ČASOPIS ZA MAŠINSKO INŽINJERSTVO
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MAŠINSTVO

Časopis je evidentiran u evidenciji javnih glasila pri Ministarstvu nauke, obrazovanja, kulture i sporta Federacije Bosne i Hercegovine pod brojem 651.

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The journal publishes scientific and professional papers and information of interest to the professionals and industry subjects in the field of mechanical engineering and branches related to the field of application and study of mechanical engineering.

The following topics are treated in particular:
> mechatronics, automation and robotics,
> metal, plastic and rubber processing technology,
> design and construction of machines and facilities,
> design of production systems,
> energy and ecology,
> maintenance of means for working and systems,
> quality, system efficiency and management of production and business systems,
> information on new books,
> information on scientific conferences,
> information from the University.

RIJEČ UREDNIKA

Poštovane kolegice i kolege,

mnogobrojni autori su dali određene definicije nauke, kao i pojmova vezanih za nju. Prema enciklopediji Wikipedia, nauka je sistem sređenih i sistematiziranih znanja o nama i svijetu koji nas okružuje. Naučni metod, kao standard za nauku, objedinjuje korištenje pažljivog posmatranja, eksperimente, mjerenja, matematiku i ponavljanje. Korištenje naučnih metoda za dostizanje novih otkrića se naziva naučno istraživanje. U modernom svijetu, naučna istraživanja su najvažnije aktivnosti svih razvijenih država, i od naučnika se očekuje da objave svoja otkrića u referentnim časopisima, naučnim periodicima, gdje recenzenti provjeravaju navedene naučne rezultate, prije nego što se rad objavi.

Upravo u vezi s gore navedenim, časopis MAŠINSTVO ima dugogodišnju misiju doprinosa u oblasti objavljivanja naučnih dostignuća u oblasti tehnike.

U ovom dvobroju časopis MAŠINSTVO nudi četiri rada iz različitih tematskih oblasti: optimizacija elemenata režima obrade pomoću planiranog eksperimenta, primjena metoda Monte Carlo za optimizaciju matematičkog modela hrapavosti površine, matematička i numerička analiza odnosa između Loschmidtove konstante, Avogadrove konstante i brzine zvuka u realnim plinovima kod različitih termodinamičkih svojstava, istraživanje govornih vještina na engleskom jeziku u inženjerskoj CLIL nastavi.

U cilju predstavljanja naučno-istraživačkih i stručnih kapaciteta časopis slijedi nove trendove i prakse u multidisciplinarnim područjima.

U sklopu odjeljka 'Uputstvo za autore' date su osnovne smjernice za pripremu i pisanje radova. Planirano je da od narednog broja radovi moraju biti isključivo na engleskom jeziku. Sve uvažene kolegice i kolege, pogotovo naše mlade kolegice i kolege sa svih univerziteta i ostalih srodnih institucija, ljubazno pozivamo da uzmu učešće u objavljivanju rezultata svojih naučno-stručnih istraživanja u okviru ovog časopisa, a koji predstavlja značajan projekt Mašinskog fakulteta Univerziteta u Zenici i priliku za predočavanje naučno-istraživačkih i stručnih rezultata istraživanja iz naglašenih i srodnih tematskih oblasti.

U posebnim odjeljcima nastavlja se tradicija prezentacija naučno-istraživačkih i privrednih kapaciteta iz okruženja.

S poštovanjem,
Fuad Hadžikadunić, glavni i odgovorni urednik

INTRODUCTION BY THE EDITOR-IN-CHIEF

Dear colleagues,

Numerous authors have given certain definitions of science, as well as terms related to it. According to the encyclopedia Wikipedia, science is a system of organized and systematized knowledge about us and the world around us. The scientific method, as a standard for science, combines the use of careful observation, experiments, measurements, mathematics, and repetition. Using scientific methods to make new discoveries is called scientific research. In the modern world, scientific research is the most important activity of all developed countries, and scientists are expected to publish their findings in reference journals, scientific periodicals, where reviewers check the stated scientific results, before publishing the work.

Given the above, the Journal of mechanical engineering MAŠINSTVO has a long-lasting mission of contributing to the publication of scientific achievements in the field of technology.

In this double issue, the Journal of mechanical engineering MAŠINSTVO offers four papers from different thematic areas: optimization of elements of the cutting processing regime using a planned experiment, application of Monte Carlo method for optimization of the mathematical model of surface roughness, mathematical and numerical analysis of the relationship among Loschmidt's constant, Avogadro's constant and the speed of sound in real gases at different thermodynamic properties, and a research into the English language speaking skills in engineering CLIL instruction.

In order to present scientific-research and professional capacities, the Journal follows new trends and practices in multidisciplinary areas.

The 'Guidelines for Authors' section provides basic guidelines for preparing and writing papers. As previously planned, all papers for (and from it on) the next issue will have to be written only in English. We kindly invite all esteemed colleagues, especially our young colleagues, from all universities and other related institutions, to take part in publishing the results of their scientific and professional research within this Journal, which is a significant project of the Faculty of Mechanical Engineering of University in Zenica and provides the opportunity for presentations of scientific research and professional research results from highlighted, and related, thematic areas.

In relevant sections, we continue the tradition of presenting scientific-research and economic capacities from our environment.

Sincerely,
Fuad Hadžikadunić, Editor-in-Chief

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CUTTING CONDITIONS OPTIMIZATION BY MEANS OF DESIGN OF EXPERIMENT

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Izlaganje s naučnog skupa

REZIME
Postoji mnogo načina za ostvarivanje optimizacije procesa obrade. U eksperimentalnom dijelu ovog rada, optimizacija obrade je ostvarena s aspekta režima obrade kao nezavisnih varijabli (brzina, posmak i dubina), a zavisne varijable se odnose na hrapavost površine, tačnije, srednje aritmetičko odstupanje visina površine i rezultantne sile rezanja, koja se sastoji od glavne, posmične i sile prodiranja. Nakon što se formira matrica eksperimentalnog plana, na osnovu potpunog višefaktornog plana sa osam tačaka, sa prethodno utvrđenim donjim, srednjim i gornjim nivoom ulaznih režima rezanja struganja, pristupilo se eksperimentu.
Nakon što su dobijeni odgovarajući rezultati hrapavosti površine, koji su izmjereni pertometrom, kao i vrijednosti sila izmjerene dinamometrom, pristupilo se optimizaciji procesa obrade prethodno definiranim metodologijama, opisanim u ovom radu.

Conference paper

SUMMARY
There are many ways to accomplish optimization of machining process. In the experimental part of this paper, the optimization of machining process is accomplished from the aspect of cutting conditions, which are independent variables (speed, feed, and cutting depth), whereas the dependent variables refer to the surface roughness, more precisely, arithmetic average of surface heights and resultant cutting force, including main cutting force, feed force and thrust force. Once the matrix of the experimental plan has been created, on the basis of a complete multifactor plan with eight points, with previously determined upper, middle and lower levels of cutting parameters for turning, the experiment followed.
Once the results of surface roughness were measured by perthometer, as well as results of cutting forces by dynamometer, the optimization of machining process was treated by means of predetermined methodologies, described in this paper.

1. INTRODUCTION

In contemporary manufacturing systems, the surface finish plays one of the most crucial roles when it comes to the characteristics of workpieces due to special requirements for specified surfaces that are to be machined upon a special request of customers. Naturally, not only the cutting parameters play a dominant role regarding quality of surface finish, but many other factors are responsible for it, such as machine stiffness, kinetic parameters, tool geometry, and so on. However, it is much easier to manipulate machining parameters, and this is why they play a crucial role in machining optimization and are mostly chosen for such activities. Optimization is very important when it comes to cutting technology and a lot of studies have been carried out for this purpose. It is important to mention that there are many methods that give us the possibility of

optimization such as Taguchi method, Simplex method, Linear programming method, Method based on Sylvester's criteria, Genetic algorithmic approach, Approach based on Neural Networks and so on. In addition, some papers that covered named methods are given below. For example, in [2], the algorithmic approach for optimization of surface roughness is used.

This methodology allows to acquire the range of surface roughness values, and their corresponding optimum cutting conditions. In paper [3] is used Sylvester's criteria to obtain optimization of the percentage of lean to machining conditions and workpiece material microhardness. When it comes to papers [4, 7, 8, 9, 10], Taguchi method is used to obtain optimization. Regarding S/N ratio, they concluded the optimum point of experiment, in dependence of which approach is used. In every single quoted paper same methodology is used for optimization in various industrial environments and for various conditions regarding machining. Furthermore, in paper [5], neural networks (NN) are used and proper methodology with outcome optimization is shown. The feedforward NN and radial basis NN are used and based on available time for training and testing and by means of required accuracy, it is easy to choose proper NN. It is important to mention surface response methodology [11,12]. Based on the chosen design and determined values of input variables, optimal point or interval, where we can find optimum, can be obtained. In the light of the aforementioned facts, knowing a specific methodology for the purpose of achieving the best results in the shortest time possible is vital considering that manufacturing of products, as well as the time frame, have been shortened. Therefore, the pivotal role of technological-engineering in production is to specifically achieve such results of cutting parameters either in the shortest time frame possible or cost effective, or else obtain the required product of desired quality including both dimensions and shape, as well as the surface roughness.

2. DESIGN OF EXPERIMENT

Design of experiment (DOE) is powerful analysis tool for modeling and analyzing of the process effect. The application design of experiment is able to reduce the experiment expenses. The design of the experiment method is an effective approach to optimize the various cutting parameters of machining processes. The most commonly used terms in the DOE methodology include: controllable and uncontrollable input factors, responses, hypothesis testing, blocking, replication and interaction. Controllable input factors are those input parameters that are in complete control of the designer and can be modified during the process. Uncontrollable input factors are the parameters that cannot be changed or controlled by the designer. These factors need to be recognized to understand their effects on the responses, or output. The responses are the elements of the process outcome that gauge the desired effect. The controllable input factors can be altered, so as to optimize the output. The relationship between the factors and responses is shown in Figure 1. In the case of this paper, controllable input factors are cutting speed, feed and depth, cutting tool, conventional lathe and coolant. Output measures are surface roughness and cutting forces, while uncontrollable factors are, for instance, metallurgy and behavior of workpiece.
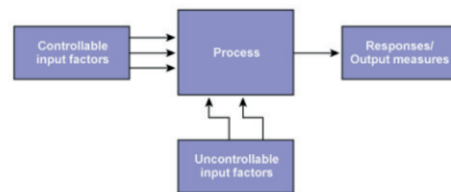
Figure 1 *Process Factors and Responses [13]*

In the turning process, these cutting parameters were selected as the independent input variables. The surface roughness and uses of cutting tool were assumed to be affected by the above three principal cutting parameters as the output responses.

2.1. The first case of gradient method

Optimal plans belong to the group of experimental plans and, therefore, rely on planned experiment theory, in which presence of regression analysis and proper methodology growingly conform with the first gradient method case, which has been used for optimization in this paper. Multifactorial linear regression is described by a formula below [1]:

$$Y = b_o + \sum_{i=1}^{k} b_i x_i \qquad (1)$$

b_0, b_i – coefficients of regression

x_i – input variables

λ – parameter, calculated from relation:

$$\lambda = \frac{\mu}{|b_b|} \qquad (2)$$

b_b - coefficient regression value for which is

$$max(b_i w_i) \wedge 0 < \mu < 1.$$

3. EXPERIMENTAL SETUP
Experimental research conditions include: cutting of all segments, performed by a mechanically fastened turning insert, serial number CNGA 120408T, where the cutting without cooling was performed on conventional *Potisje ADA* lathe, serial number MA50. The indicators of quality surface finish were measured by perthometer Mahr and, additionally, cutting forces were measured by means of dynamometer, as well. The workpiece material was made from constructional steel, serial number St 52-3 with diameter $\varnothing52$.

Figure 2 Potisje ADA *conventional lathe*

Table 1 Mechanical and chemical properties of workpiece

Material	Index			Ultimate strength	Modul of elasticity E	Poisson's ratio ν
	EN 10027-1	DIN	JUS	490		
Structural steel	S355J2	St 52-3	Č.0562		$2{,}1 \cdot 10^5$	0,3
Chemical structure	C	Si	Mn	P	S	
	$\leq$ 0,24	$\leq$ 0,55	$\leq$ 1,6	$\leq$ 0,035	$\leq$ 0,03	

3.1. Cutting Conditions Optimization Using First Case of Gradient Method
The main goal of this research is to establish the optimal cutting parameters that result in minimum value of surface roughness based on the aforementioned methodology. Firstly, it is necessary to define a plan matrix. A full factorial plan of experiment with 2^3 points without repetition will be used. The experiment plan matrix is shown in Table 2. It is important to pinpoint that relevant factors regarding output of surface roughness are, in fact, cutting parameters and, thus by varying them, the very experiment

is accomplished. Once the plan matrix is established, it is necessary to determine the upper, middle and lower level of natural values that correspond with coded values from the matrix. Moreover, it is pivotal to ascertain an equal interval between the levels to continue the procedure.

