can be applied means and tools that support this approach.
At Fig. 7 is the example of two assembly workplaces created from the components and modules of the Boschrexroth company. The workplaces were designed in CATIA by using of the 3D models modified in the specialized Boschrexroth software Mtpro.

In the design process in CATIA were subsequently applied available tools for ergonomic design.

Unlike assembly workstations dedicated for real assembly, the laboratory workplaces must satisfy also the criteria that results from the fact, that at the workstations will be assembled several types of products, can exist different technological procedures and requirements to the workplace facilities.
Therefore, the workstation must to be adjustable, some devices re-configurable and also interchangeable so, that can be realized different assembly tasks.

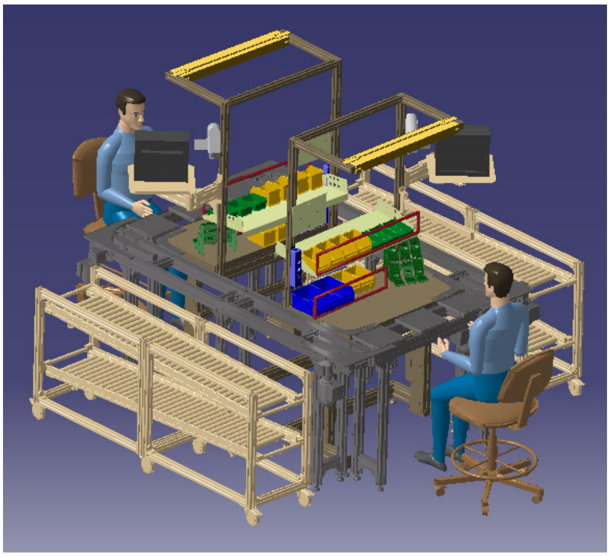

Fig. 7. Manual assembly workstation design proposal

3.2 Application of the POKA-YOKE principles

Poka-Yoke is a Japanese term that means "to prevent inadvertent errors." The author of this approach is the Japanese Shigeo Shingo. Poka-Yoke is an integral part of Kaizen.

The basic objective of the Poka-Yoke is to reach a mistake free product. It is the application of such a relatively simple and effective measures, which ensure, that errors in the manufacturing and assembly process did not affect the quality of the final product.

The mentioned principle can be applied also at the laboratory workstations. In this context, one possibility is the development of own pick to light system, the concept of which is indicated at the Fig. 8.

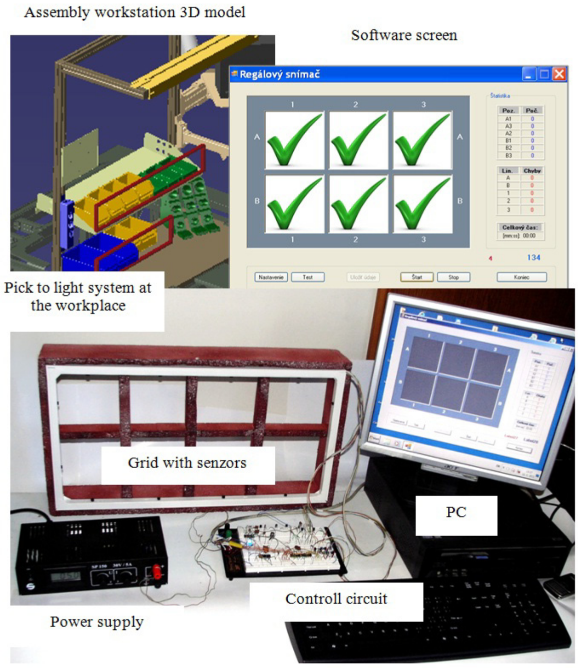

Fig. 8. Experimental Pick-to light system

3.3 Catia ergonomic modules application

In the procedure of the workplace analysis as well as the assembly procedure can be applied several CAD system modules [10, 11, 12, 13], that support the workstation ergonomic characteristics [3, 9, 14]. In this procedure can be used for instance the Catia ergonomic modules as a base of analysis. The advantage is that the entire laboratory is created as a detailed 3D model what can be the base of the “Digital Factory” approach. In Fig. 9 is an example of the ergonomic analysis result realised at manual assembly workstation.

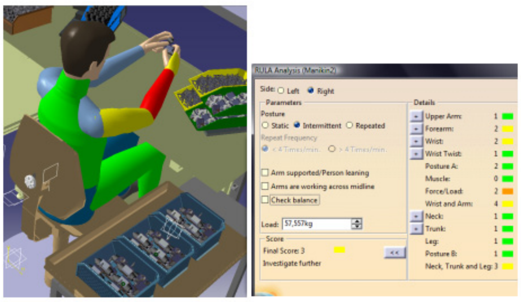

Fig. 9. Catia ergonomic analysis results

3.4 Videoanalysis

The further applicable tool dedicated to assembly support is the videoanalysis software developped and used at our department. On the Fig. 10 is presented an example of the software screenshot. This software application enables the detailed assembly operation analysis with the goal to determine the real assembly time, the operation structure and the assembly efficiency.

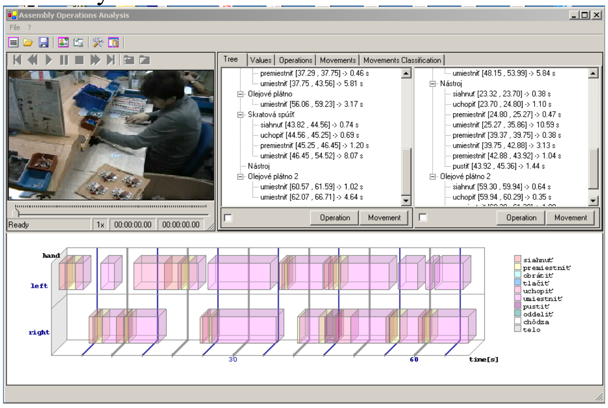

Fig. 10. Videoanalysis software screeshot

3.5 Data glove application

Data glove can be used as a tool in phases of workstation design and also as an tool to evaluate real assembly workstation.

