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RESEARCH ARTICLE

EXPERIMENTAL-ANALYTICAL DETERMINATION OF CUTTING CONDITIONS BY MEANS OF MINIMAL FRICTION FORCE ON RAKE PLANE OF THE CUTTING TOOL

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Abstract

In this paper, the influence of four factors on the forces during cutting, especially on the friction force was investigated. These factors are water quantity in MQL, speed, depth, and feed rate. In this study, the optimization of those factors to find their optimal combination for obtaining minimal intensity friction force has been looked into. The null hypothesis is that by using the MQL technique, the friction force can be significantly reduced. The experiment was planned using Taguchi's L9 design of experiments. The study included performing the machining of the workpiece through different combinations of levels for the spindle speed, feed rate, amount of water, and depth of cut as the main parameters.

Introduction:-

In current industrial processes, it is not enough to only obtain the final product. The new goal is to find the optimal way to produce by developing technology and new machines. The final product should aim to be as high quality and as low cost as possible. In addition, the production process should guarantee the maximum service life of tools and machines, since their repair and replacement represent a cost to manufacturers.

When it comes to cutting tools, many are not used to the maximum from the point of view of durability. Therefore, it is desirable to pay special attention to controlling factors that affect the production process and to investigate how to maximize the use of the tool before its replacement.

A problem in cutting processes is friction. When the rake surface of the tool has contact with the workpiece, friction arises, which impacts both process quality and the service life of the tool.

Several factors affect the process quality, changing the intensity of friction force and the durability of the cutting tool. Also, the friction force is influenced by many factors. This study focuses on four: MQL (one component of the MQL, or "near-dry-machining" [1] technique - the water quantity), depth of cut, feed rate, and cutting speed.

The initial hypothesis for this study is that MQL has a greater influence on friction force than the other factors. According to [2], by using the MQL, the cutting temperature can be reduced 10% to 30% compared to dry cutting. The reduction of temperature improves the tool life thus contributing to sustainable manufacturing. Also, according to [2], [4] and [5], by using the MQL, cutting force can be reduced by 5-17% and even to 28% compared to dry

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cutting. The reduced cutting force also means reduced power consumption, which is very important in terms of sustainability (energy savings) [3]. Since vegetable oil is used for this technique, it is much more acceptable than other cutting fluids from an environmental standpoint [4].

Experimental setup

The experiment was performed at the Faculty of Mechanical Engineering (University of Zenica), at the Laboratory for Metal Cutting and Machine Tools.

The cutting tool used for all the experimental procedures was a Mitsubishi SNMG120408-MA. The lathe used for operating the turning was a Potisje PA501M model, which is shown in Figure 1. The workpiece material is steel 1530, with a constant cross-section being Ø41.7 millimetres.

In addition to three originally planned factors: feed rate, depth of cut and spindle speed, a fourth factor was added: one component of the MQL (Minimum Quantity Lubrication) technique - the quantity of water. The fourth factor could be water or oil. In this study, it was decided that the water droplets variated (three levels: 10mL/min, 20mL/min, and 30mL/min) and the oil at a constant value of 30mL/h or every 12 seconds was set.

MQL is also known as „micro lubrication" and "near-dry-machining" [1]. It is commonly used instead of traditional cooling lubricants. This method itself has many economic and ecological advantages. MQL fluids replace mineral oils with a lesser amount of vegetable oil, which is environmentally friendly and more affordable. At the same time, cutting forces are reduced by 17% [5].

In Table 1, all four factors chosen for this study and their levels are presented. In table 2, the orthogonal array for Taguchi method is shown. This experiment contains four factors, every factor has three levels. For the optimal results, nine combinations of those factors and their levels will be needed.

Table 1:- Factors and their levels.