Table 2 Plan matrix of research

Points	x_0	x_1	x_2	x_3	v	s	a
1	1	1	1	1	150	0.196	1.5
2	1	1	-1	1	150	0.05	1.5

3	1	-1	-1	1	50	0.05	1.5
4	1	-1	-1	-1	50	0.05	0,5
5	1	1	1	-1	150	0.196	0.5
6	1	1	-1	-1	150	0.05	0.5
7	1	-1	1	-1	50	0.196	0.5
8	1	-1	1	1	50	0.196	1.5

Following the turning process done on lathe, the values of surface roughness have been measured by perthometer. The parameters of surface roughness on cylindrical workpieces have been measured on three points, precisely, every 120 degrees. Moreover, the mean value has been used for further calculations.

Table 3 Results of experiment

Points	x_0	x_1	x_2	x_3	R_a
1	1	1	1	1	1.39
2	1	1	-1	1	1.118
3	1	-1	-1	1	1.799
4	1	-1	-1	-1	2.324
5	1	1	1	-1	1.415
6	1	1	-1	-1	0.774
7	1	-1	1	-1	4.105
8	1	-1	1	1	1.825

The table above plainly shows the minimum value of surface roughness has been acquired at sixth point by using maximum speed, minimum level of feed and minimum level of cutting depth. It is well known that with increasing of cutting speed comes increase of surface quality. Furthermore, cutting speed is a major factor for surface quality. According to the Microsoft Excel chart and Data Analysis features, a variance analysis (ANOVA) has been executed. Based on ANOVA analysis results, regression coefficients, as well as significance test, have been formed.

Table 4 Regression statistics and ANOVA

Regression Statistics	
Multiple R	0,844548935
R Square	0,713262903
Adjusted R Square	0,498210081
Standard Error	0,728675682
Observations	8

	df	SS	MS	F	Significance F
Regression	3	5,2831665	1,7610555	3,316687015	0,138525203
Residual	4	2,123873	0,53096825		
Total	7	7,4070395			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	1,84375	0,257625758	7,156698978	0,002017367	1,128466225
v	-0,6695	0,257625758	-2,59873082	0,060128398	-1,384783775
s	0,34	0,257625758	1,319743812	0,257384747	-0,375283775
a	-0,31075	0,257625758	-1,20620702	0,29420054	-1,026033775

According to the Student's test, it has been concluded that only speed parameter plays a significant role because:

$$t_{rač} = |-2{,}59874| > t_{n-2, \alpha=0,05}$$
$$= 2{,}447$$

(3)

while the first order model, in fact, encompasses both the effect of feed rate and depth of cut;

$$Y = b_o - b_1 \cdot v + b_2 \cdot s - b_3 \cdot a, \qquad (4)$$

When the regression coefficients have been enlisted respectively:

$$Y = 1,8437 - 0,6695 \cdot v + 0,34 \cdot s - 0,311 \cdot a \qquad (5)$$

Intervals of cutting parameters are:

$$w_1 = 50, w_2 = 0.071, w_3 = 0.5 \qquad (6)$$

It is necessary to set interval multiplication and regression coefficients:

$$b_1 w_1 = -33,475 \qquad (7)$$
$$b_2 w_2 = 0.02414$$
$$b_3 w_3 = -0.15538$$

Once the products have been established and the maximum influential product chosen, thus is $max\,(b_i w_i)$, in this case $b_1 w_1 = -33,475$.

Furthermore, with the determined maximum product, the regression coefficient corresponding to that product has been used to specify the parameter λ.

$$(0 \le \mu \le 1) - 0,8 \qquad (8)$$

$$\lambda = \frac{0.8}{0.6695} = 1,194 \qquad (9)$$

Afterwards, the step representing the product $\lambda b_i w_i$ has been specified as shown below:
$$\lambda |b_1 w_1| = 40$$
$$\lambda b_2 w_2 = 0.0288$$

$$\lambda |b_3 w_3| = 0.1856 \qquad (10)$$

Given amounts are rounded and added to a basic natural value level of cutting parameters.

Moreover, the plan matrix is formed in natural coordinates. To obtain the output model, performing coding according to the D optimality in natural coordinates is mandatory.
Coding the factors is maintained according to the formula:

$$X_i = \frac{x_i - x_{oi}}{\frac{x_{imax} - x_{imin}}{2}} \qquad (11)$$

Meaning:

$$x_{oi} = \frac{x_{max} + x_{min}}{2} - \text{mean value}$$
$$X_1 = \frac{x_1 - 100}{50} = 0.02x_1 - 2$$
$$X_2 = \frac{x_1 - 0.124}{0,071} = 14.08x_2 - 1.74 \qquad (1)$$
$$X_3 = \frac{x_3 - 1}{0.5} = 2x_3 - 2$$

Obtained equations are inserted into the inital linear model resulting in the output equation for R_a.

$$Y = 3.21265 - 0.01339X_1 + 4.7879X_2 - 0.6125X_3$$

$$(2)$$

A new chart containing six additional points, where speed and cutting depth ascend with obtained patch, whereas the feed descends, is formed. Such conditions seemingly contribute to the enhancement of surface finish.

Table 5 New experimental points of the research and results of first two points after machining

New points	v	s	a	n	Y model	s	a	N	R_a
9	140	0.095	1.2	856.98	1.047	0.098	1.2	910	1.087
10	180	0.066	1.4	1101.84	0.24	0.062	1.4	1100	0.873
11	220	0.037	1.6	1346.69	-0.5				
12	260	0.008	1.8	1591.54	-1.3				
13	300	-0.021	2	1836.40	-2.1				
14	340	-0.05	2.2	2081.25	-2.9				

Based on the obtained values of cutting parameters, machining is implemented with approximate cutting modes, as it is a stepped gear that can only achieve certain values.

Moreover, the negative values have been rejected and thus the initial two points have been processed. This indicates that increasing velocity effect is powerful to contribute to a nullification of the action referring to the free linear regression factor.

3.2. Example of Taguchi Method Optimization

During the experiment, cutting forces were measured by means of dynamometer Kistler and signals saved in the suitable Dynoware software. Mean values of three cutting forces were acquired and resultant forces for every point were calculated with the following formula:

$$F_R = \sqrt{F_1^2 + F_2^2 + F_3^2} \tag{3}$$

$F_1 -$ the main cutting force

$F_2 -$ feed force

$F_3 -$ thrust force

Table 6 Plan matrix of research with corresponding resultant cutting forces

L8	v	s	a	F_{rez}	S/N ratio
1	1	1	1	98,20	-39,8
2	1	1	2	343,61	-50,7
3	1	2	1	227,42	-47,1
4	1	2	2	1072,56	-60,6
5	2	1	1	145,22	-43,2
6	2	1	2	351,98	-50,9
7	2	2	1	308,31	-49,8
8	2	2	2	790,70	-58

The data in the table above are adjusted to easily obtain input into the Minitab. Upper level is 2, and lower level in defined as 1. Taguchi method is a simple and efficient method for optimization approach. This uses two main tools signal to noise ratio and orthogonal array. Signal to noise ratio gives quality characteristic with respect to variation in process and orthogonal array adjusts many design factors in logical combination, which gives better results in less experimental runs and hence reduces time for experiment [7]. Taguchi experimental plan was used in the form of orthogonal arrays and linear graphs that give different combinations of parameters and their levels for each experiment. Based on this technique, the entire parameter space with the minimum number of experiments was used. This is a very powerful tool when the process is influenced by a large number of parameters. In Taguchi design, the choice of orthogonal arrays and appropriate linear graph are very important in order to draw valid conclusions after conduction of experimental runs. Table 6 shows Taguchi orthogonal arrays L8(2^7); eight experimental runs with two levels of the each seven factors. Common L8 orthogonal array is given bellow.
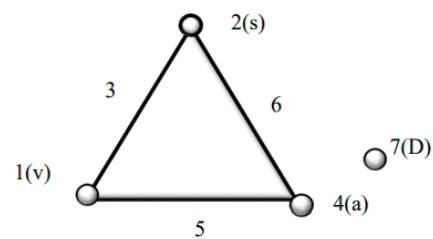
Figure 4 Standard linear graph for L8 array [14]

In this paper, *Smaller is better* approach is used. Besides, there are two other approaches: *Nominal is better* and *Larger is better*.

S/N ratio formula for *Smaller is better* approach is:

$$S/N_s = -10 \cdot \log\left(\frac{1}{r}\sum_{i=1}^{r} y_1^2\right) \tag{4}$$

Mean values for upper and lower levels are calculated in the table below based on the table 6. For example, for the lower level of cutting speed, first four rows are summed and divided by four. In the next chapter, following results and conclusions are given and it would be explained on which cutting condition levels would be obvious to expect optimal values of resultant cutting force.

Methodology for Taguchi optimization applied in this chapter of research paper is given bellow. In addition, Table 8 is created from the Table 6 as average of S/N ratios for upper and lower levels to determine the rank of significance.
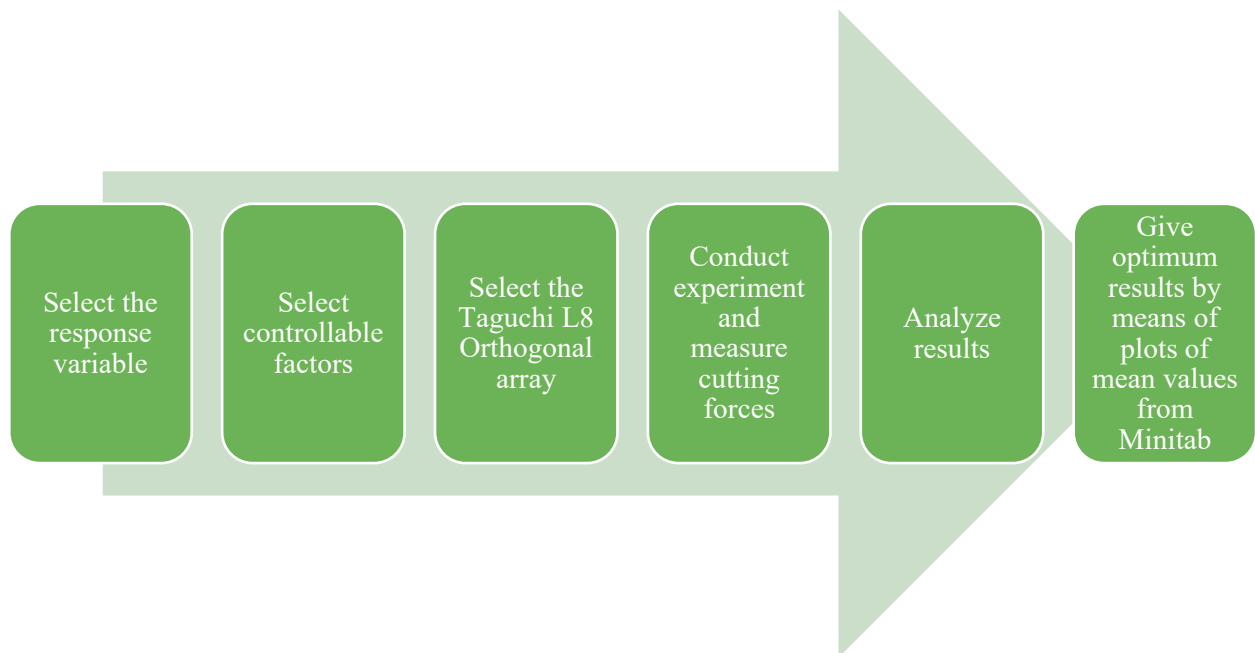
Figure 3 *Methodology for Taguchi optimization*

Table 7 Mean values for upper and lower levels for cutting conditions and their interactions

	v	*s*	*v·s*	*a*	*v·a*	*s·a*	*Error*
1	435,45	234,75	385,20	194,79	367,07	526,67	457,76
2	399,05	599,75	449,29	639,71	467,42	307,83	376,74
Δ	36,39	364,99	64,08	444,92	100,34	218,83	81,02
Rank	7	2	6	1	4	3	5

Table 8 S/N ratios for upper and lower levels and rank of significance for cutting conditions

Level	*Speed [m/min]*	*Feed [mm/o]*	*Depth [mm]*
1	-49,5771	-46,1836	-44,9998
2	-50,4777	-53,8712	-55,0551
Δ	0,900581	7,687639	10,05531
Rank	3	2	1

4. RESULTS AND DISCUSSION

Table 9 Summary methodology and results of first case of gradient method

Factors	$X_1(v)$	$X_2(s)$	$X_3(a)$	y	
Middle level x_{oi}	100	0.124	1		
Interval of variation w_i	50	0.071	0.5		
Upper level x_{gi}	150	0.196	1.5		
Lower level x_{di}	50	0.05	0.5		
Coded factors values	x_1	x_2	x_3	R_a	
1	+1	+1	+1	1.39	
2	+1	-1	+1	1.118	
3	-1	-1	+1	1.799	
4	-1	-1	-1	2.324	
5	+1	+1	-1	1.415	
6	+1	-1	-1	0.774	
7	-1	+1	-1	4.105	
8	-1	+1	+1	1.825	
Regression coefficients	b_1 −0.6695	b_2 0.34	b_3 -0.31075		
$b_i w_i$	-33.475	0.02414	-0.155375		
$\lambda = \frac{\mu}{|b_b|} = \frac{0.8}{0.6695} = 1.194922$					
Pace $\lambda b_i w_i$	40	0.028845407	0.18566		
Rounded values:	40	0.029	0.2		
New experimental points:	$X_1(v)$	$X_2(s)$	$X_3(a)$	Linear model results	Experimental results
9	140	0.095	1.2	1.047034	1.087
10	180	0.066	1.4	0.2483052	0.873