In first case there is a possibility to simulate assembly process without have the real workstation and parts, and it is also possible to use numerous of analytics tools included in some CAD systems e.g. in CATIA it is RULA analysis, NIOSH, Push-pull analysis, Cary analysis etc. as it was mentioned in chapter 3.3.

In second case there is a possibility to make analysis of real workstation, by using data glove during assembly operation and recording movements and time (Fig. 11). Gained data are transferred to appropriate software and then they are processed. Result is finding out of ergonomics deficiencies of real assembly workstation (Fig. 12) and propose of actions to remove these deficiencies.

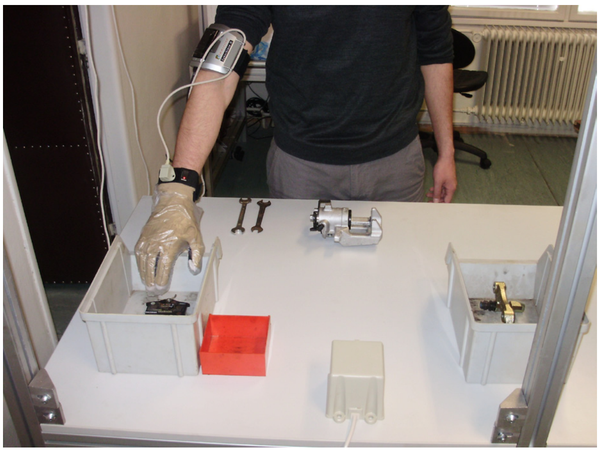

Fig. 11. Gaining data from real assembly process by using data glove

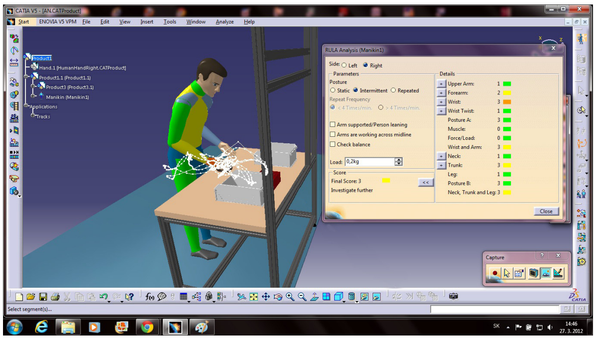

Fig. 12. Analysis of assembly process by using data gained by data glove

4. CONCLUSION

The key to “Lean” implementation is construction of workstations with components that are easily re-configurable. Modular structure of assembly system, and construction system kit, offer a wide range of variable components for the individual and flexible configuration of workstations. As a result, waste in production is minimized and available workspace is used effectively.
Modular components and accessories from building-block construction system are incredibly flexible and can be used to build everything from a simple workbench all the way up to a full assembly cell or even a production line. Workstations can be designed to accommodate a wide product mix and reconfigured if the process changes. Conveniences from modular kit can also be incorporated into a workstation to hold parts bins (which are compatible e.g. with Kanban systems). Continuous improvement is also simplified as the profiles and joints used to build the workstation can be rapidly changed during Kaizen events. Finally if the workstation is no longer required, it can be disassembled and the parts used to build other, e.g. frames structures.

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Preliminary Note

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A THEORETICAL STUDY ON SURFACE ROUGHING IN PURE BENDING OF VISCOPLASTIC SHEETS

Received: 17 June 2012 / Accepted: 11 August 2012

Abstract: *An analysis of plane-strain bending at large strains for a rigid viscoplastic incompressible material model is performed. The Mises-type yield criterion is adopted. The yield stress depends on the equivalent strain rate (the quadratic invariant of the strain rate tensor). The solution is combined with an empirical equation for surface roughness evolution.*
Key words: *Pure bending, large strains, viscoplasticity, surface roughing*

Teoretska studija o hrapavosti površine pri čistom savijanju viskoplastičnih limova. *U ovom radu je izvršena analiza ravanskog stanja napona pri savijanju visokog naprezanja, modela nekompresibilnog materijala. Kao tip ocene je usvojen Miseov tip kriterijuma. Napon zavisi od ekvivalentnog odnosa vrednosti napona (kvadratna invarijanta vrednosti naponskog tenzora). Rezultat je kombinovan sa empirijskom jednačinom za razvoj površinske hrapavosti.*
Ključne reči: *čisto savijanje, visoki naponi, viskoplastičnost, površinska hrapavost*

1. INTRODUCTION

Pure plane-strain bending at large strains is one of the classical problems in plasticity theory. A unified method to analyze this process for isotropic incompressible materials has been proposed in [1]. The method has been extended to a class of anisotropic materials in [2]. The process of bending can also provide some data for the empirical model for surface roughness evolution proposed in [3].