Factor level	Water [mL/min]	Feed rate [mm/rev]	Depth [mm]	Spindle speed [rpmin]
1	10	0.049	0.5	330
2	20	0.124	1.25	600
3	30	0.2	2	910

Figure 1:- Experimental setup with detail of nozzle section

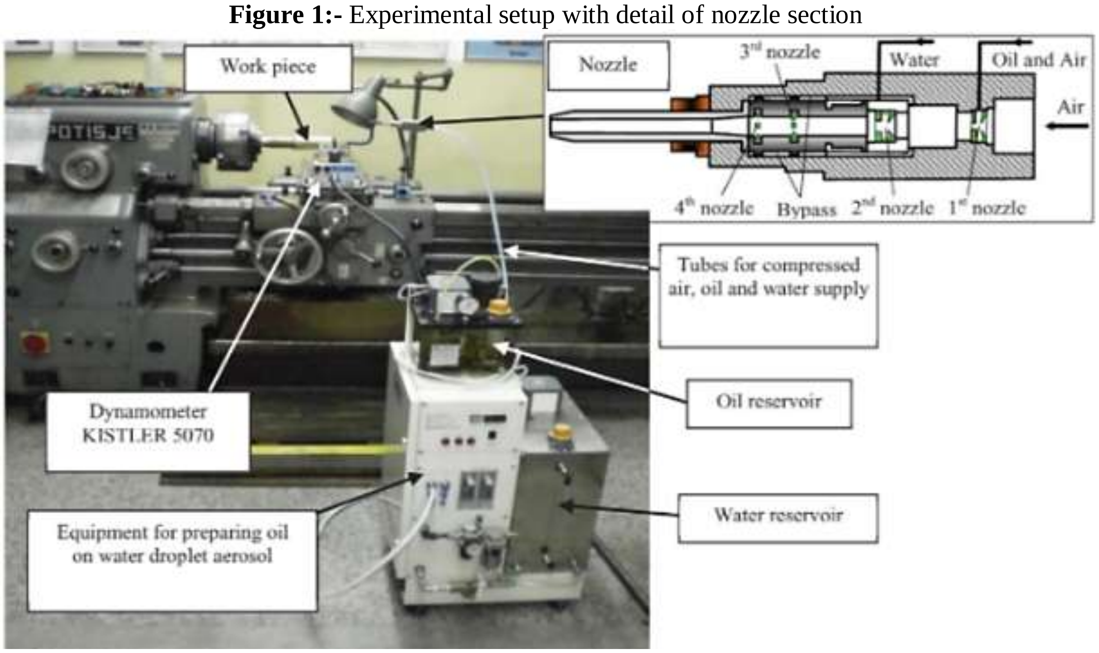

Table 2:- Orthogonal array for L_9 (3^4).

Experiment no.	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The resulting cutting force could not be measured, so it had to be calculated using measurements of the main cutting forces (Fz), thrust forces (Fy), and feed forces (Fx). In fact, these are the components of the resulting cutting force (FR), and they were measured using a Kistler dynamometer type 5070. The resulting force is calculated according to the expression (1):

$$F_R = \sqrt{F_x{}^2 + F_y{}^2 + F_z{}^2} \quad (1)$$

Friction force (T) also could not be measured, so it had to be calculated using the Merchant cycle, which is shown in figure 2:

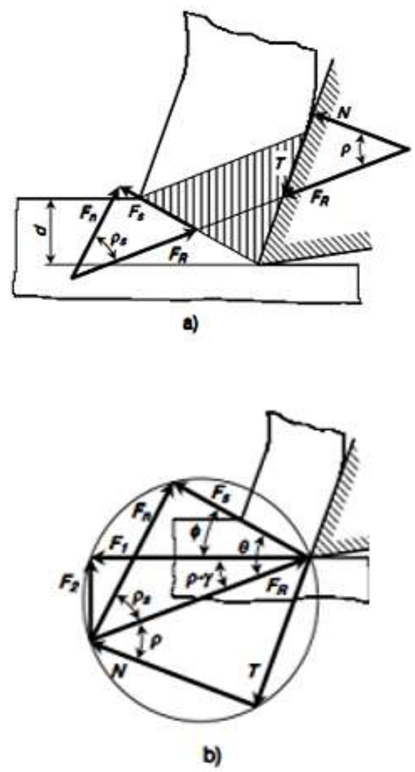

Figure 2:- Orthogonal cutting forces.

Values of the cutting angles are γ = 5°, α = 0° and coefficient of friction between cutting tool and workpiece is μ = 0.4.

$$T = \tan(\rho \cdot N) = \mu \cdot N.$$

$$\mu = \tan \rho$$

$\rho = \tan^{-1} \mu = \tan^{-1}(0.4) = 21.8°$ (2)

According to fig.2:

$$F_R = \frac{T}{\sin \rho} \quad (3)$$

$$T = F_R \cdot \sin \rho$$

Forces and angles used in formulas (2) and (3) are:

F_R - resulting cutting force [N]
T – friction force between a chip and a rake plane of the tool [N]
γ – rake angle of the tool
ρ – friction angle
μ - coefficient of friction between a chip and a rake plane of the tool.