Therefore, the measured surface roughness results are presented in the table above, and in line with them, the conclusion is that the deviations of the cutting parameters and problems referring to the chip removal occur during machining at point 10. The optimization point is, in fact, the sixth point of the experiment, meaning all other values circulate around it. The difficulty regarding chip removal is important as striplined chip form appears. During the winding process revolving the workpiece, the striplined chip form is drawn under the knife and thus results in distortion of the surface finish integrity. On top of that, it can harm the operator. One of the problems due to conventional lathe was that how the speed increased, it also increased the interval between adjacent rounded speed value. So, it is the

reason why experimental investigation required this speed values and interval, not only the highest that gives the lowest surface roughness. The model of linear regression for cutting regimes, implemented in this experiment, implies that by increasing the speed, value of

surface roughness decreases. This fact is known from cutting theory and it is confirmed with given model of first-order linear regression. Due to these constrains, it was almost expected that the lowest value or the best surface finish is accomplished in first eight points.
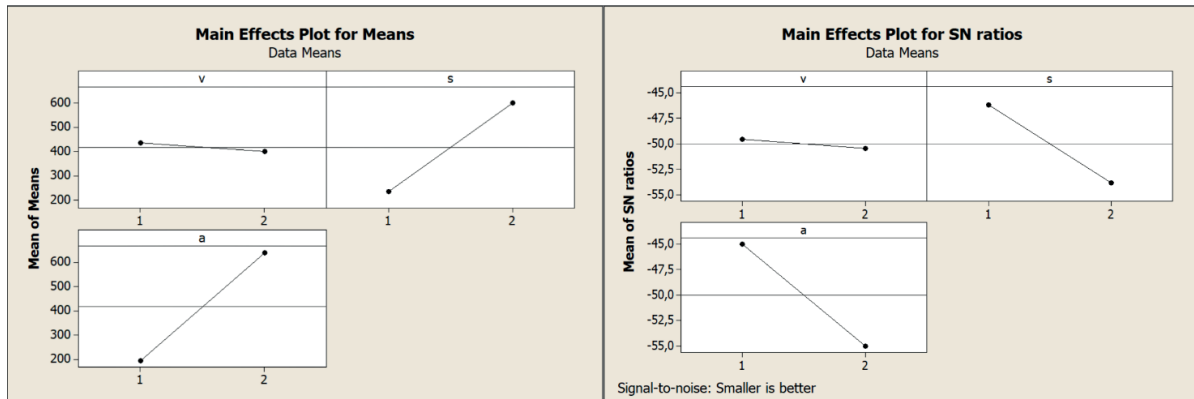
Figure 5 *Plots for SN ratios and means*

From the figures above, it is easy to conclude that both feed and cutting depth affect cutting forces. The cutting speed graph line is almost flat, so it cannot affect output values that much. Moreover, the smallest values for means and S/N ratios are obtained in the following levels: for speed it is level 2 (v = 150 m/min), for feed it is level 1 (s = 0,05 mm/rev) and for cutting depth it is level 1 (a = 1,5 mm), as well. Consequently, the smallest values of cutting forces are expected on these three levels of cutting conditions and further research can be continued from this point. Also, highest value of resultant cutting force can be expected with

the lower level of cutting force, and upper levels of feed and depth. From Table 7 and Table 8, it is obvious that the highest impact has cutting depth and it is concluded by the rank of Δ. In addition, figures of the interaction of the input variables by means of S/N ratio and means are given bellow. Obviously, these patterns indicate that there is possibility only for interactions to be significant between speed – feed, feed – depth. It is required to check the p-value of the interaction term in the analysis of variance table.

Figure 6 *Plots of input variables interactions*

5. CONCLUSION

This paper shows successful optimization of cutting conditions, even though optimization is not accomplished in additional points of experiment required, due to the used methodology. Optimization gives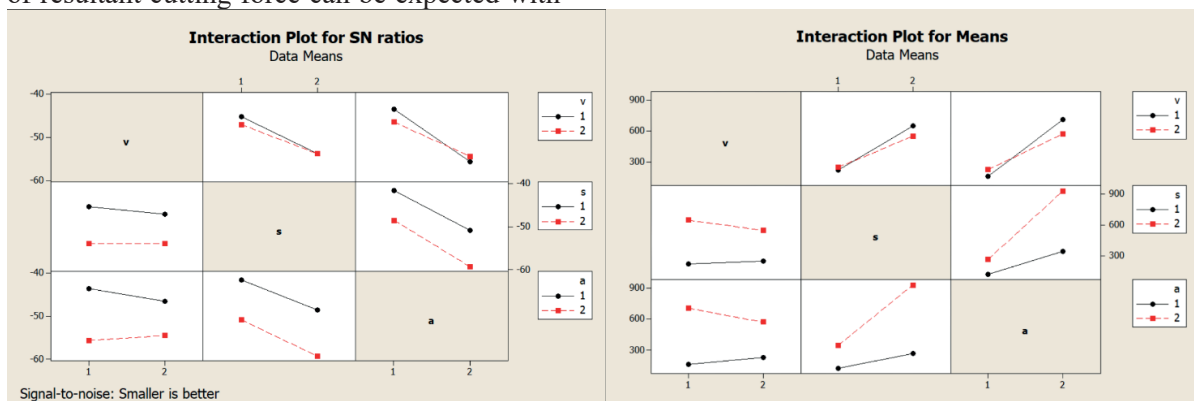 a very low value of surface roughness in sixth point of experiment that may be regarded as a optimum point. So, there is no need to go in further analysis and these results can be considered as valid. These results show us that by means of relevant methodology and with all constrains, it is possible to perform the optimization. This paper tackles one of the examples of optimization with experimental background, bringing out a very low roughness level, proving the very goal of the paper. Selecting appropriate values of cutting parameters and using some other items such as coolant led to the achievement of increasing of surface finish. In addition, Taguchi optimization method is accomplished, showing that this method represents a strong weapon to obtain optimal results quickly.

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PRIMJENA METODA *MONTE CARLO* ZA OPTIMIZACIJU MATEMATIČKOG MODELA HRAPAVOSTI POVRŠINE

APPLICATION OF THE MONTE CARLO METHOD FOR THE OPTIMIZATION OF MATHEMATICAL MODEL OF SURFACE ROUGHNESS

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Stručni rad

REZIME

U ovom radu pokazana je optimizacija primjenom metoda Monte Carlo, *matematičkog modela hrapavosti, odnosno srednjeg aritmetičkog odstupanja profila. Optimizacija je pronalaženje najboljeg od svih mogućih rješenja. Prethodno je izvršen eksperiment, prema planu eksperimenta. Na osnovu rezultata eksperimenta i plan-matrice određeni su koeficijenti matematičkog modela. Adekvatan i nelinearan matematički model, pogodan za optimizaciju, daje zavisnost srednjeg aritmetičkog odstupanja profila od broja obrtaja, posmaka, promjera alata i dubine rezanja. Metod* Monte Carlo *simulira neku pojavu ili proces izvođenjem brojnih fiktivnih eksperimenata pomoću slučajnih brojeva. Primjena metoda* Monte Carlo *u optimizaciju nije originalna. Međutim, prikazana tehnika u ovom radu, korištenjem softvera* MS Excel, *jeste originalna, pouzdana i jednostavna. Nedostatak je nepreciznost. Preporučuje se da se ovaj metod za optimizaciju koristi kao kontrolni metod optimizacije, u odnosu na neki drugi metod.*

Professional paper

SUMMARY

This paper shows optimization by using the Monte Carlo method, the mathematical model of roughness, or the mean arithmetic deviation of the profile. Optimization means finding the best of all possible solutions. According to the experiment plan, an experiment was previously performed. Based on the results of the experiment and the plan matrix, the coefficients of the mathematical model were determined. An adequate and nonlinear mathematical model, suitable for optimization, gives the dependence of the mean arithmetic deviation of the profile from the number of main spindle revolutions, feed rate, tool diameter and cutting depth. The Monte Carlo method simulates action or proces by performing number of fictitious experiments using random numbers. The application of Monte Carlo method in optimization is not original. However, using MS Excel as a technique shown in this paper is original, reliable and simple. The disadvantage is imprecision. It is recommended to use Monte Carlo method as a control method in relation to some other method.

1. INTRODUCTION

Roughness of surface is an essential characteristic of machine elements and has an impact on the properties of machine parts and structures, especially in places of mutual connection. Surface quality affects the dynamic durability of the element. Therefore, it is important to ensure as little roughness as

possible, because in addition to functional, it also has an aesthetic role, especially in aluminum elements. During the part production on CNC machines, there are numerous parameters that affect the quality of the surface, in this paper four input parameters have been taken in account on five levels: the number of main spindle revolutions n, feed rate s, tool diameter d and cut depth a. The output of the process is mean arithmetic deviation of the profile Ra. During the experiment, the parameters were varied according to the plan of the experiment, within the limits which are applicable in production. Based on the results of the experiment and the plan matrix, the coefficients of the mathematical model were determined. Optimization means finding the best solution of all possible solutions. The result of optimization are those parameter values that give the optimal value of roughness. Optimization is done by using the Monte Carlo method, that simulates a phenomenon or process by performing an experiment of random numbers. A simulation is the execution of a model, represented by a computer program that gives information about the system being investigated. Monte Carlo Simulation, also known as the Monte Carlo Method or a multiple probability simulation, is a mathematical technique, which is used to estimate the possible outcomes of an uncertain event. It was invented during the Manhattan Project by John von Neumann [1903-1957], Nicholas Metropolis [1915-1999] and Stanislaw Ulam [1909-1984] and named for Ulam's uncle, who enjoyed playing games of chance in Monte Carlo, Monaco. This is a probabilistic method based on performing numerous fictive experiments using random numbers. The Monte Carlo method requires the use of a computer because a large number of random variables need to be generated [1, 3, 6, 8, 9].

In mathematics, engineering, computer science and economics, an optimization problem is the problem of finding the best solution from all feasible solutions. There are many Mathematical Programming Techniques, Stochastic (Probabilistic) Process Techniques and Statistical Methods to solve optimization problems. Mathematical programming techniques are useful in finding the minimum of a function of several variables under a prescribed set of constraints. Stochastic or Probabilistic process techniques can be used to analyze problems described by a set of random variables having known probability distributions. Statistical methods enable one to analyze the experimental data and build empirical models to obtain the most accurate representation of the physical situation [2, 4, 5,7].

In this paper the Monte Carlo method is introduced for optimizing mathematical models of machining processes. This technique is original and simple and uses MS Excel software.

2. RANDOM NUMBER, RANDOM VARIABLE AND STOCHASTIC PROCESS GENERATION

Most of today's random number generators are not based on physical devices but on simple algorithms that can be easily implemented on a computer. These generators are called pseudo-random. Pseudo-random number generators require tests as exclusive verifications for their "randomness," as they are decidedly not produced by "truly random" processes, but rather by deterministic algorithms. Over the history of random number generation, many sources of numbers thought to appear "random" under testing have later been discovered to be very non-random when subjected to certain types of tests. The notion of pseudo-random numbers was developed to circumvent some of these problems, though pseudo-random number generators are still extensively used in many applications as they are good enough for most applications. Non-parametric hypothesis tests can be used for testing randomness of sequence random numbers. There are several popular types of non-parametric hypothesis tests used in research nowadays: chi-square χ^2 test, Friedman one, Romanovsky, Kolmogorov-Smirnov one and others [3, 10].

It is easy to generate uniformly distributed pseudo-random numbers on a computer. The probability that a uniformly distributed random number falls within any interval of fixed length is independent of the location of the interval itself (but it is dependent on the interval size), so long as the interval is contained in the distribution's support.
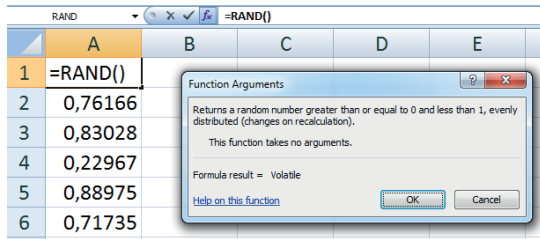
Figure 1 RAND() function in MS Excel

In MS Excel, the RAND () function is used to generate random numbers in the interval between 0 and 1 (Figure 1).