2. KINEMATICS

The approach proposed in [1] is based on the mapping between Eulerian Cartesian coordinates (x, y) and Lagrangian coordinates (ζ, η) in the form

$$\frac{x}{H} = \sqrt{\frac{\zeta}{a} + \frac{s}{a^2}} \cos(2a\eta) - \frac{\sqrt{s}}{a} \quad \text{and}$$
$$\frac{y}{H} = \sqrt{\frac{\zeta}{a} + \frac{s}{a^2}} \sin(2a\eta) \qquad (1)$$

where H is the initial thickness of the sheet, s is an arbitrary function of a, a is a function of the time, t, and $a = 0$ at $t = 0$. At the initial instant, $a = 0$,

$$s = 1/4 . \qquad (2)$$

Substituting Eq. 2 into Eq. 1 and applying l'Hospital's rule gives $x = \zeta H$ and $y = \eta H$ at the initial instant when the shape of the specimen is the rectangle defined by the equations $x = -H$, $x = 0$ and $y = \pm L$. The initial shape and the Cartesian coordinate system are shown in Fig. 1. It is possible to assume, with no loss of generality, that the origin of this coordinate system is located at the intersection of the axis of symmetry and surface AB throughout the process of deformation. An intermediate shape is also shown in Fig. 1. It is obvious that $\zeta = 0$ for AB and $\zeta = -1$ for CD throughout the process of deformation. According to Eq. 1, any intermediate shape is determined by two circular arcs, AB and CD, and two straight lines, AD and CB. These circular arcs coincide with coordinate curves of the plane polar coordinate system $r\theta$ defined by the following transformation equations

$$\frac{r}{H} = \sqrt{\frac{\zeta}{a} + \frac{s}{a^2}} \quad \text{and} \quad \theta = 2a\eta . \qquad (3)$$

Geometric parameters of the shape at any instant are given by (Fig. 1)

$$\frac{R_{AB}}{H} = \frac{\sqrt{s}}{a}, \quad \frac{R_{CD}}{H} = \sqrt{\frac{s}{a^2} - \frac{1}{a}},$$
$$\frac{h}{H} = \frac{\sqrt{s} - \sqrt{s-a}}{a} \qquad (4)$$

where R_{AB} is the radius of surface AB, R_{CD} is the radius of surface CD, and h is the current thickness of the sheet. It is possible to verify by inspection that the Lagrangian coordinates coincide with trajectories of the principal strain rates and that the mapping given by Eq.1 satisfies the equation of incompressibility at any instant. It will be shown in the next section that the assumption that the Lagrangian coordinates coincide with the trajectories of the stress tensor allows one to solve the stress equations.

In the case under consideration these two conditions (coincidence of the trajectories for the principal stresses and principal strain rates and the equation of incompressibility) are equivalent to the associated flow rule of the classical rate formulation of plasticity theory.

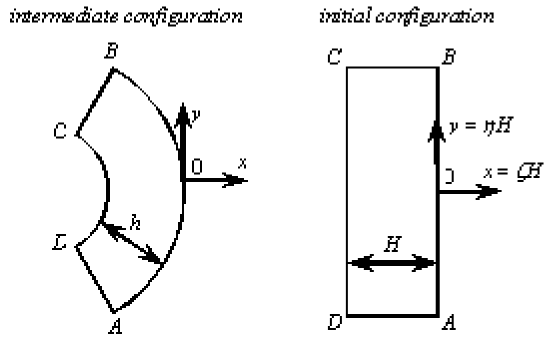

Fig. 1. Coordinate systems, initial shape and intermediate shape in pure bending.

The strain rate components can be found from Eq. 1 and, then, the position of the neutral line is determined by

$$\zeta = \zeta_n = -ds/da \ , \tag{5}$$

the equivalent strain rate by

$$\xi_{eq} = \frac{|\zeta + \mathrm{d}s/\mathrm{d}a|}{\sqrt{3}(\zeta a + s)} \frac{\mathrm{d}a}{\mathrm{d}t} \tag{6}$$

and the equivalent strain by

$$\varepsilon_{eq} = \frac{1}{\sqrt{3}} \ln\left[4(\zeta a + s)\right],$$

$$\varepsilon_{eq} = \frac{1}{\sqrt{3}} \ln\left\{\frac{\zeta a + s}{4\left[\zeta a_c(\zeta) + s_c(\zeta)\right]^2}\right\}, \tag{7}$$

$$\varepsilon_{eq} = -\frac{1}{\sqrt{3}} \ln\left[4(\zeta a + s)\right]$$

in regions 1, 2 and 3, respectively. In region 1, $0 \ge \zeta \ge -1/2$, the principal strain rate $\xi_{\zeta\zeta} < 0$ (and $\xi_{\eta\eta} > 0$) during the entire process. In region 3, $-1 \le \zeta \le \zeta_n^f$, the principal strain rate $\xi_{\zeta\zeta} > 0$ (and $\xi_{\eta\eta} < 0$) during the entire process. A property of all curves $\zeta = const$ in region 2, $\zeta_n^f \le \zeta \le -1/2$, is that each of these curves coincides with the neutral line at one time instant. Consider any ζ-curve of this class and denote a_c the value of *a* at which the curve coincides with the neutral line. Then, $\xi_{\zeta\zeta} < 0$ ($\xi_{\eta\eta} > 0$) at $a < a_c$ and $\xi_{\zeta\zeta} > 0$ ($\xi_{\eta\eta} < 0$) at $a > a_c$ for this curve. Obviously, the time instant at which the sign is changed depends on the curve such that $a_c = a_c(\zeta)$. The corresponding value of *s* will be denoted by $s_c(\zeta)$ where $s_c(\zeta) = s\left[a_c(\zeta)\right]$. These values of $a_c(\zeta)$ and $s_c(\zeta)$ are involved in Eq. 7. Also, ζ_n^f is the ζ-coordinate of the neutral surface at the end of the process. If $s(a)$ were known, Eq. 5 would determine $a_c(\zeta)$ and, therefore, $s_c(\zeta)$. Thus, $s(a)$ is the only unknown function in the analysis of kinematics and this function should be found from the analysis of stress.

