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OPTIMIZATION OF MACHINING PARAMETERS IN BALL-END MILLING USING TAGUCHI METHOD

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ABSTRACT
This paper outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in ball-end milling when hardened steel. Ball-end milling parameters evaluated are the cutting sped, feed per tooth, depth of cut and radial depth of cut. The experiments were conducted by using $L_9(3^4)$ orthogonal array as suggested by Taguchi. Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA) are employed to analyze the effect of ball-end milling parameters on the orthogonal cutting forces in other words to find optimal levels of the process parameters. The study shows that the Taguchi method is suitable to solve the stated problem with minimum number of trials.
Keywords: Ball-end milling, Taguchi method

1. INTRODUCTION
Ball-end milling of complex surfaces is one of more common activities in the manufacturing of dies and moulds, aeronautical, aerospace or biomedical sectors. In the ball-end mill machining, many researches have treated of the cutting forces by using different methods. Reliable prediction of ball-end milling forces is significant for the simulation of the machinability, cutter breakage, cutter wear, chatter and surface quality. Subject of this study is to analysis dependence of the orthogonal cutting forces on the following four milling parameters: cutting speed $\boldsymbol{v}$, feed per tooth $\boldsymbol{f}$, depth of cut $\boldsymbol{a}$ and radial depth of cut $\boldsymbol{b}$. The Taguchi method, based on orthogonal arrays, has been used for determining the influence of particular cutting parameters. Taguchi method can be applied for optimization of process parameters to produce high quality products with lower manufacturing costs.

2. TAGUCHI METHOD
Classical experimental design method, i.e. rotatable central composite design, is too complex and not easy to use. A large number of experiments have to carried out especially when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments. Signal to noise ratio and orthogonal arrays are two major tools used in Taguchi method. Orthogonal arrays allow designers to study many design parameters simultaneously and can be used to estimate the effects of each factor independently. S/N ratio measures quality with emphasis on variation and orthogonal arrays accommodate many design factors simulataneously [1].

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The S/N ratio characteristics can be divided into three categories when the characteristic is continuous: nominal is the best, smaller the better and larger is better characteristics. For the minimal orthogonal cutting forces, the solution is „smaller is better", and S/N ratio is determined according to the following equation:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

where n is the number of replication and y_i is the measured value of output variable.
For each type of the characteristics, with above S/N ratio transformation, the higher S/N ratio the better is the result. To objective of experiment is to optimize the ball-end milling parameters to get better (i.e. low value) the orthogonal cutting forces values, the "smaller the better" characteristics are used, equation (1). The influence of each control factor can be more clearly presented with response graphs [2]. Optimal cutting conditions of control factors can be very easily determined from S/N response graphs, too.
Parameters design is the key step in Taguchi method to achieve reliable results without increasing the experimental costs. The experimental layout for the machining parameters using $L_9(3^4)$ orthogonal array was used in this study. The experimental results were analyzed with Analysis of Variance (ANOVA), which is used for identifying the factors significantly affecting the performance measures.

3. EXPERIMENTAL WORK

The experimental work was carried out at the company "ELMETAL" doo in Senta (Serbia). The experiments were conducted on vertical machining centre type "HAAS VF-3YT" in dry condition, using a carbide coated (TiAlN-T3) ball-end mill with ∅8 mm diameter ("EMUGE FRANKEN" type 1877A). All experiments were carried out using pre-annealed steel Č4150 (EN X210CR12) with hardness 58 HRC by orthogonal arrays with three levels (coded by: 1, 2 and 3), Table 1. During the experiments, orthogonal cutting forces were measured using Kistler dynamometer and sampled using a PC based data acquisition system with LabVIEW software. Experimental setup is shown in Figure 1.