I. Results of measurement and discussion

Results of measurement, along with results of the calculation, are shown in table 3.

Table 3:- Results of measurement and calculation.

No.	F_x [N]	F_y [N]	F_z [N]	F_R [N]	T [N]
1	38.9	44.50	91.50	108.93	40.404
2	167.3	173.20	375.60	446.16	165.492
3	341.9	346.80	800.90	937.34	347.679
4	134.6	134.80	210.90	284.19	105.414
5	219.8	212.20	568.70	645.57	239.455
6	86.5	17.60	240.50	256.18	95.025
7	155.4	152.00	296.80	367.89	136.458
8	83.3	106.46	186.88	230.64	85.551
9	217.1	223.36	563.90	644.20	238.950

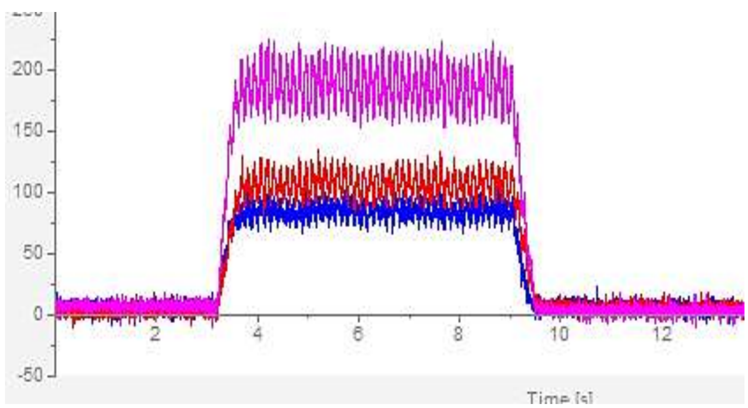

Figure 3:- Experiment no.8.

The results of measurement for experiment no.8 are given in figure 3. Once measured using a dynamometer, it is possible to observe how those results depend on time by connecting the dynamometer with a computer. The software which can be used for analysis of the measurement results is available on Kistler.com.

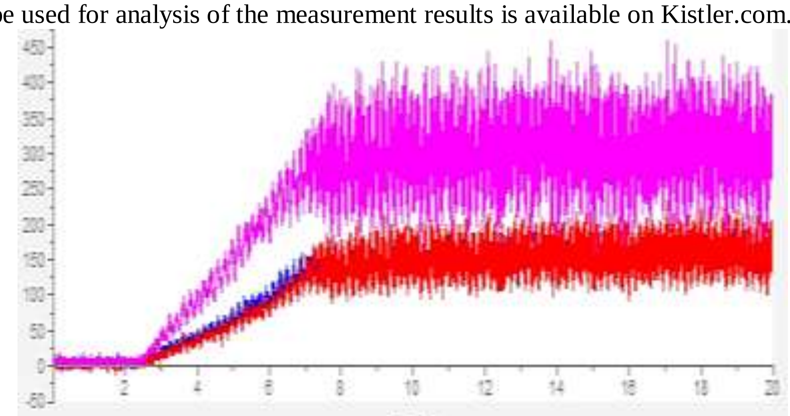

Figure 4:- Experiment no.8.

Self-generated vibrations appeared during experiment no.7. In the cutting processing, those vibrations occur when the cutting depth increases continuously. After a critical cutting depth, hence some critical width of the chip's cross-section is reached and a jump in oscillation amplitude is noticeable. The appearance of self-generated vibrations is not desirable because it implies that the entire machine-workpiece-tool system is unstable.

S/N ratio represents a particular type of data summary that combines two characteristics: the values which can be controlled (signal) according to the values which cannot be controlled (noise) and is used in the analysis of the data obtained in the determination of parameters. The signal-to-noise ratio represents a scattering around the desired value. The higher the value, the less wastage is. In this case, the S/N ratio is calculated according to "smaller the better", because the goal is to find the smallest magnitude of friction force value.