3. STRESS ANALYSIS

The only non-trivial equilibrium equation in the plane polar coordinate system (r,θ) in terms of the radial and circumferential stresses has the form

$$\frac{\partial \sigma_r}{\partial r} + \frac{\sigma_r - \sigma_\theta}{r} = 0 \ . \tag{8}$$

It is obvious that $\sigma_r \equiv \sigma_{\zeta\zeta}$ and $\sigma_\theta \equiv \sigma_{\eta\eta}$. The plane-strain yield condition in the case under consideration is

$$\sigma_r - \sigma_\theta = \pm \frac{2}{\sqrt{3}} \sigma_0 \Phi\left(\xi_{eq}\right) \tag{9}$$

where the upper sign corresponds to the region $-1 \le \zeta \le \zeta_n$ and the lower sign to the region $\zeta_n \le \zeta \le 0$. Also, the function $\Phi\left(\xi_{eq}\right)$ satisfies the condition $\Phi(0) = 1$, σ_0 is the yield stress in tension at $\xi_{eq} = 0$. Using Eq. 3 it is possible to replace *r* and differentiation with respect to *r* with ζ and differentiation with respect to ζ in Eq. 8. Then, using Eq. 9,

$$\frac{\partial \sigma_r}{\partial \zeta} = \mp \frac{a\sigma_0 \Phi\left(\xi_{eq}\right)}{\sqrt{3}(\zeta a + s)} . \tag{10}$$

The function $\Phi\left(\xi_{eq}\right)$ should be prescribed and ξ_{eq} can be excluded by means of Eq. 6. The boundary conditions on the radial stress are

$$\sigma_r = 0 \tag{11}$$

for $\zeta = -1$ and $\zeta = 0$. Since there are the two boundary conditions for the differential equation of first order, the function $s(a)$ and, consequently, the neutral line position (see Eq. 5) should be found from the solution to Eq. 10 simultaneously with constant of integration. Also, the radial stress must be continuous across the boundary of the aforementioned regions 1, 2, and 3. Once the solution for stress components has been found, the bending moment per unit length is determined by integration [1]

$$M = \frac{H^2}{2a} \int_{-1}^{0} \sigma_{\theta\theta} d\zeta \ . \tag{12}$$

At the initial instant, the polar coordinate system (r,θ) transforms to the Cartesian coordinate system (x,y). In order to facilitate numerical solution of Eq. 10 for the initial stage of the process, the second derivative d^2s/da^2 at the initial instant can be found analytically.

4. SOLUTION FOR THE INITIAL STAGE OF THE PROCESS

Since the distribution of the damage parameter is uniform at the initial instant, $\zeta_n = -1/2$ at $a = 0$. Then, it follows from Eq. 5 that

$$ds/da = 1/2 \tag{13}$$

at $a = 0$. Moreover, at the initial instant

$$\sigma_r = 0 \quad \text{everywhere},$$

$$\sigma_\theta = \frac{2}{\sqrt{3}}\sigma_0 \Phi_0(\zeta)$$

in the range $1 \le \zeta < -1/2$, (14)

$$\sigma_\theta = -\frac{2}{\sqrt{3}}\sigma_0 \Phi_0(\zeta)$$

in the range $-1/2 < \zeta \le 0$.

The function $\Phi_0(\zeta)$ determines the through-thickness distribution of the function $\Phi(\xi_{eq})$ at the initial instant. Thus, it follows from Eqs. 2, 6 and 13 that

$$\Phi_0(\zeta) = \Phi\left(\left|\zeta + \frac{1}{2}\right| \frac{4}{\sqrt{3}} \frac{da}{dt}\right). \tag{15}$$

It is seen from this equation that the function $\Phi_0(\zeta)$ is symmetric relative to the neutral line. Therefore, it follows from Eq. 14 that $\int_{-1}^{0} \sigma_\theta d\zeta = 0$, as it should be in pure bending. The solution of Eq. 10 in the range $-1 \le \zeta \le \zeta_n$ satisfying Eq. (11) at $\zeta = -1$ can be written in the form

$$\sigma_r = -\frac{a\sigma_0}{\sqrt{3}} \int_{-1}^{\zeta} \frac{\Phi(\xi_{eq})}{(za+s)} dz \tag{16}$$

where z is a dummy variable of integration. Then, the radial stress acting at $\zeta = \zeta_n$ is

$$\sigma_{32} = -\frac{a\sigma_0}{\sqrt{3}} \int_{-1}^{\zeta_n} \frac{\Phi(\xi_{eq})}{(za+s)} dz\,. \tag{17}$$

The solution of Eq. 10 in the range $\zeta_n \le \zeta \le -1/2$ satisfying the boundary condition $\sigma_r = \sigma_{32}$ at $\zeta = \zeta_n$ can be written in the form

$$\sigma_r = \sigma_{32} + \frac{a\sigma_0}{\sqrt{3}} \int_{\zeta_n}^{\zeta} \frac{\Phi(\xi_{eq})}{(za+s)} dz\,. \tag{18}$$

Then, the radial stress acting at $\zeta = -1/2$ is

$$\sigma_{21} = \sigma_{32} + \frac{a\sigma_0}{\sqrt{3}} \int_{\zeta_n}^{-1/2} \frac{\Phi(\xi_{eq})}{(za+s)} dz\,. \tag{19}$$

Finally, the solution of Eq. 10 in the range $-1/2 \le \zeta \le 0$ satisfying the boundary condition $\sigma_r = \sigma_{21}$ at $\zeta = -1/2$ can be written in the form

$$\sigma_r = \sigma_{21} + \frac{a\sigma_0}{\sqrt{3}} \int_{-1/2}^{\zeta} \frac{\Phi(\xi_{eq})}{(za+s)} dz\,. \tag{20}$$