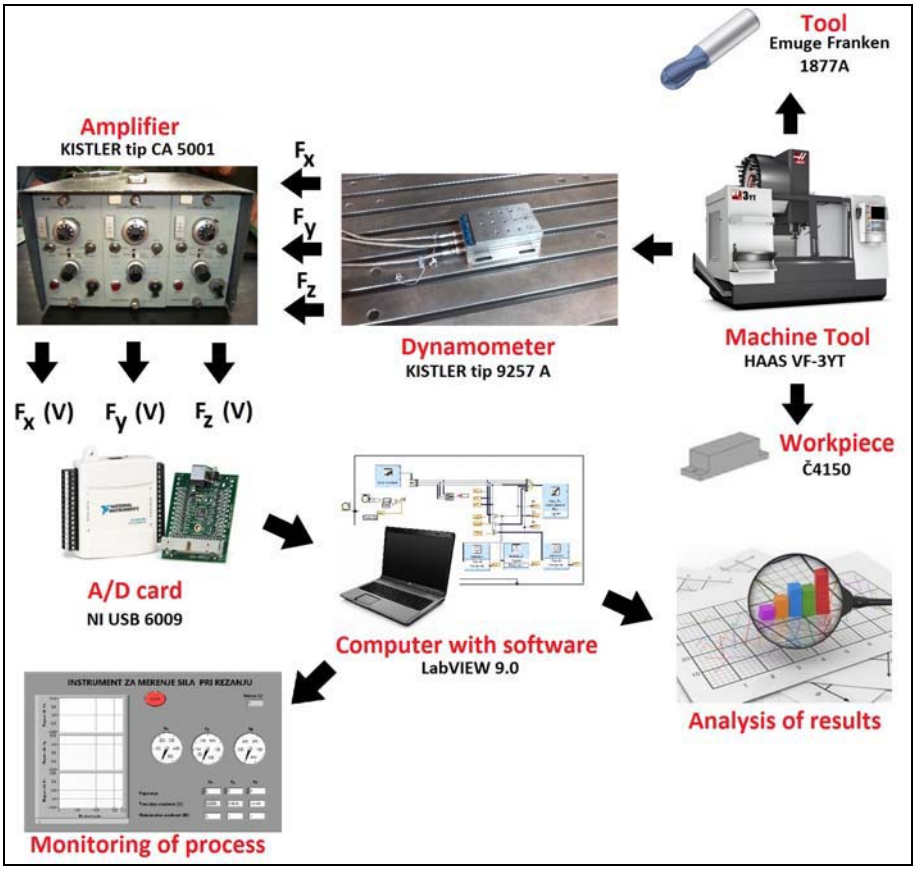

Figure 1. Experimental setup

Table 1. Machining parameters and their levels

Symbol	Parameters	Levels		
		1	2	3
A	Cutting speed, v (m/min)	80	100	125
B	Feed per tooth, f (mm/tooth)	0,04	0,05	0,0625
C	Depth of cut, a (mm)	0,32	0,40	0,50
D	Radial depth of cut, b (mm)	0,64	0,80	1,00

4. RESULTS AND DISCUSSIONS

Experimental results, together with their transformations into signal-to-noise ratios are given in Table 2. In this study all the analysis based on Taguchi method is done by Minitab14 software to determine the main effects of the cutting parameters, to perform the Analysis of Variance (ANOVA) and establish the optimum conditions.

Table 2. Orthogonal array $L_9(3^4)$ with experimental results and calculated S/N ratio

№	Factors				Parameters				Measured parameters			Calculated S/N ratio		
	A	B	C	D	v (m/min)	f (mm/tooth)	a(mm)	b(mm)	F_x (N)	F_y (N)	F_z (N)	S/N for F_x	S/N for F_y	S/N for F_z
	v	f	a	b										
1	1	1	1	1	80	0,04	0,32	0,64	114	74	100	-41,14	-37,38	-40,00
2	1	2	2	2	80	0,05	0,4	0,8	164	164	174	-44,30	-44,30	-44,81
3	1	3	3	3	80	0,0625	0,5	1	132	154	127	-42,41	-43,75	-42,08
4	2	1	2	3	100	0,04	0,4	1	184	222	172	-45,30	-46,93	-44,71
5	2	2	3	1	100	0,05	0,5	0,64	231	177	163	-47,27	-44,96	-44,24
6	2	3	1	2	100	0,0625	0,32	0,8	153	95	124	-43,69	-39,55	-41,87
7	3	1	3	2	125	0,04	0,5	0,8	101	161	175	-40,09	-44,14	-44,86
8	3	2	1	3	125	0,05	0,32	1	123	83	106	-41,80	-38,38	-40,51
9	2	3	2	1	125	0,0625	0,4	0,64	169	258	252	-44,56	-48,23	-48,03

From Table 2 it can be determined which control factors have strong influence on the orthogonal cutting forces in ball-end milling. Optimal cutting conditions of these control factors can be very easily determined from the S/N response graphs. The response graphics of cutting forces F_x, F_y i F_z have been shown for all four factors, in Figures 2, 3 and 4.