Random numbers, distributed uniformly in the interval [0;1], are the basis for determining random variables. The basic idea is that the cumulative distribution function F for any continuous random quantity x is also random number. If the cumulative distribution function of random quantity x is described by the expression [1]:

$$u = F(x) \quad (1)$$

then the random variables of x can be obtained from the random numbers u with uniform distribution in (0; 1) using the inverse formula:

$$x = F^{-1}(u) \quad (2)$$

Here, F^{-1} means inverse probabilistic transformation (Figure 2).
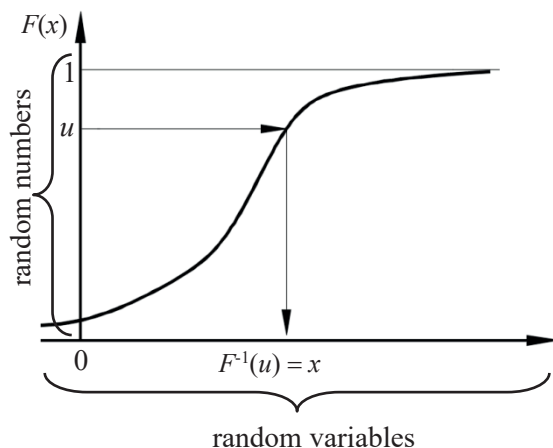
Figure 2 Generation of random variables by inverse probabilistic transformation

For example, the cumulative distribution function for normal distribution is:

$$u = F(x) = \int_{-\infty}^{x} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (3)$$

with the parameters μ and σ. The inverse transformation for the distribution (3) does not have analytical solutions.

The value of random variable is obtained from function NORMINV (A2;\$F\$1;\$F\$2), which is inverse function of normal distribution, and random number, function RAND () (Figure 3). Specific parameter values are shown in cells F1 and F2. In this case the probability is represented by pseudo-random number =RAND().
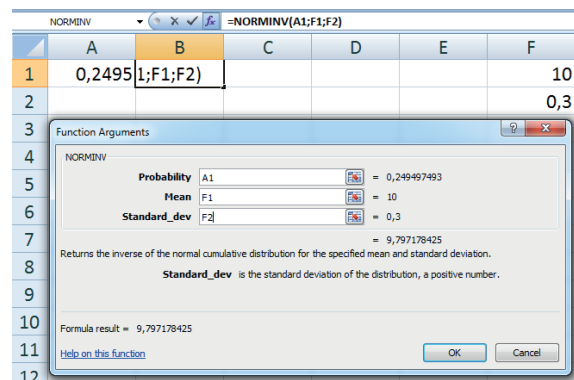
Figure 3 Generation of random variables using MC Excel

The simulation of a random process is obtained by copying the first row in sufficiently large number of iterations.

If the function F can be distributed uniformly in the interval $[a,b]$, then the calculation of random value for variable $x_i \in [a,b]$ can be done based on equation [4]:

$$rand(x_i) = (b - a) \cdot RAND() + a \quad (4)$$

which is the basis for the Monte Carlo method.

3. MATHEMATICAL MODEL OPTIMIZATION BY MONTE CARLO METHOD OF SIMULATION

Mathematical model optimization by Monte Carlo method is explained and shown using the example of optimization for non-linear coded mathematical model of arithmetical profile surface deviation:

$$Ra = 0,1999 - 0,4473 \cdot X_1 - 0,1056 \cdot X_2 +$$

$$+0.2151 \cdot X_3 + 0.0406 \cdot X_4 + 0.4972 \cdot X_1^2 +$$
$$+0.2234 \cdot X_2^2 + 0.2141 \cdot X_3^2 + 0.2221 \cdot X_4^2 + \quad (5)$$
$$+0.0519 \cdot X_1 X_2 - 0.066 \cdot X_1 X_3 -$$
$$-0.0576 \cdot X_1 X_4 - 0.0313 \cdot X_2 X_3 -$$
$$-0.0021 \cdot X_2 X_4 - 0.0141 \cdot X_3 X_4$$

Coded values are:

$$\left.\begin{array}{l} X_1 = 2\dfrac{d-d_0}{d_{+1}-d_{-1}} = 2\dfrac{d-10}{12-8} = \dfrac{d-10}{2} \\[2mm] X_2 = 2\dfrac{n-n_0}{n_{+1}-n_{-1}} = 2\dfrac{n-8000}{8500-7500} = \dfrac{n-8000}{500} \\[2mm] X_3 = 2\dfrac{s-s_0}{s_{+1}-s_{-1}} = 2\dfrac{s-3000}{3500-2500} = \dfrac{s-3000}{500} \\[2mm] X_4 = 2\dfrac{a-a_0}{a_{+1}-a_{-1}} = 2\dfrac{a-0.6}{0.7-0.5} = \dfrac{a-0.6}{0.1} \end{array}\right\} \quad (6)$$

and the parameters are:
– d [mm] tool diameter,

– n [rpm] number of main spindle revolutions,
– s [mm/min] feedrate,
– a [mm] cutting depth.

From equations (6) follows:

$$\left.\begin{array}{l} d = 2X_1 + 10 \\ n = 500 X_2 + 8000 \\ s = 500 X_3 + 3000 \\ a = 0.1 X_4 + 0.6 \end{array}\right\} \quad (7)$$

Optimization is done by using MS Excel, and shown by steps, the goal was to get minimal value of Ra defined by specific values of parameters.

1. The random values of input parameters are generated by equation (4) and limits $-2 \le X_i \le 2$, $i = 1,2,3,4$.

B2			f_x	=(2-(-2))*RAND()+(-2)	
	A	B	C	D	E
1	N	X 1	X 2	X 3	X 4
2	1	1,33028	-1,17954	-0,40138	-1,33646

Figure 4 Step 1 – Random values generated

2. The given mathematical model equation is defined in corresponding cell (E2), where the cell addresses are used instead of input variables: B2 = X_1, C2 = X_2, D2 = X_3 and E2 = X_4.

F2			f_x	=0,199-0,4473*B2-0,1056*C2+0,2151*D2+0,0406*E2+0,0519*B2*C2-0,066*B2*D2-0,0576*B2*E2-0,0313*C2*D2-0,0021*C2*E2-0,0141*D2*E2+0,4972*B2*B2+ 0,2234*C2*C2+0,2141*D2*D2+0,2221*E2*E2										
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	N	X 1	X 2	X 3	X 4	Ra									
2	1	-0,30452	0,922381	1,703088	0,942597	1,432064									

Figure 5 Step 2 – Mathematical model equation

3. Row 2 is copied arbitrary number of times, to get sufficient number of iterations. In this case that number is 50.000.

A50001			f_x	=A50000+1	
	A	B	C	D	E	F
49998	49997	-0,26464	-1,12583	-0,4485	1,200622	1,091366
49999	49998	0,779538	-1,43322	-1,54421	-0,35526	0,914701
50000	49999	1,768301	0,651285	-0,87598	-1,99953	2,133816
50001	50000	1,408976	1,165786	1,511412	-1,8868	2,352747

Figure 6 Step 3 – Copying until sufficient iteration number

4. The minimal value is defined in column F, for randomly determined values of *Ra*.

***Figure 7** Step 4 – Determination of minimal value*

5. Number of rows for column F, in which is the minimal value, are determined by using the function =MATCH (K4; F: 50001; -1). The -1 is written because in this case the first row is not counted.

***Figure 8** Step 5 – Determination of the row number where is the minimal value*

6. The value of input parameter X_1 is shown by function =INDIRECT("B"&L4), for certain row in column F where is the minimal value, and in the combination with other input parameters, they give minimal value of *Ramin.*
In the similar way by using =INDIRECT("C"&L4), =INDIRECT("D"&L4) and =INDIRECT("E"&L4), the requested values of input parameters are given *X2, X3,* and *X4* respectively.
By decoding based on equations (6) and (7), the results are values of input quantities for minimal value of *Ra*, (Figure 9).

***Figure 9** Step 6 – Defined input parameters for minimal value*

The exact values can be shown by using another optimization methods, with input parameter values of:

$d_{opt} = 10,8421$
$n_{opt} = 8087$

$s_{opt} = 2797$
$a_{opt} = 0,05975$, (Figure 9).

4. CONCLUSION

Optimization of mathematical models with the Monte Carlo method is simple and reliable process. By using the widely available MS Excel program, which is user-friendly because of its accesible interface, mistakes are immediately shown, without mistrust of background calculations and possible code errors.
Method is based on typical (generic) behavior of processes, because the input values are realistic in comparison with mathematical model, that means there are no unrealistic theoretical values.
The Monte Carlo simulation method is a numerical stochastic model, which requires a large iteration number. Although the iteration number is arbitrary, for optimization application it should be 10^4 order. Monte Carlo optimization immediately determines the kind of extremes in the process, whether it is a maximum or a minimum. Interval values of input variables do not have any impact on method efficiency. Also, there are no additional constrains for mathematical model, such as

complexity, continuity, linearity and differentiability, it is totally arbitrary.

Disadvantage of Monte Carlo optimization is inaccuracy which can be eliminated by increased number of iterations.

But regardless of some disadvantages, the Monte Carlo method is suitable, due to its simplicity and can be used as a control method, compared to optimization with a genetic algorithm, neural networks or classical method.

If it is found that the optimal values, obtained by Monte Carlo optimization, are similar to the values obtained by some other optimization method, there is almost no doubt that the results are correct. There is no theoretical possibility that the results are wrong if the both methods give similar results.

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MATEMATIČKA I NUMERIČKA ANALIZA ODNOSA IZMEĐU LOSCHMIDTOVE KONSTANTE, AVOGADROVE KONSTANTE I BRZINE ZVUKA U REALNIM PLINOVIMA KOD RAZLIČITIH TERMODINAMIČKIH SVOJSTAVA (pvT)

MATHEMATICAL AND NUMERICAL ANALYSIS OF THE RELATIONSHIP AMONG THE LOSCHMIDT CONSTANT, THE AVOGADRO CONSTANT, AND THE SPEED OF SOUND IN REAL GASES AT DIFFERENT THE *pvT* THERMODYNAMIC PROPERTIES

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1) Univerzitet u Zenici

Kratki originalni naučni članak

REZIME:

U ovom radu izvedena je diferencijalna jednadžba koja daje odnos između Loschmidtove konstante, Avogadrove konstante i brzine zvuka u stvarnim plinovima kao funkcije termodinamičkih svojstava plina (tlak, temperatura i volumen). Konstantni omjeri NL/NA i relativno odstupanje omjera NL/NA od srednje vrijednosti za plinove (vodik, helij, ugljenmonoksid, argon, dušik, kisik, ugljendioksid i metan) izračunati su korištenjem njihovih stvarnih jednadžbi stanja, potvrđujući valjanost izvedene jednadžbe. Prvi izračun omjera konstanti NL/NA i relativnog odstupanja omjera NL/NA od srednje vrijednosti za plinove u standardnom stanju (temperatura 273,15 K i tlak 101,325 Pa) pokazuje dobro slaganje s objavljenim rezultatima u literaturi, s obzirom na to da je literaturni podatak omjera NL/NA 0,04461498 u standardnom stanju. Drugi izračun konstantnih omjera NL/NA i relativnog odstupanja omjera NL/NA od srednje (prosječne) vrijednosti za stvarne plinove napravljen je za tlak od 500 000 Pa i temperaturu od 293,15 K, što je također rezultiralo sličnim ponašanjem kao u prethodnom slučaju. Treći izračun konstantnih omjera NL/NA i relativnog odstupanja omjera NL/NA od srednje (prosječne) vrijednosti za stvarne plinove napravljen je za tlak od 1000 000 Pa i temperaturu od 320,0 K, što također daje slično ponašanje kao u prethodnom slučaju.

Short original scientific paper

SUMMARY:

In this paper, a differential equation is derived that gives the relationship among the Loschmidt constant, the Avogadro constant, and the speed of sound in real gases as a function of the thermodynamic properties of the gas (pressure, temperature, and volume). The constant ratios N_L/N_A and the relative deviation of the N_L/N_A ratio from the mean value for the gases (hydrogen, helium, carbon monoxide, argon, nitrogen, oxygen, carbon dioxide, and methane) were calculated using their real-equations of state, confirming the validity of the derived equation. The first calculation of the ratio of the constants N_L/N_A and the relative deviation of the N_L/N_A ratio from the mean value for the gases at standard state (temperature 273.15 K and pressure 101,325 Pa) shows a good agreement with the published results in the literature, given the fact that the literature data of the N_L/N_A ratio is 0.04461498 at standard state. The second calculation of the constant ratios N_L/N_A and the relative deviation of the N_L/N_A ratio from the mean (average) value for the real gases was made for a pressure of 500,000 Pa and a temperature of 293.15 K, which also resulted in similar behavior as in previous case. The third calculation of the constant ratios N_L/N_A and the relative deviation of the N_L/N_A ratio from the mean (average) value for the real gases was made for a pressure of 1000,000 Pa and a temperature of 320.0 K, which also gave similar behavior as in previous case.