Substituting the boundary condition (11) at $\zeta = 0$ into Eq. 20 gives

$$\sigma_{21} + \frac{a\sigma_0}{\sqrt{3}} \int_{-1/2}^{0} \frac{\Phi(\xi_{eq})}{(za+s)} dz = 0\,. \tag{21}$$

Using Eqs. 5 and 19 it is possible to transform Eq. 21 to

$$I_1 + I_2 - I_3 = 0\,, \tag{22}$$

where

$$I_1 = \int_{-ds/da}^{-1/2} \frac{\Phi(\xi_{eq})}{(za+s)} dz, \quad I_2 = \int_{-1/2}^{0} \frac{\Phi(\xi_{eq})}{(za+s)} dz, \quad I_3 = \int_{-1}^{-ds/da} \frac{\Phi(\xi_{eq})}{(za+s)} dz \tag{23}$$

Differentiating each of these integrals with respect to a and, then, putting $a = 0$ and taking into account Eqs. 2 and 13 give

$$\left.\frac{\partial I_1}{\partial a}\right|_{a=0} = 4\left.\frac{d^2 s}{da^2}\right|_{a=0},$$

$$\left.\frac{\partial I_2}{\partial a}\right|_{a=0} = 4\int_{-1/2}^{0} \left.\left(\frac{d\Phi}{d\xi_{eq}}\frac{\partial \xi_{eq}}{\partial a}\right)\right|_{a=0} dz - 16\int_{-1/2}^{0} \Phi_0\left(z + \frac{1}{2}\right) dz,$$

$$\left.\frac{\partial I_3}{\partial a}\right|_{a=0} = -4\Phi_0 \left.\frac{d^2 s}{da^2}\right|_{a=0} - 4(1-D_0)\int_{-1/2}^{-1} \left.\left(\frac{d\Phi}{d\xi_{eq}}\frac{\partial \xi_{eq}}{\partial a}\right)\right|_{a=0} dz + 16\int_{-1/2}^{-1} \Phi_0\left(z + \frac{1}{2}\right) dz. \tag{24}$$

Since $\Phi(\xi_{eq})$ is a prescribed function of ξ_{eq}, the derivative $d\Phi/d\xi_{eq}$ at $a = 0$ can be found as a function of ζ by means of Eqs. 2, 6 and 13. The derivative $\partial \xi_{eq}/\partial a$ at $a = 0$ can be evaluated using Eq. 6. It is convenient to introduce the new variable γ by the equation $\gamma = \zeta + 1/2$. Then,

$$\left.\frac{\partial \xi_{eq}}{\partial a}\right|_{a=0} = \mp \mathrm{E}_0(\gamma), \quad \mathrm{E}_0(\gamma) = \frac{4}{\sqrt{3}}\left[\left.\frac{d^2 s}{da^2}\right|_{a=0} - 16\gamma^2\right]\frac{da}{dt}. \tag{25}$$

It is also convenient to introduce the following notation

$$\Omega(\gamma) = \mathrm{E}_0(\gamma)\left.\left(\frac{d\Phi}{d\xi_{eq}}\right)\right|_{a=0}. \tag{26}$$

Differentiating Eq. 22 with respect to a, using Eqs. 24 and Eq. 26, and replacing ζ with γ yield

$$2\left.\frac{d^2 s}{da^2}\right|_{a=0} + \int_0^{1/2} \Omega(\gamma) d\gamma - \int_0^{-1/2} \Omega(\gamma) d\gamma - \left[\int_0^{-1/2} \Phi_0 \left.\frac{\partial D}{\partial a}\right|_{a=0} d\gamma\right] - 4\left[\int_0^{-1/2} \gamma\Phi_0 d\gamma + \int_0^{1/2} \gamma\Phi_0 d\gamma\right] = 0 \tag{27}$$

It is seen from Eq. 25 that $E_0(\gamma)$ is an even function of γ. It follows from Eq. 6 that ξ_{eq} at $a=0$ is also an even function of γ. Therefore, $d\Phi/d\xi_{eq}$ being a function of ξ_{eq} is also an even function of γ at $a=0$. Finally, the definition for the function $\Omega(\gamma)$ given in Eq. 26 shows that it is an even function of γ. Then,

$$\int_0^{1/2}\Omega(\gamma)d\gamma-\int_0^{-1/2}\Omega(\gamma)d\gamma= \\ =\int_0^{1/2}\Omega(\gamma)d\gamma+\int_{-1/2}^{0}\Omega(\gamma)d\gamma=2\left[\Sigma_1\left(\frac{1}{2}\right)-\Sigma_1(0)\right] \quad (28)$$

where $\Sigma_1(\gamma)$ is the anti-derivative of $\Omega(\gamma)$. Analogously, it is seen from Eq. 15 that the function $\Phi_0(\zeta)$ involved in Eq. 27 can be replaced with an even function of γ, say $\Phi_1(\gamma)$. Then, the anti-derivative of the function $\gamma\Phi_1(\gamma)$ is an even function of γ, say $\Sigma_2(\gamma)$. Therefore, $\Sigma_2(1/2)=\Sigma_2(-1/2)$ and

$$\int_0^{-1/2}\gamma\Phi_0 d\gamma+\int_0^{1/2}\gamma\Phi_0 d\gamma= \\ =\Sigma_2\left(-\frac{1}{2}\right)-2\Sigma_2(0)+\Sigma_2\left(\frac{1}{2}\right)=. \quad (29) \\ =2\left[\Sigma_2\left(\frac{1}{2}\right)-\Sigma_2(0)\right]$$