The formula used for S/N calculation is:
$\frac{S}{N} = -10 \log_{10} \left[\frac{1}{n} \left(\sum y^2\right)\right]$(4)

In the equation (4), y is equal to the magnitude of friction force.

The Minitab program calculates the S/N ratio for each combination of factors and then calculates the average S/N for each factor level.

Delta represents the difference between the highest and lowest average output value (in this case, friction force) for each factor. Minitab ranks these values as follows: 1 is assigned to the highest delta value, 2 is assigned to the lower value, and so on. The aim is to show the relative impact of each factor on the output.

Table 4:- Response table for Signal to Noise Ratios.

Level	Water [mL/min]	Feed rate [m/rev]	Depth [mm]	Spindle speed [r/min]
1	-42.44	-38.43	-36.78	-42.43
2	-42.53	-43.53	-44.13	-42.21
3	-42.97	-45.98	-47.04	-43.31
Delta	0.53	7.55	10.26	1.10
Rank	4	2	1	3

In table 5, the coefficients of regression are presented.

Table 5:- Coefficients of regression.

Term	Coef.	SE coef.	T-value	P-value	VIF
Constant	-65.9	56.0	-1.18	0.305	
Water [mL/min]	-1.54	1.47	-1.05	0.352	1.00
Feed rate [mm/rev]	882	194	4.54	0.010	1.00
Depth [mm]	111.7	19.5	5.72	0.005	1.00
Spindle speed [r/min]	0.0149	0.0505	0.29	0.783	1.00

According to table 5, the estimated regression equation is:

T[N] = -65,9 - 1,54 W (mL/min) + 882 F (mm/rev) + 111,7 D (mm) + 0,0149 S (r/min)

W – water [mL/min],

F – feed rate [mm/rev],

D – depth [mm],

S – spindle speed [r/min]

Conclusion:-

From the regression equation, that is, the regression model, the intensity of the friction force is most affected by the cutting depth, from which the null hypothesis that the MQL has the most impact can be rejected. MQL has the least impact when it is compared to three other factors examined in this study, such as depth, feed rate, and even speed.

By increasing the cutting speed, the intensity of the friction force is reduced. The minimum friction force is obtained by the following combination: water: 10 mL/min, feed rate: 0.049 mm/rev, depth: 0.50 mm, and speed 330 r/min. The maximum friction force is obtained by the following combination: water: 10 mL/min, feed: 0.200 mm/rev, depth: 2,00 mm and speed: 910 r/min. The latter combination is also the one (of all those listed in table 3) that should be avoided in practice because it affects the tool in the most damaging/negative way.

This study has some limitations that should be considered in applications and further research, and they can be defined as follows:

This paper did not examine the influence of temperature on friction force and on the overall cutting force. It is known that the MQL lowers the cutting temperature, and according to [2], the average cutting temperature could be reduced by 10-30% compared to dry machining, so the temperature could still be one of the crucial factors affecting the force of friction, leaving room for further research.

In addition, other studies could compare the intensity of the force of friction for a smaller or larger diameter of the workpiece with the same values of other factors.

References:-

[1] Boubekri N., Shaikh V., “Minimum Quantity Lubrication (MQL) in Machining: Benefits and Drawbacks”, Journal of Industrial and Intelligent Information Vol. 3, No. 3, September 2015

[2] E. A. Rahim, M. R. Ibrahim, A. A. Rahim, S. Aziz, Z. Mohid, “Experimental Investigation of Minimum Quantity Lubrication (MQL) as a Sustainable Cooling Technique”, Elsevier, available online at www.sciencedirect.com, 2015.

[3] Ekinović S., Begovic E., Ekinovic E., Fakic B., “Cutting Forces and Chip Shape in MQL Machining of Aluminium Bronze”, Journal of Trends in the Development of Machinery and Associated Technology Vol.17, No.1, 2013.

[4] Ekinovic S., Prcanovic B., Begovic E., “Investigation of influence of MQL machining parameters on cutting forces during MQL turning of carbon steel St52-3”, Elsevier, available online at www.sciencedirect.com, 2015.

[5] Kostadin, Tihana & Cukor, Goran & Mihalić, Tihomir, “Application of ecological principles in machining” Sigurnost. 61. 85-93. 10.31306/s.61.2.5., 2019.