1. INTRODUCTION

In 1811, an Italian professor of physics *Amadeo Carlo Avogadro* suggested an important hypothesis 'that equal volumes of all gases at the same temperature and pressure contain the same number of molecules', or 'the volume of a gas at a given pressure and temperature is proportional to the number of atoms or molecules regardless of the nature of the gas', which is well known as the Avogadro's Principle (law) or Avogadro's constant (number). The greatest problem Avogadro had to resolve was the confusion at that time regarding atoms and molecules. One of his most important contributions was clearly distinguishing one from the other, stating that gases are composed of molecules, and these molecules are composed of atoms. Avogadro did not actually use the word 'atom' as the words 'atom' and 'molecule' were used almost without difference. He believed that there were three kinds of 'molecules', including an 'elementary molecule' ('atom') [1]. Thus, the hypothesis has been extremely visionary, and her confirmation, using the kinetic theory of gases, came decades later.

The scientific community did not give great attention to his theory, so Avogadro's hypothesis was not immediately accepted. The studies by *Charles Frédéric Gerhardt* and *Auguste Laurent* on organic chemistry made it possible to demonstrate what Avogadro's law explained, i.e. why the same quantities of molecules in a gas have the same volume. Unfortunately, related experiments in organic substances showed seeming exceptions to the law. This was finally resolved by *Stanislao Cannizzaro,* as announced at the Karlsruhe Congress in 1860, four years after Avogadro's death. He explained that these exceptions were due to molecular dissociations at certain temperatures, and that Avogadro's law determined not only molecular masses, but atomic masses as well. In 1911, a meeting in Turin commemorated the hundredth anniversary of the publication of Avogadro's classic 1811 paper. Thus, Avogadro's great contribution to chemistry was recognised. *Rudolf Clausius*, with his kinetic theory

on gases, gave another confirmation of Avogadro's Law. *Jacobus Henricus van 't Hoff* showed that Avogadro's theory also applied to dilute solutions. Avogadro is hailed as a founder of the atomic-molecular theory [1].

Despite the fact that Avogadro did not specify the ratio of the number of constituent particles in a sample to the amount of substance, the French physicist *Jean Baptiste Perrin* (1909) proposed naming the constant in honor of Avogadro. *Jean B. Perrin* won the Nobel Prize in Physics (1926) in a large part for his work in determinig the Avogadro constant. Perrin's method was based on the Brouwnian motion [2].

In the years since then, several different methods (coulometry, electron mass measurement, x-ray crystal density method) have been used to estimate the magnitude of this fundamental constant. In general, accurate determinations of Avogadro's number require the measurement of a single quantity on both the atomic and macroscopic scales using the same unit of measurements. This became possible for the first time when physicist *Robert Milllikan* measured the charge on an electron in 1910. The charge of a mole of electrons had been known since 1834 when *Michael Faraday* published his works on electrolysis. The charge was called the Faraday constant, and the best value of the constant is 96,485.3383 (3) C/mol, according to the NIST. The best estimate of the charge on an electron, based on modern experiments, is $1.60217653 \cdot 10^{-19}$ C/electron. When divide the charge on a mole of electrons by the charge on a single electron we obtain a value of Avogadro's number of $6.02214154 \cdot 10^{23}$ particles/mole [3]. Since 1910, newer calculations have more accurately determined the value for Farady's constant and elementary charge. Another approach to determining Avogadro's number starts with careful measurements of the density of an ultrapure sample of a material on the macroscopic scale.

In fact, Perrin originally proposed the name Avogadro's number to refer to the

number of molecules in one gram-molecule of oxigen, and this term is still widesly used in introductory works. The change of name to the Avogadro constant came with the introduction of the mole as a unit in the International System of Units (SI) in 1971, which recognised amount of substance as an independent dimension of measurements. Thus, the Avogadro constant was no longer a pure number, now it had a unit of measurements, the reciprocal mole (mol^{-1}) [4, 5].

The Avogadro constant is a scaling factor between macroscopic and microscopic observations of nature, and can be applied to any substance. The most significant consequence of Avogadro's law is that the gas constant has the same value for all gases. Because of its role as a scaling factor, it provides the relation between other physical constants and properties. For example, it establishes a relationship between: ■ the universal gas constant (R_u) and the Boltzmann constant (k_B): $R_u=k_B \cdot N_A$=8.314472 (15) J/mol K; ■ the Faradey constant (F) and the elementary charge (e): $F=N_A \cdot e$=96,485.3383 (3) C/mol, and ■ the Avogadro constant and the definition of the unified atomic mass unit (u): 1 $u=M/N_A$= 1.660538782(83)$\cdot 10^{-24}$ g.

The Loschmidt number is defined as the number of atoms in a gram-atom or the number of molecules in a gram-molecule. This number, in literature, is frequently referred to as the Avogadro's number. But, the term Loschmidt number is reserved for the number of molecules in a cubic centimeter of a gas under standard conditions. In German language literature may refer to both constants by the same name, distinguished only by the units of measurement. The first actual estimate of the number of molecules in one cubic centimeter of a gas under standard conditions was made in 1865 by the Austrian physicist *Johan Josef Loschmidt*, professor at the University of Vienna. The number density of particles in a gas is now called the Loschmidt constant in his honor, and is approximately proportional to the

Avogadro constant. Loschmidt's method was based on the kinetic theory of gases. The kinetic theory had been developed with great success by the efforts of two scientists *James Clerk Maxwell* and *Rudolph Clausius*. Loschmidt was the first to estimate the physical size of molecules in 1865, but he did not actually calculate a value for the constant which now bears his name. Loschmidt number is, by virtue of its definition, the same for atoms and molecules of all kinds. Though molecules may vary in size, shape and mass, the number of molecules in a gram-molecule is a universal constant for all solids, liquids and gases, elements and compounds [6].Thus, the number of molecules in a specific volume of gas is independent of the size or mass of the gas molecules. As an example, equal volumes of molecular hydrogen and nitrogen, as ideal gasous, would contain the same number of molecules, as long as they are at the same temperature and pressure.

The Loschmidt constant is usually quoted at standard state of substance (i.e., temperature T_0=273,15K and pressure p_0=1atm=1.01325bar=101325 Pa), and recommended value is 2.6867774(47)$\cdot 10^{25}$ particles/m^3. The pressure and temperature can be chosen freely, and must be quoted with values of the Loschmidt constant. The precision to which the Loschmidt constant is currently known is limited entirely by the uncertainty in the value of the gas constant.

The sound waves are a result of the movement of the elastic pieces of the substance environment whether it is a substance in the gas, liquid or solid. A change in gas density (or pressure) is transmitted in all directions with a certain speed. Number of compression and expansion of the environment, performed by the sound source by a sinuous curve in the unit of time is called *frequency* – unit is the number of cycles per second (c/s). The distance between the two maximum and minimum in a sinuous curve represents *wavelength* – unit is meters (m). Pressure changes represent *sound pressure* – the unit is N/m^2. Sound energy (J) per unit time

(s) passing through a unit area (m^2) normal to the direction of propagation is called **the intensity of sound waves** or alternatively **the power density** – the unit is W/m^2 [7]. The quantity has practical importance. The human ear is a very sensitive organ and at the same time it is very flexible. The lower limit of the audible intensity of sound is of the order of 10^{-12} W/m^2 and the maximum safety limit is the order of 1 W/m^2. The sound waves intensity of ordinary conversation is the order of 10^{-6} W/m^2, street traffic is 10^{-5} W/m^2 and jet plane is 10^{-2} W/m^2.

Propagation speed of sound waves depends only on the properties of the medium through which the propagation takes place. The speed of sound varies from substance to substance, for instance: sound travels most

slowly in gases (the average gas speed of sound is about 330 m/s); it travels faster in liquids (the average gas speed of sound is about 1,500 m/s); and it travels fastest in solids (the average gas speed of sound is about 4,000 m/s). In an exceptionally stiff material, such as diamond, sound travels at 12,000 m/s - which is around the maximum speed that sound will travel under normal conditions. In common everyday speech, speed of sound refers to the speed of sound waves in air. At 20°C the speed of sound in air is about 343 m/s. The speed of sound in an ideal gas depends only on its temperature and composition. The speed of sound has a weak dependence on frequency and pressure in ordinary air, deviating slightly from ideal behavior.

2. MATHEMATICAL ANALYSIS

2.1. The thermodynamic speed of sound
The thermodynamic speed of sound (i.e., the speed of sound at zero frequency) in a fluid u,

m/s is defined by the Laplace equation

$$u^2 = \left(\frac{\partial p}{\partial \rho}\right)_s \tag{1a}$$

where: ρ, kg/m^3 is the density of the substance; p, N/m^2 is the pressure; s, J/kg·K is the specific entropy of the substance. Since $\rho = 1/v$, the

Laplace equation has the following form, according to Ref. [8, p.127]:

$$u^2 = -v^2 \left(\frac{\partial p}{\partial v}\right)_s \tag{1b}$$

By combining the above equation with the important relationship that determines the

following derivative, rarely mentioned in the literature, according to Ref. [8, p.124]:

$$\left(\frac{\partial p}{\partial v}\right)_s = \left(\frac{\partial p}{\partial v}\right)_T - \frac{T}{c_v}\left(\frac{\partial p}{\partial T}\right)_v^2 \tag{2}$$

it is obtained that

$$u^2 = v^2\left[\frac{T}{c_v}\left(\frac{\partial p}{\partial T}\right)_v^2 - \left(\frac{\partial p}{\partial v}\right)_T\right] \tag{3}$$

An equivalent form of Eq. (3) can be found by replacing the derivative $(\partial p/\partial T)_v$ in

terms of the cyclic equation, according to Ref. [9, p.636]:

$$\left(\frac{\partial p}{\partial T}\right)_v = -\left(\frac{\partial v}{\partial T}\right)_p\left(\frac{\partial p}{\partial v}\right)_T \tag{4}$$

so that Eq. (3) results

$$u^2 = v^2 \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial v} \right)_T^2 \left(\frac{\partial v}{\partial T} \right)_p^2 - \left(\frac{\partial p}{\partial v} \right)_T \right] \tag{5}$$

or

$$v = u \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial v} \right)_T^2 \left(\frac{\partial v}{\partial T} \right)_p^2 - \left(\frac{\partial p}{\partial v} \right)_T \right]^{-\frac{1}{2}} \tag{5a}$$

2.2. Relationship among the Loschmidt constant, the Avogadro constant, and the speed of sound

The Loschmidt constant is related to the Avogadro constant by relation, according to Ref. [10, p. 418]:

$$N_L = \frac{p}{R_u T} N_A = \frac{\rho(p,T)}{M} N_A = \frac{1}{v(p,T) \cdot M} N_A, \quad \frac{\text{particles}}{\text{m}^3}, \tag{6}$$

where: N_L, particles/m^3 is the Loschmidt constant; p, N/m^2 is the pressure; T, K is the temperature; R_u, J/kmol·K is the universal gas constant; ρ (p, T), kg/m^3 is the density of the substance; v (p, T), m^3/kg is the specific volume of the substance; M, kg/kmol is the atomic mass of the substance, and N_A, particles /kmol is the Avogadro constant.

Combining Eq. (5a) and (6), the relationship among the Loschmidt constant, the Avogadro constant, and the speed of sound, is obtained in the following form:

$$\frac{N_L}{N_A} = \frac{1}{u \cdot M} \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial v} \right)_T^2 \left(\frac{\partial v}{\partial T} \right)_p^2 - \left(\frac{\partial p}{\partial v} \right)_T \right]^{\frac{1}{2}} \tag{7}$$

Since the specific volume and density are inversely proportional, that is $v = 1/\rho$, the following relation for the partial derivatives is obtained:

$$\left(\frac{\partial p}{\partial v} \right)_T = \left(\frac{\partial p}{\partial \rho} \right)_T \left(\frac{\partial \rho}{\partial v} \right)_T = -\rho^2 \left(\frac{\partial p}{\partial \rho} \right)_T \tag{a}$$

and

$$\left(\frac{\partial v}{\partial T} \right)_p = \left(\frac{\partial \rho}{\partial T} \right)_p \left(\frac{\partial v}{\partial \rho} \right)_p = -\frac{1}{\rho^2} \left(\frac{\partial \rho}{\partial T} \right)_p \tag{b}$$

When the previous relations are inserted in Eq. (7), relation in the following form is obtained:

$$\frac{N_L}{N_A} = \frac{1}{u \cdot M} \left[\frac{T}{c_v} \left(\frac{\partial p}{\partial \rho} \right)_T^2 \left(\frac{\partial \rho}{\partial T} \right)_p^2 + \rho^2 \left(\frac{\partial p}{\partial \rho} \right)_T \right]^{1/2} \tag{8}$$

The relative deviation of the N_L/N_A ratio from the mean value of real gases: argon, hydrogen, helium, carbon monoxide, carbon dioxide, nitrogen, oxygen, and methane, is calculated as follows:

$$\Delta\left(\frac{N_L}{N_A}\right) = \frac{\left(\dfrac{N_L}{N_A}\right)_{average} - \left(\dfrac{N_L}{N_A}\right)_{gas}}{\left(\dfrac{N_L}{N_A}\right)_{average}} 100\% \tag{9}$$

3. NUMERICAL ANALYSIS

3.1. Numerical analysis of the constant ratios and the relative deviation of the N_L/N_A ratio from the mean value for the real gases at standard state (temperature 273.15 K and pressure 101325 Pa)

The calculation of the constant ratios N_L/N_A and the relative deviation of the N_L/N_A ratio for the real gases at standard state (i.e., temperature 273.15 K and pressure 101,325 Pa) show a good agreement with the results in the literature, given the fact that the literature data of the N_L/N_A ratio is 0.04461498 at standard state, Ref. [3, 6]. The mean value of the constant ratios N_L/N_A is 0.04467675. **Table 1** data shows a good agreement with the literature because the absolute difference appears in the fifth decimal and reaches its maximum value for methane, carbon dioxide, nitrogen, and helium. **Table 1** and **Figure 1** present the absolute values and relative deviations from the mean value of the N_L/N_A ratio for the real gases were calculated using their real-equations of state at standard state, according to Ref. [11 to 19], as well as Eqs. (3), (8), (9). Thus, **Table 1** shows that the absolute differences from the mean value of the N_L/N_A ratio range from 0.00002779 for oxygen to 0.00024082 for carbon dioxide, while the relative deviations range from 0.03981548% for oxygen to 0.5390307% for carbon dioxide.