Substituting Eqs. 28 and 29 into Eq. 27 leads to

$$\left.\frac{d^2s}{da^2}\right|_{a=0}=4\left[\Sigma_2\left(\frac{1}{2}\right)-\Sigma_2(0)\right]-\Sigma_1\left(\frac{1}{2}\right)+\Sigma_1(0). \quad (30)$$

The right hand side of Eq. 30 can be evaluated and, then, using Eqs. 2 and 13 the function $s(a)$ at the initial stage of the process can be approximated by

$$s(a)=\frac{1}{4}+\frac{a}{2}+\frac{1}{2}\left(\left.\frac{d^2s}{da^2}\right|_{a=0}\right)a^2. \quad (31)$$

5. SURFACE ROUGHNESS EVOLUTION

Having the solution for $s(a)$ it is possible to find the equivalent strain from Eq. 7 and the radial strain from Eq. 1. These two strains are involved in the empirical surface roughness evolution proposed in [3]. Thus the evolution of surface roughness in pure bending can be predicted and comparison with experimental data can be made.

6. CONCLUSIONS

The general solution proposed describes the process of pure bending of incompressible, rigid viscoplastic material al large strains. The dependence of the yield stress on the equivalent strain rate is quite arbitrary. Using the solution found and the empirical equation proposed in [3] the evolution of surface roughness can be predicted. Then, experimental data can be used to approximate the function involved in this empirical equation.

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Preliminary Note

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ISO 50001 AS THE BASIS FOR IMPLEMENTING AN ENVIRONMENTAL MANAGEMENT SYSTEM

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Abstract: *By the publishing of new standards for energy management system the international organization for stardardization provided a new type of tool for defining the possibilities for company cost reduction as well as for indirect protection of natural resources. This tool can make significant contribution to the field of environmental protection in this period of global economic instability. The majority of organizations are looking for ways to reduce their expences, and give priority to the economic aspect. The environment management system is determinant to provide the economic stabilization to the companies by applying the ISO 50001. This tool clearly demonstrates the company´s cost-saving options which might be of interest to a unilaterally minded management and it has direct interest in global environmental protection. This article discusses the possibility of using the standard as the first steps towards the introduction of an environmental management in companies with a defensive approach to environmental protection.*
Keywords: *environmental management, environmental protection, ISO 50001*

ISO 50001 kao osnova za implementaciju sistema upravljanja životnom sredinom. *Objavljivanjem novih standarda sistema upravljanja energijom međunarodna organizacija za stardardizaciju obezbeđuje novi tip standarda za definisanje mogućnosti smanjenja troškova kompanije kao i indirektnu zaštitu prirodnih resursa. Ovaj standard može da napravi značajan doprinos u oblasti zaštite životne sredine u ovom periodu globalne ekonomske nestabilnosti. Većina organizacija traže načine da smanje svoje rashode , kao i da daju prioritet ekonomskom aspektu. Upravljanje zaštitom životne sredine je odrednica da se obezbedi ekonomska stabilizacija u preduzećima primenom ISO 50001. Ovaj standard jasno pokazuje opcije ušteda troškova kompanije koji bi mogli biti od interesa jednostranog orijentisanog upravljanja i ima direktan interes u globalnoj zaštiti životne sredine. Ovaj rad govori o mogućnosti korišćenja standarda kao prvog koraka ka uvođenju ekološkog upravljanja u preduzećima sa defanzivnim pristupom zaštiti životne sredine.*
Ključne reči: *upravljanje zaštitom životne sredine, zaštita životne sredine, ISO 50001*

1. INTRODUCTION

Despite the growing environmental awareness, in practice market environment, the main attention is still often focused on economic considerations. Despite the increasing pressure of legislative proceeding in favor of environmental protection, many organizations are confronted to their respect and interest in the organizations of such a systematic approach to managing its environmental aspects. This approach mainly depends on the environmental awareness of top managers. If the oranization is not subject to direct pressure from their customers to implement an environmental management and if the top management is focused on achieving the best economic results, it is not possible to expect a proactive and systematic approach to managing environmental aspects and impacts of such an organization. Moreover, at the time of continuing economic instability in world markets and direct confrontation, small and large companies are concerned with the global economic crisis and in this case, economic stabilitization is achieved through the reduction of fixed costs. Therefore, logically it is not possible to expect the implementation of environmental management by the company that is not force to do so by their customers.

Implementation of environmental management system such as ISO 14001 is still seen by a lot of managers and top representatives of companies as something extra, which requires the input costs of ill-defined benefits or potential cost savings. This particularly works for organizations whose activities go few beyond, or even not achieve legislative defined emission or environmatal limits. Although the introduction of environamental management system was able to improve their environmental behavior, it is not considered necessary and economically as an unnecessarry investment. On the other hand, there is a standard that should rather supplement ISO 14001 as its basis, and the ISO 50001 for system energy mangement. For the above mentioned reasons it is possible to assume that the standard ISO 50001 that defines requirements for the energy management system can precede the introduction of ISO 14001 and make the base for simplified implementation of environmental management according to ISO 14001. Question like why should this be so, or could it have already been so, were already mentioned in introduction. However, it is necessary to analyze the reality of this possibility and futher discuss both standards and mainly analyze and compare their atractiveness and possibility of using them in a real market environment.

2. ISO 50001 STANDARD

a. Principle standards

The standard introduces principles guaranteeing the analysis of existing manufacturing processes, the reassessment of their use and the optimization of the use of production facilities and human resources. It deals with the management system and energy management in order to determine their optimal use and to achieve cost savings. It specifes the simple principle, the management of company define their goals and plans in the field of energy policy and these goals are gradually performed by the set of procedures and their effectiveness is measured and monitored by the organization to take effective precaution.

2.2 The contribution of standards for the organization

- It primarily deliveres significant energy savings in the main production process and it saves money on expenses.
- It helps to optimize the utilization of production equipment to lower consumption.
- It helps to optimize the organization of work in order to save heat, air - conditioning and lighting.
- It allows to influence future consumption when planning future productin capacity.
- It confirms the importance of integration and optimization of quality management systems, energy management and environmental protection [1].

2.3 Advantage and disadvantage of standards:

+ Standard is an excellent tool for any organization because it constitutes a significant energy savings what is confirmed by several studies and practical applications even if only for a relatively short period.

- Due to the short history of ISO 50001 it is necessary to wait to detect any deficiencies.

3. ISO 14001 STANDARD

a. Principle standards

The standard defines a simple methodology, that management of the company define goals and plans in the field of environmental aspects and impacts of their activities (although only complete the legal limits). These plans and goals are gradually accomplished with appropriately configured procedures, which are monitored and measured in order to take effective steps for changes if needed. Standard imposes upon requirements for document management, human resources, infrastructure, implementing processes to communicate with the authorities and the public, and it is allowing the measurement of process performance through internal audits.

b. The contributions of organization are:

- An effective tool to manage effects of the organization's activities on the environment.
- Create a reputation of a prestigious company in the field of environmental protection.
- Reduce future costs resulting from the planning production of infrastructure especially in conjunction with the quality management system.
- Early recognition of problems and prevent any accidents, effective risk management.
- Providing more guarantees for the fulfillment of legislative requirements.
- Energy and material resources savings [2].

3.3 Advantages (+) and disadvantages (-) of standards

+ Standard is a good tool for helping to achieve the accomplishment of legal requirements in the field of environmental protection by reducing the risk of unexpected accidents. It is universal and applicable in all areas of human activites. Its structure is suitable for integration with other standardized management systems.

- Certificate ISO 14001 is often underestimated by the authorities and also top leaders of organizations even if companies which are certificated present significantly lower risk with legal requirements and the emergence of unexpected events with negative impact on the environment.

4. STRUCTURE OF STANDARDS

As follows from the above brief summary and the descriptions of both standards it is not necessary to analyze and compare the structures of both standards in terms of the utilization of the structures of a system for the subsequent implementation of the second one.

As every ISO standards for management systems these are also based on uniform PDCA cycle methodology. It facilitates the introduction of multiple systems using a single structure and therefore it supports the development of integrated management systems. The same philosophy is shared by ISO 50001, as it was assumed that this standard will be integrated into environmental management system ISO 14001 and it will create a superstructure that is more detailed and focused on energy issues. From a technical point of view it is possible to conclude that the using of established structures of energy management according to ISO 50001 it is sebsequent possibble for subsequent simplified implementation of environmental management system according to ISO 14001. Whether and why this process of introducing an energy and environmental management should be relevant in practice, it is determinated by top representatives of the organizations themselves. They usually assess it in terms of attractiveness or standards for achieving its economic goals.

5. ACCTRACTIVENESS OF STANDARDS

When it comes to assessing the attractiveness of standards it is important to take into account in particular and within specific standards the awereness and attitude of the organization itself and its top managers. Top managers of companies are the people who define the strategy and development of a given company and therfore they take the decision concerning the introduction of management systems and their subsequent certification. Organizations that have not been forced to introduce an environmental management system and have not felt the need to systematically manage their environmental aspects and risks, will hardly look for motivation and the reasons for introduction of the ISO 14001 system even though their economical activities have achieved a signifacant succsess. Top managers of such organizations perceive environmental management system as surplus and their environmental awareness of the issue is purely financial. They do not see saving opportunities that a properly implemented and maintained environmental management system offers mainly with the possibility of reduction of material inputs and waste generation etc. The belief that a standard and system established according to the standard will help them improve those factors is small and standard or potential certification is less actractive. Perhaps this is due to the relatively poor marketing and proven results. Despite of the great popularity of ISO 14001 as the second most widely certified management system in the world, the importance and benefits of the quite well-established standards is limited only for opporturnity to better manage environmental risks and increase the company´s image. For the unilaterally economically minded managers the ambition of economic stabilization of the firm that could exist on the market wihout ISO 14001 certification, the above mentioned arguments are not so attractive and their effort to reduce total fixed costs of the organization is not convincing.

For so-minded managers is newly published standard for energy management system ISO 50001 more attractive. This standard presents clearly the main purpose of energy saving and its efficient and economic use. For this reason, it can be assumed to be a useful tool for a wide range of top managers. Partly for those who consider only economically it offers an opporturnity and for those who see the benefits of savings in addition to the standards in the environmental sphere. There is a matter of time that ISO 50001 will be adopted and supported by the management and introducion of an energy management system [3]. Of course, the motivation is saving company‘s costs. In the case that a system of energy management really shows savings energy costs in the company, it will have strong support in the leadership of the organization. Bulding and improving such a system will be a priority for top managers and therefore can be assumed that the overall structure and operation of system will be in the high level. Based on this strong and correctly maintained structure of the energy management system it is possible implement without significant cost even the environmental management system. The decision ot top management of organization concerning the introduction of ISO 14001 after previous good experience with ISO 50001 is easier than in the case of a decision to introduce ISO 14001 with no previous experience with the successful ISO 50001. In addition, built structure of the energy management system brings benefits in the form of savings and it is useful for environmental mangement system and thereby saves many other costs that the company would have to spend in independent implementation of ISO 14001. In this case, any small requirement to the introduction ISO 14001 with „stakeholders“ by top managers is more acceptable than if they were venturing into the implementation of ISO 14001 from the beginning and separately [4].