Table 1 The calculations for real-gases using their real-equations of state, Ref. [11 to 19]

| Gas	M, kg/kmol	c_v, J/kgK	u, m/s	$(\partial p/\partial \rho)_T$, Pa/(kg/m³)	$(\partial \rho/\partial T)_p$, kg/m³K	N_L/N_A; Eq. (8)	$\Delta(N_L/N_A)$, %; Eq. (9)
H₂	2.01588	10070.55	1261.06	1128010.0	-0.000328954	0.04458716	0.200521
He	4.00260	3116.176	972.940	568010.6	-0.000653797	0.04455534	0.1914395
CO	28.0101	743.1707	336.942	80974.04	-0.004596181	0.04464465	0.07184297
Ar	39.948	312.4416	307.857	56744.36	-0.00655719	0.04465695	0.04430984
N₂	28.013	742.8848	336.969	81061.654	-0.00460508	0.04471501	0.09137965
O₂	31.9988	655.2213	314.8105	70836.00	-0.005253419	0.04465896	0.03981548
CO₂	44.0098	632.0157	258.0763	50909.44	-0.007399405	0.04491757	-0.5390307
CH₄	16.0428	1656.75	430.667	140890.5	-0.002648078	0.04472155	-0.1002850
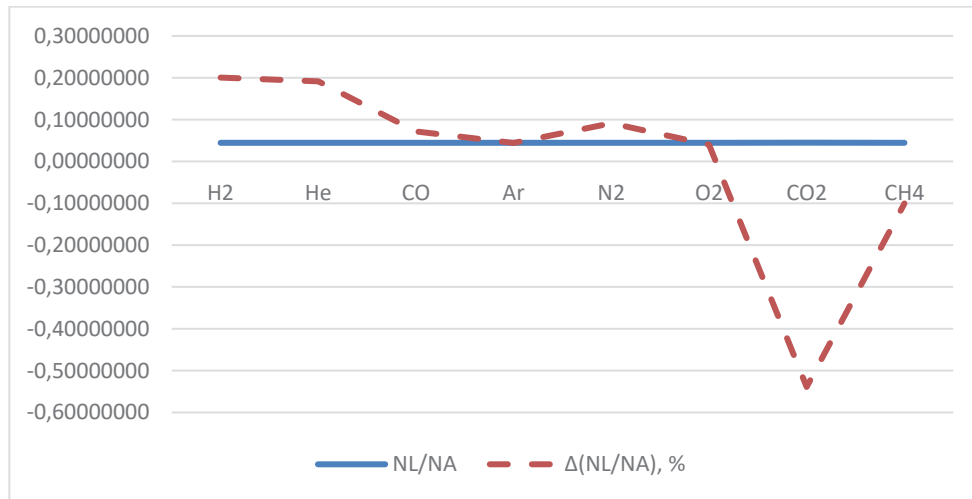
Figure 1 *The ratio of the constants and the relative deviation of the N_L/N_A ratio from the mean value for the real gases at standard state (i.e., temperature 273.15 K and pressure 101325 Pa)*

3.2. Numerical analysis of the constant ratios and the relative deviation of the N_L/N_A ratio from the mean value for the real gases at a pressure of 500,000 Pa and temperature of 293.15 K

  The constant ratios N_L/N_A and the relative deviations from the mean value of the N_L/N_A ratio for the real gases at state (temperature 293.15 K and pressure 500,000 Pa) were calculated and presented in **Table 2** and **Figure 2** using their real-equations of

state, according to Ref. [11 to 19], as well as Eqs. (3), (8), (9). The mean value constant ratios N_L/N_A is 0.2061974. Thus, **Table 2** shows that the absolute differences from the mean value of the N_L/N_A ratio range from 0.0003472 for oxygen to 0.0045752 for carbon dioxide, while the relative deviations range from 0.1683953% for oxygen to 2.218877% for carbon dioxide.:

Table 2 The calculations for real-gases using their real-equations of state, Ref. [11 to 19]

Gas	$M,$ kg/kmol	$c_v,$ J/kgK	$u,$ m/s	$(\partial p/\partial \rho)_T,$ Pa/(kg/m³)	$(\partial \rho/\partial T)_p,$ kg/m³K	$N_L/N_A;$ Eq. (8)	$\Delta(N_L/N_A),$ %; Eq. (9)
H₂	2.01588	10164.56	1308.066	1216278.0	-0.001404064	0.2045311	0.8081208
He	4.00260	3117.16	1009.697	611916.9	-0.002786614	0.2046398	0.7554015
CO	28.0101	744.5997	349.5669	86683.76	-0.01994752	0.2055418	0.3179580
Ar	39.948	313.1745	319.2481	60605.88	-0.02850255	0.20583031	0.1780429
N₂	28.013	744.1177	349.6914	86812.89	-0.01988569	0.205376814	0.3979787
O₂	31.9988	658.75	326.014	75648.23	-0.02284682	0.2058502	0.1683953
CO₂	44.0098	663.3485	263.296	52433.20	-0.03458745	0.21077266	-2.218877
CH₄	16.0428	1701.507	443.6379	149159.1	-0.01171133	0.2061974	-0.4070265

Figure 2 *The ratio of the constants and the relative deviation of the N_L/N_A ratio from the mean value for the real gases at pressure of 500,000 Pa and temperature of 293.15 K*

3.3 Numerical analysis of the constant ratios and the relative deviation of the N_L/N_A ratio from the mean value for the real gases at a pressure of 1000,000 Pa and temperature of 320.0 K

The constant ratios N_L/N_A and the relative deviation from the mean value of the N_L/N_A ratio for the real gases at state (temperature 320.0 K and pressure 1000,000 Pa) were calculated and presented in **Table 3** and

Figure 3 using their real-equations of state, according to Ref. [11 to 19], as well as Eqs. (3), (8), (9). The mean value of the constant ratios N_L/N_A is 0.3784468125. Thus, **Table 3** shows that the absolute differences from the mean value of the N_L/N_A ratio range from 0.0009857 for oxygen to 0.0131547 for carbon dioxide, while the relative deviations range from 0.2604626% for oxygen to 3.475967% for carbon dioxide.

Table 3 The calculations for real-gases using their real-equations of state, Ref.[11 to 19]

Gas	M, kg/kmol	c_v, J/kgK	u, m/s	$(\partial p/\partial \rho)_T$, Pa/(kg/m³)	$(\partial \rho/\partial T)_p$, kg/m³K	N_L/N_A; Eq. (8)	$\Delta(N_L/N_A)$, %; Eq. (9)
H_2	2.01588	10252.78	1368.837	1334725.0	-0.00234579	0.3737498	1.2411288
He	4.00260	3118.185	1056.824	670601.1	-0.004657565	0.3741995	1.1230735
CO	28.0101	746.4248	366.2333	94750.75	-0.0337198	0.376373	0.547927
Ar	39.948	313.7312	334.2333	66055.13	-0.0482924	0.3774277	0.269288
N_2	28.013	745.4526	366.4218	94960.55	-0.03355621	0.375925	0.6663585
O_2	31.9988	663.9546	340.7687	82450.42	-0.03872109	0.3774611	0.2604626
CO_2	44.0098	696.045	271.8047	55632.12	-0.06171518	0.3916015	-3.475967
CH_4	16.0428	1770.058	461.1317	161557.4	-0.02010286	0.3808367	-0.6314989

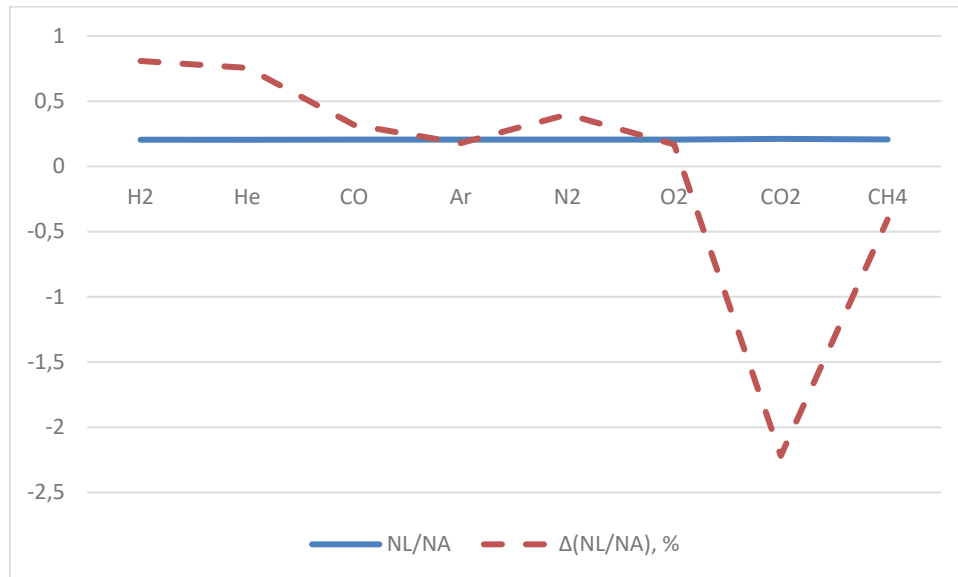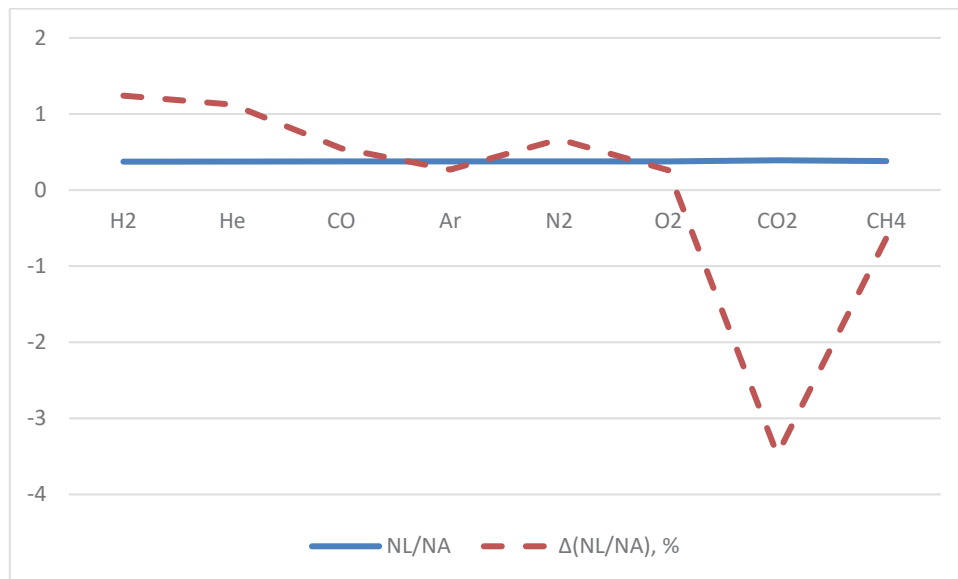**Figure 3** *The ratio of the constants and the relative deviation of the N_L/N_A ratio from the mean value for the real gases at pressure of 1000,000 Pa and temperature of 320.0 K*

4. CONCLUSION

■ The contribution of the paper is reflected in the derivation of equation (8), which defines the analytical relationship between Avogadro and Loschmidt numbers as a function of the speed of sound and *pvT* - the thermodynamic properties of the gas. The Loschmidt constant is approximately proportional to the Avogadro constant, according to Ref. [6], which is also numerically confirmed for real-gases in the paper (argon, hydrogen, helium, carbon monoxide, carbon dioxide, nitrogen, oxygen, and methane).