Based on the above it can be alleged that the road to implementing an environmental managment system could be easier and more acceptable to the dismissive minded managers through successfully implemented energy management system according to ISO 50001.

6. CONCLUSION

Unilateraly economically minded managers are often negative for the introduction of standardized management systems such as ISO 14001. Their priority is saving costs and the introduction of environmental management system is perceived as additional costs. As shown in the article, that managers need the tool that offer a clear opportunity for cost savings. The energy management system according to ISO 50001 is such a tool. After the successful implementation and demonstration of the economic benefits of energy management, top managers are more willing to agree to the implementation of other tools. Throughout the structure already built within the system it is possible to introduce more systems e.g. EMS according to ISO 14001 with a much lower entry costs.

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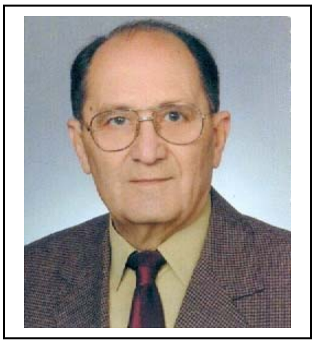
IN MEMORIAM

Prof. Dr. Jožef Rekecki (1930–2013)



As quietly as he had lived, on Saturday, January 26, after a long and grueling illness, died our esteemed Dr. Jožef Rekecki, Professor of the Faculty of Technical Sciences in Novi Sad.

Jožef Rekecki was born in 1930, in Kanjiža. He finished elementary school in Trešnjevac, gymnasium in Senta, and graduated from the Faculty of Mechanical Engineering in Belgrade, in 1956. In Budapest, 1975, he received Ph.D. degree.

Dr. Rekecki began his professional career in 1954, with the "Potisje" machine tool factory in Ada, first as a designer engineer, then head of the design department, and finally as managing director. Since 1964, he spent two years at Machine tools and cutting tools bureau in Novi Sad as the chief machine tool designer. His university career began in parallel, in 1965, when he took up teaching Machine tools at the Faculty of Mechanical Engineering in Novi Sad.

Starting as a part-time lecturer, and then, next year, entering the tenure track, Prof. Rekecki had 26 years of very fruitful university career. To meet the requirements of laboratory classes and research, he founded a modern equipped Laboratory for Machine Tools and contributed to development and promotion of young scientists. More than one hundred engineering bachelors, five MSc. and four Ph.D. candidates received their degrees under his guidance. He authored and co-authored eight books and over a hundred scientific and professional papers.

Professor Rekecki was a designer engineer of exquisite talent. His long career was strewn with remarkable professional achievements. Prior to joining the Faculty, he had completed a number of projects related to development of novel machine tool designs and devices. During his university career, Prof. Rekecki managed a large number of research projects, either within the Laboratory for machine Tools or within the special development bureau, IPM-POTISJE PROJEKT, located at the Institute for Manufacturing Engineering, which he helped establish. This effort resulted in design solutions which were incorporated in the most advanced machine tools of that time manufactured by POTISJE, Ada, Livnica KIKINDA, Kikinda, MAJEVICA, Bačka Palanka, POBEDA-IMO, Novi Sad, and successfully sold on domestic market and abroad.

Besides being head of Laboratory for Machine Tools, Prof. Rekecki also performed duties of the head of chair, Institute director, and vice-dean for research at the Faculty of Technical Sciences.

For his fruitful and dedicated work, Prof. Rekecki received numerous awards: Order of Labour with silver wreath, Vojvodina Liberation Award, Charter and Plaque Prof. Dr. Pavle Stanković, Charter and Plaque of the Faculty of Technical Sciences, University of Novi Sad, Life Award Gold Plaque, etc.

The retirement in 1990 did not mean giving up his work. Prof. Rekecki continued to be a valuable advisor and consultant to his younger colleagues and took part in everyday research and professional activities at the Faculty, Institute, and his Laboratory for Machine Tools.

Respecting the wish of Prof. Rekecki, his earthly remains were buried without prior announcement, on January 29, in the presence of his family, relatives and closest friends.

We, his associates, colleagues, former students, and admirers of his devoted work, shall always hold **Professor Jožef Rekecki** in dear memory**.**

INSTRUCTIONS FOR CONTRIBUTORS

No. of pages:	4 DIN A4 pages
Margins:	left: 2,5 cm
	right: 2 cm
	top: 2 cm
	bottom: 2 cm
Font:	Times New Roman
Title:	Bold 12, capitals
Abstract:	Italic 10
Headings:	Bold 10, capitals
Subheadings:	Bold 10, small letters
Text:	Regular 10
Columns:	Equal column width with 0,7 cm spacing
Spacing:	Single line spacing
Formulae:	Centered and numerated from 1 in ascending order. Equations must be typed in Equation Editor, with following settings: Style>Math – Times New Roman Size>Full 12pt, Subscript/Superscript 7pt, Symbol 18 pt
Figures:	High quality, numerated from 1 in ascending order (e.g.: Fig.1, Fig. 2 etc.); Figures and tables can spread over both two columns, please avoid photographs and color prints
Tables:	Numerated from 1 in ascending order (e.g..: Tab. 1, Tab. 2, etc.)
References:	Numerated from [1] in ascending order; cited papers should be marked by the number from the reference list (e.g. [1], [2, 3] ...)
Submission:	**Papers prepared in MS Word format should be e-mailed to: pkovac@uns.ac.rs, savkovic@uns.ac.rs**
Notice:	**Papers are to be printed in Journal of Production Engineering** Sample paper with detailed instructions can be found at: **http://www.jpe.ftn.uns.ac.rs/**

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