■ The number of particles (atoms or molecules) in the same volume for all gases is equal at the same temperature and pressure. The conclusion is due to the fact that the N_L/N_A ratio is calculated using equation (8) almost the same for the considered gases, namely the absolute differences appear on the fourth decimal place for carbon dioxide and methan, and the fifth decimal place for the other considered gases (**Table 1**). The conclusion corresponds to the Avogadro's hypothesis 'that equal volumes of all gases at the same temperature and pressure contain the same number of molecules'. Therefore, there are greater absolute differences and relative deviations of the constant ratios from the mean value for much higher *pvT*-thermodynamic gas properties when compared to the standard state, as shown in **Table 2**, **3**.

■ The authors consider this occurs primarily because of the uncertainty of equations of state of real gases used in calculations, in accordance with Ref. [11 to 19]. The heat capacity of gases also appears in equation (8) and, as is known, in real gases the heat capacities depend simultaneously on both pressure and temperature, in contrast to ideal gases where the heat capacities depend only on temperature. Also, in relation (8), the speed of sound is calculated using equation (5) and the corresponding state equations of real gases, although there is also an option for experimental determination. According to the above, the suggestion is that the derived equation (8) can be a good test for the newly derived equations of state for real gases because, simply put, the ratio defined by equation (8) must be the same for all gases under the same *pvT* – the thermodynamic properties of the gases.

■ The velocities of sound are different in gases under the same *pvT* – the thermodynamic properties of the gas, despite the fact that in these circumstances all gases have the same number of particles in the same volumes (Avogadro's hypothesis). Thus, it is clear that the speed of sound in gases depends on the type of gas (i.e. molecular weight and heat capacity of the gas) and temperature. In other words, all gases under the same *pvT* – the thermodynamic properties of the gas have the same number of particles (atoms or molecules)

in equal volumes, but in these circumstances have different the speed of sound.

■ The explanation of the previous conclusion is possible by analogy with the conduction of thermal energy in gases. Sound is an energy form, as is thermal energy. Thus, the propagation of sound in gases can be compared to the propagation of thermal energy. In the theory of heat transfer in gases and liquids, there are very successful correlations between the coefficient of heat conduction and the speed of sound in these fluids. The heat conduction coefficient of gases can be observed to be several times higher for hydrogen and helium, compared to the coefficients of other gases, what is also the same with the speed of sound. This fact is explained by that hydrogen and helium have small molecular masses compared to other gases and therefore have a higher mean velocity of elementary particles in volume, which is directly proportional in functional relations to both the coefficient of heat conduction and the speed of sound in gas. Thus, the mean velocity of elementary particles in the volume of a gas directly and in the same way affects both the conduction of thermal energy and the propagation of sound.

■ Experimental, as well as calculated, data indicate the fact that the speed of sound in real gases increases with increasing pressure, i.e., gas density (**Table 1**, **2**, **3**). On the other hand, according to the kinetic theory of gases, increasing the pressure (i.e. density) of a gas reduces the mean trajectory of a particle (atom, molecule) during the interval between two collisions. This indicates that the increase in gas pressure (density) will not have as significant an impact on the increase in the speed of sound in the gas as the type and temperature of the gas, because in functional relations the density and mean particle path between two collisions are proportional to both heat conduction coefficient and speed of sound.

■ Can it be said that matter (i.e. atoms or molecules) is also an energy form? Namely, in one of Nikola Tesla's last interviews, to the journalist's remark 'that his claim that matter has no energy – is very strange', Tesla replied: 'first it was energy, then matter'. Explaining the birth of the universe, Tesla says 'Matter is created from the original and eternal energy we know as light. Matter is an expression of infinite forms of light, so energy is older than it' - also an interesting statement. On the other hand, from the well-known Albert Einstain's equation ($E=mc^2$) it follows that energy is proportional to mass with a constant of proportionality - the speed of light in a vacuum squared. Is that why equation (8), but also numerous other equations in thermodynamics, necessarily contain atomic or molecular mass and heat capacities of gases. Sound in a given volume of gas (i.e., system) is the result of bringing energy from another system (for example environment) into a system where sound propagation occurs. Thus, one part of the energy supplied to the system (i.e., gas) is transformed into sound energy and the other part into other energy forms in the system. According to the First and the Second Law of Thermodynamics, a very complex interaction of different energy forms and simultaneous transformation of one energy form into another occurs in the considered volume of gas (i.e., system) during the process of sound propagation in gas, for example: thermal, mechanical, internal (translational, rotational, and vibrational energy of particles), kinetic, potential, sound energies, etc.

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ISTRAŽIVANJE GOVORNIH VJEŠTINA NA ENGLESKOM JEZIKU U INŽENJERSKOJ CLIL NASTAVI

A RESEARCH INTO THE ENGLISH LANGUAGE SPEAKING SKILLS IN ENGINEERING CLIL INSTRUCTION

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Kratki naučni članak

REZIME
U doba narastajuće svjetske potrebe za višejezičnošću nužno je propitati sve mogućnosti bržeg i efikasnijeg načina podučavanja stranih jezika. Umjesto pasivnih korisnika, potrebni su nam inžinjeri koji aktivno koriste strane jezike. CLIL je pristup koji insistira na ekonomizaciji vremena potrebnog za usvajanje stranog jezika. On to čini integriranjem nastave stranog jezika i nejezičkih nastavnih predmeta, što kod studenata povećava interesovanje i motiviranost. Rad istražuje govorne vještine na engleskom jeziku u inžinjerskoj CLIL nastavi.

Short original scientific paper

SUMMARY
In the time of the world's growing need for multilingualism it is necessary to examine all possibilities for teaching foreign languages in a faster and more efficient manner. Instead of passive users, we need engineers who actively use foreign languages. CLIL is an approach that insists on economization of time needed for foreign language acquisition. It does so by integrating a foreign language instruction into a non-linguistic subject matter, which increases students' interest and motivation. The paper investigates English language speaking skills in an engineering CLIL classroom.

1. INTRODUCTION

Modern era engineers are in a constant urge to translate various professional texts either from or into English. At the same time, they are supposed to be fluent in different speaking situations which, owing to the global digitalization and online communication, have become an everyday need.

For a long time, foreign language teaching praxis at engineering faculties utilized methods of *English for Specific Purposes* (ESP). This approach is language focused. The only connection to engineering is the fact that it uses specialized engineering vocabulary to exemplify grammar phenomena. Bearing in mind that the number of classes allocated for such type of instruction is usually insufficient, little time is left to communication and development of language skills.

When the method of *Content and Language Integrated Learning* (CLIL), which prefers development of language skills to grammatical accuracy, came into prominence, the Faculty of Mechanical Engineering in Zenica considered the possibility of its implementation. A pilot project and subsequent research was carried out. One of their phases addressing oral activities is the focus of this paper.

The next chapter presents some of the main features of CLIL, special attention being paid to speaking skills.

2. THEORETICAL BACKGROUND

2.1. Content and Language Integrated Learning – CLIL

CLIL is an approach in which a foreign language is used as a tool for mastering a non-language subject [1]. It emerged in 1990s and the idea behind was promotion of bilingualism and cross-curricular competencies [2]. Nevertheless, there are some other approaches which also promote similar values. The most popular ones are *immersion method* and *English for Specific Purposes*. Distinction among them arises from the fact that CLIL is the only one

that puts the same focus on the both: foreign language and the content of the non-language subject. Therefore, it can be said that CLIL is dual focused.

On the other hand, ESP and *immersion method* have only one focus each. ESP uses the content of non-language subject exclusively for its prime goal – foreign language acquisition, whereas *immersion method* subjects foreign language to the content of a non-language subject. In our country, immersion method is used predominantly in international schools where students are taught different subjects in a foreign language (usually English), the fluency of which is a precondition for enrollment into such schools. In other words, foreign language is only a tool for transferring knowledge related to different non-linguistic subjects.

In CLIL, however, foreign language has the same value as any other subject, and deserves equal attention and elaboration. The relation between them is not subordination but complementation, that is: foreign language is not only the means for transferring the content of a particular subject but also an additional and equally important curricular goal. CLIL is organized in such a way that a content of a certain subject is addressed through the use of those language forms and structures which are inevitable for its comprehension. In this process, it is important to keep the learning environment as natural and spontaneous as possible.

The language acquisition theory highlights two main types of environment: natural/spontaneous and artificial/guided [3]. While the traditional, *ex cathedra* language instruction is carried out in artificial/guided environment, where a teacher is the main source of foreign language, CLIL offers natural conditions in which students are exposed to ample foreign language iput from various sources and, as a consequence, master foreign language much more efficiently [1].

It should also be highlighted that CLIL presents a vivid, interactive approach which enables students to constantly apply and, if necessary, format their acquired knowledge during their mutual communication, thus providing yet another significant dimension to this approach. During the process, CLIL teachers are observers and guardians who incite students to work autonomously. This fact is highly important in developing speaking skills.

2.2. Oral activities in CLIL

Teaching speaking skills in a CLIL classroom is based on theoretical framework [4] which is largely drawn from empirical studies and underpinned by the central notions of second language acquisition such as *communicative competence, comprehensible input, negotiated interaction, input processing and communication strategies*. These notions have huge relevance in understanding oral language instructional practice and, as such, should stand behind each CLIL lesson preparation. Talking about oral practice, we should distinguish between oral production and oral communication activities. Oral production relates to formal speeches, presentations, lectures, etc. On the other hand, oral communication is an interactive process where an individual takes the role of a listener as well as of a speaker, e.g. conversation, discussions, debates, etc. Both activities are important in CLIL, but oral communication is the one that is usually first addressed before the students get self-confidence enough to independently produce longer chunks of language. CLIL actually stands on four, so called 'pillars', one of them being communication [1]. The very use of foreign language to communicate meaningful content enhances not only language acquisition but also the content comprehension, which is the main idea behind this approach. Language and content are intertwined in a way that all language objectives are derived from the content. Thus, rather than using social and everyday conversational language functions, speaking activities in CLIL use content matter specialized language and fulfill content matter specialized language functions.

There are two simultaneous processes going on during speaking activities in a CLIL classroom. The first one is negotiation of meaning, which is oriented towards the resolution of communication problems caused by specificies of content. The second process is *negotiation of form*, which is oriented towards linguistic issues resolution. In the process of *meaning negotiation*, CLIL calls for the interactive teaching style where students actively engage in communication with teachers and other fellow students. This leads to settling possible misunderstandings related to content, and to monitoring students' progress. At the same time, in the course of *form negotiation* students become aware of the formal features of

the message they are conveying. This process relies on peer and teacher's feedback as well.

Achievement of the above-mentioned goals poses many challenges before CLIL learners who are often reluctant to speak because they do not like to be under the classroom spotlight. There are many other reasons for their reluctance to speak in a foreign language such as, for example:

- Students feel uncomfortable while speaking a language in which they know they are making mistakes.
- It feels odd for them to communicate with classmates in a foreign language.
- It is very tiring to concentrate on producing a foreign language, especially when proficiency level is low.
- They often do not understand the point of speaking English all the time in class.
- Speaking English is not fun.

Therefore, especially in a traditional foreign language classroom, teachers usually talk most of the time, leaving students' talking time a very small percentage of the total class time. On the occasions when teachers initiate interaction, they normally get either one-word (yes/no) or a very simple, straightforward factual answers.

In order to overcome the challenges, CLIL finds necessary for teachers to provide certain spoken activities which enhance students' thinking skills and thus increase the amount of students' talking time in class. Thinking skills that proved to be the most efficient in that sense are *analyzing, comparing, problem solving* and *persuading*. It was the reason why we decided to include these skills in our research.

3. METHODOLOGY

3.1. Time, venue and participants

The research took place at the University of Zenica, in the period from 2009 to 2012. The participants were fourth-year students from two engineering faculties.

The experimental cohort that was exposed to CLIL classes (20 students) was from the Faculty of Mechanical Engineering (ME) and the control cohort that was not exposed to CLIL was from the Faculty of Metallurgy and Materials Science (FMM). Both were previously exposed to classes of English for Specific Purposes (ESP) for a period of an academic year.

3.2. Instruments

Instruments used in the research were as follows:
1. Textbooks in engineering (automatization)
2. Classroom material that was *ad hoc* prepared for the CLIL instruction.
3. Tests
4. Questionnaires

3.3. Preliminary research

To establish which language skill is the one that our participants were mostly interested in during the CLIL course, we asked them the following question:

> *As future engineers, which skill you find important to develop?*

Students were given the possibility of giving multiple answers. Table 1 shows the distribution of their answers:

Table 1. Students' responses in terms of importance of language skills

Language skill	Experimental	Percentage	Control cohort	Percentage
1. Speaking skill	20	100%	20	100%
2. Reading skill	18	90%	14	70%
3. Writing skill	10	50%	6	30%
4. Listening skill	16	80%	12	60%

The highest number of students' responses in both cohorts (experimental and control) was given to speaking skill (100%) which was chosen to be the focus of this paper. Both

cohorts recognised the importance of other skills as well, and they were an inevitable part of the research. Table 1 illustrates only students' preferences, in line with their needs.

Considering the fact that, in this paper, we aim to show only achievements related to speaking skills, results pertaining students' grammar knowledge and translation (test results) as well as the ones related to other skills will not be displayed here. In other words, we will present only that part of a research which addresses teaching speaking skills via development of students thinking skills which was already mentioned in the previous chapter. In that respect, it is necessary to provide a brief information on further research implementation.

3.4. Teaching speaking through thinking

The thinking skills that we wanted to develop in order to trigger students' speaking skills were *analyzing, comparing, problem-solving and persuading.* Those skills are inevitable in engineering praxis and, as such, familiar to our students. The principle used during the course was that the students were offered certain task (e.g. describe the process of designing new automation equipment). While analyzing the process and discussing it, students were using useful vocabulary that, along with some phrases, was given to them as scaffold. Scaffolding is important in this CLIL because students are not worrying about how to express themselves. Their thoughts are primarily occupied with the task (analyzing the given process) rather than with the language which comes in spontaneously. Thus, during the discussion, some of them showed that they knew additional words, some of them asked the professor for an unknown word, some of them looked up the word they needed in dictionaries. Speaking was not impeded by any need to be exceptionally precise in a linguistic sense, which made them free to speak and relaxed to acquire a new language. In other words, language acquisition was facilitated in a natural environment (see Chapter 2). Thinking skills, along with speaking skills, were constantly practiced during the course. Table 2 provides some of the instructions for activities used to incite conversation among the students in a CLIL classroom:

Table 2. Thinking skills in facilitating speaking and language acquisition

Skill	Sample task	Scaffold vocabulary	Scaffold phrases (Some of examples)	Language acquired
Analyzing	Analyze the auto-regulation stages	Analyze, break down, elements, aspects, components	a) the stages of auto-regulation are b) the process is divided into five main stages c) this stage takes about... hours d) the component plays a role of	a) listing b) classifying and passive c) phrasal verbs (to take about) d) illustration
Comparison	Compare and list differences between hydraulic and pneumatic drive	compare, in comparison, similar, analogy, same, like	a) despite these similarities, the two differ in b) It is important to distinguish between c) The two differ because one... while the other	a) markers of contrast, markers of similarity, b) regular and irregular comparison, c) complex conjunctions
Problem solving	Solve how to transmit digital signal in an environment with strong electromagnetic field	solve, possible solution, issue, hypothetically, chances are, likely, challenge, obstacle	a) The main problem is b) There are different ways to solve it c) I think the answer is... because... d) If we do...problem can be solved	Cause-effect markers, Conditionals

Skill	Sample task	Scaffold vocabulary	Scaffold phrases (Some of examples)	Language acquired
Persuading	Persuade your audience in necessity of using optical sensors rather than mechanical	persuade, convince, on the other hand, argue, claim, maintain, reason, (dis)advantages	a) I have several reasons for arguing this point of view b) Although not everybody would agree, I claim that c) These strongly suggest that d) It's also vital to consider	Concessive clauses

4. RESULTS AND DISCUSSION

At the end of the research students filled out a questionnaire in which they expressed themselves in terms of the achieved competencies (Table 3).

In experimental cohort (which attended CLIL classes) 50% of students stated that they succeeded to lead a short professional conversation in English as well as to make a short oral production on professional topics. In control cohort (the one that did not attend CLIL classes), such answers were given only by 15% of students.

The difference between these two groups (35%), showing progress in oral skills development, is on the side of experimental group (see Fig.1).
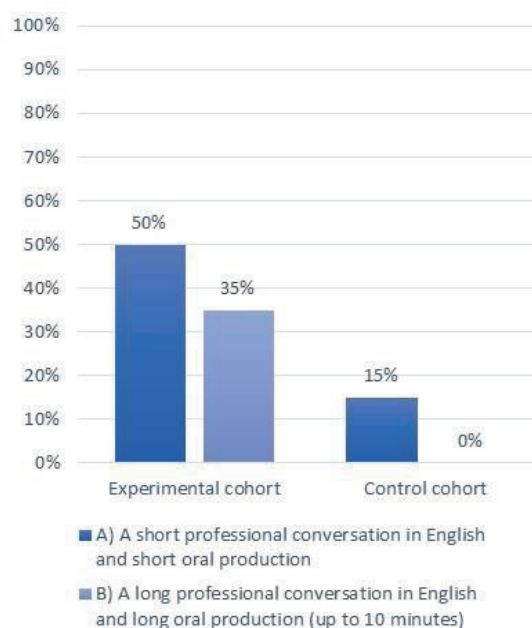

Fig 1. *Students' responses as to their speaking skills*

Table 3. Students' responses as to their speaking skills

I am capable of	Experimental cohort	Control cohort	Difference
	a	b	a-b
A) A short professional conversation in English and short oral production	50 %	15 %	35%
B) A long professional conversation in English and long oral production (up to 10 minutes)	35 %	0 %	35%

In case of students' leading a longer professional conversation or making longer oral production in English (over 10 minutes) 35% of students from the experimental cohort felt capable of leading such conversation, whereas nobody from the control cohort (the one that did not attend CLIL classes) stated to be able to lead longer conversation or to make longer oral production (Fig. 1).

A relatively huge difference in percentage which is, in any case, on the side of students who attended CLIL classes, confirms an important role of this approach in developing speaking skills.

The questionnaire included some other questions related to CLIL approach in general. In one of them, students were asked if they liked the instruction in which teaching of English is integrated with teaching a non-linguistic subject.

All of the students from experimental cohort were positive and here are some comments:

-   *Yes, I like it. We study such English that we need in our engineering praxis.*

- *There was a lot of conversation and I like it.*
- *We can learn two subjects at the same time.*
- *In this approach even the students who are not excellent in English could successfully participate.*
- *I like it because it helped me to pass the exam in Automation.*
- *In this way we learn faster.*

Finally, it should be noted that the questionnaire included a question related to the time which the students spent during the both types of instruction. No big difference between the cohorts was identified in this respect. This means that a possible introduction of CLIL in the current university curricula would not require corrections in ECTS credits, at least when foreign language instruction is concerned.

5. CONCLUSIONS AND RECOMMENDATIONS

The research has proven that CLIL at the tertiary level of education can have significant results in developing speaking skills. Application of this method can transform students from being passive observers (who do not dare to speak) to active speakers and learners. Also, CLIL students show satisfaction, not only in terms of the foreign language proficiency advancement, but also in terms of mastering the non-linguistic subject which was also included in CLIL.

Therefore, we feel free to recommend this type of instruction to other higher education institutions.

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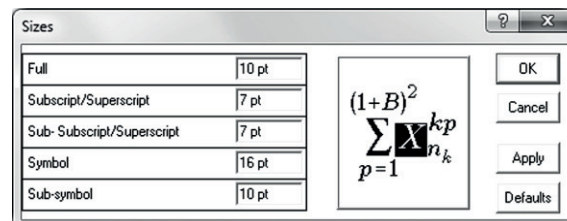

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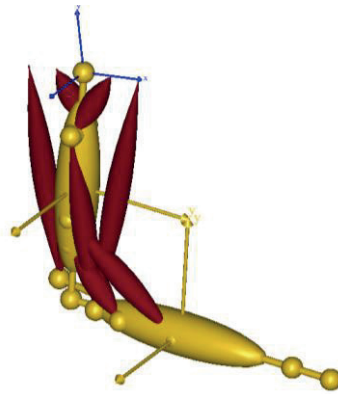*(Style: Times New Roman, 11pt, Italic)*

Figure 2 *Simplified musculoskeletal model of an arm*
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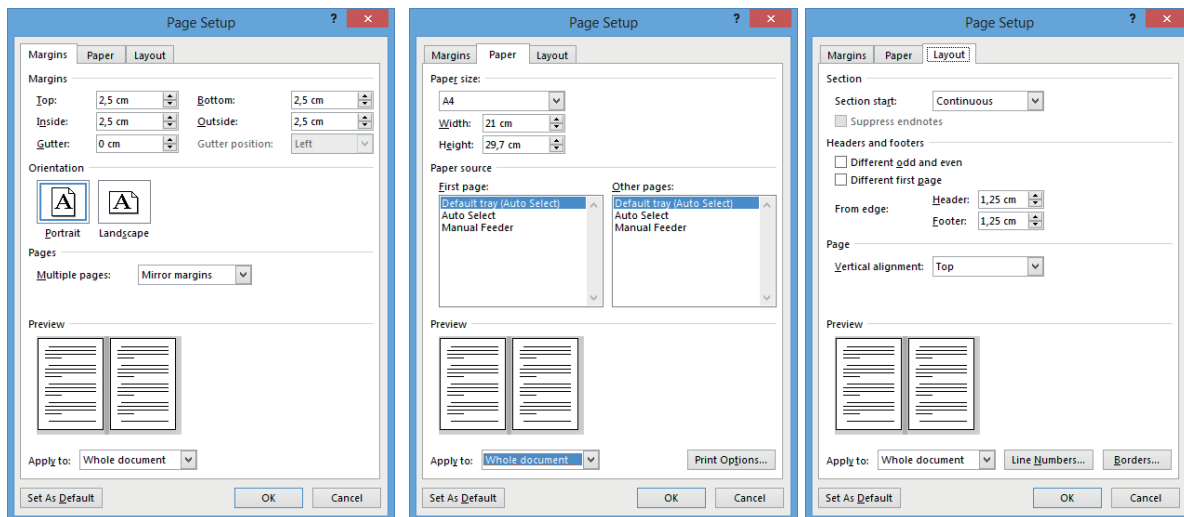
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Contribution to editorial decisions. Peer review assists the editor in making editorial decisions and through the editorial communications with the author may also assist the author in improving the paper.

Acknowledgement of sources. Reviewers should identify relevant published work that has not been cited by the authors. Any statement that an observation, derivation, or argument had been previously reported should be accompanied by the relevant citation. A reviewer should also call to the editor's attention any substantial similarity or overlap between the manuscript under consideration and any other published paper of which they have personal knowledge.

Table 1 Table titles
(Style: Times New Roman, 11pt, Normal)

Engineering stress σ_e / MPa	Engineering plastic strain $\varepsilon_{e,pl}$ / %	True stress σ_t / MPa	True plastic strain $\varepsilon_{t,pl}$ / %
250,0	0,00	250,8	0,00
250,0	0,21	250,8	0,21
285,7	1,35	290,0	1,34
322,7	2,13	330,1	2,10
358,4	3,06	370,0	3,00
393,1	4,35	411,0	4,24
423,6	6,05	450,1	5,85
449,7	8,76	490,1	8,36
457,0	15,79	530,1	14,59
467,9	21,58	570,0	19,45
475,0	29,77	617,5	25,94

(Style in table: Times New Roman, 11pt, Normal)

4.   CONCLUSION

Paper manuscripts, prepared in accordance with the Instructions for Authors, are to be submitted to the Editorial Board of the **"Mašinstvo"** journal. Manuscripts and the CD-ROM are not returned to authors. When prepared for printing, the text may undergo small alternations by the Editorial Board. Papers not prepared in accordance with the Instructions shall be returned to the first author. When there are several authors, the first author will be contacted. The Editorial Board shall accept the statements made by the first author.

5.   STYLE CITATION GUIDE
Bibliography
(Style: Times New Roman, 11pt, Normal)

The following recommendations are from The Chicago Manual of Style, University of Chicago Press, 15th ed., 2003. For further information and examples of additional types of sources, please visit http://www.chicagomanualofstyle.org

In the bibliography, please state your sources in accordance with the exmaples given below. Also, indent the second and subsequent lines.

Online sources that are analogous to print sources (such as articles published in online journals, magazines, or newspapers) should be cited similarly to their print counterparts but with the addition of a URL. Some publishers or disciplines may also require an access date. For online or other electronic sources that do not have a direct print counterpart (such as an institutional website or a weblog), give as much information as you can in addition to the URL.

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One author
[1] Doniger, Wendy. *Splitting the Difference*. Chicago: University of Chicago Press, 1999.

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New Suburban History, edited by Kevin M. Kruse and Thomas J. Sugrue, 99–119. Chicago: University of Chicago Press, 2006.

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If a book is available in more than one format, you should cite the version you consulted, but you may also list the other formats, as given below.
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[8] Martin, Steve. "Sports-Interview Shocker." *New Yorker*, May 6, 2002.

Article in an online journal, magazine or newspaper
Add the article's URL to the basic citation. However, for articles accessed through a third-party database (e.g., JSTOR), list the URL of the "main entrance" page of the database instead of the individual article, e.g. http://www.jstor.org/ or http://muse.jhu.edu/ If an access date is required by your discipline, include it parenthetically at the end of the citation.
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Websites
Websites may be cited in running text ("On its website, the Evanston Public Library Board of Trustees states . . .") instead of in an in-text citation, and they are commonly omitted from a bibliography or reference list as well. The following examples show the more formal versions of the citations. If an access date is required by your discipline, include it parenthetically at the end of the citation, as in the example below.
[10] Evanston Public Library Board of Trustees. "Evanston Public Library Strategic Plan, 2000–2010: A Decade of Outreach." Evanston Public Library. http://www.epl.org/library/strategic-plan-00.html (accessed June 1, 2005).

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