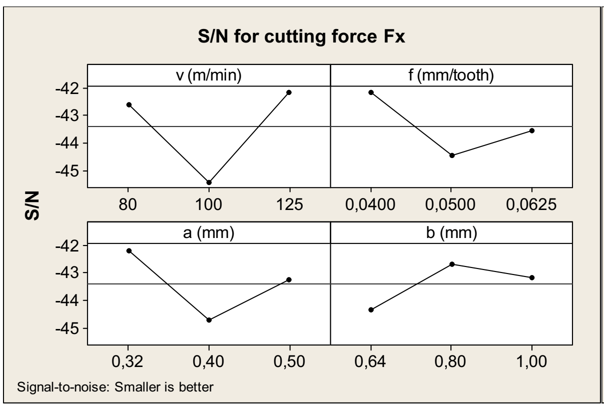

Figure 2. S/N response graphs for F_x

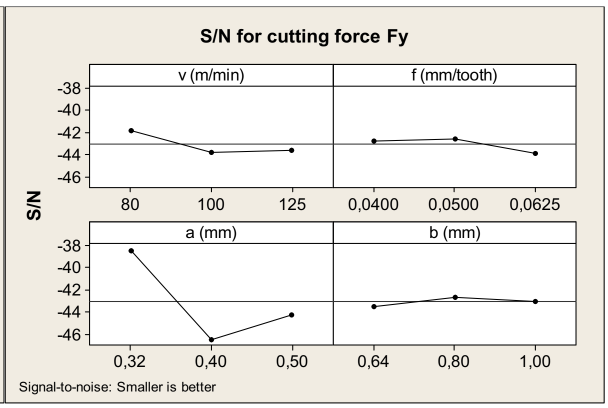

Figure 3. S/N response graphs for F_y

It can be seen from the presented graphs that cutting speed has the greatest influence on the cutting force F_x and depth of cut has the greatest influence on the cutting force F_y and F_z.

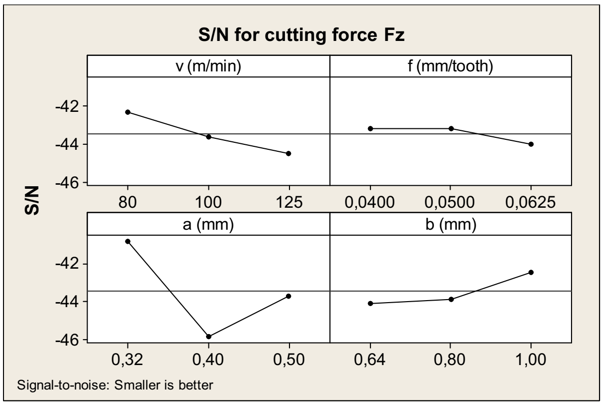

Figure 3. S/N response graphs for F_z

Optimal cutting conditions for the cutting forces F_x, F_y and F_z are shown in Table 3. These combinations enables the lowest the orthogonal cutting forces. ANOVA can be useful for determining influence of any given input parameter from a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. The experimental results were analyzed with ANOVA, which is used for identifying the factors significantly affecting the performance measures are shown in Table 4.

Table 3. Optimal settings of control parameters for F_x, F_y and F_z

	Cutting force Fx				Cutting force Fy				Cutting force Fz			
Control parameters	Level	Setting	F_x(N) obtained using Taguchi method	F_x (N) obtained using verif. test	Level	Setting	F_y(N) obtained using Taguchi method	F_y (N) obtained using verif. test	Level	Setting	F_z(N) obtained using Taguchi method	F_z (N) obtained using verif. test
v (m/min)	3	120	S/N=-39,04 F_x=89,6	F_x=93,6	1	80	S/N=-36,14 F_y=64,1	F_y=66,3	1	80	S/N=-38,34 F_z=82,5	F_z=85,4
f (mm/tooth)	1	0,04			2	0,05			2	0,05		
a (mm)	1	0,32			1	0,32			1	0,32		
b (mm)	2	0,8			2	0,80			3	1,00		

Table 4. ANOVA results for orthogonal cutting forces F_x, F_y and F_z

Para meter	DOF	Sum of squares			Variance			F-ratio			Pure Sum			Percent %		
		Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz
v	2	18,8	7,6	7,2	9,4	3,8	3,6	-	-	-	18,8	7,6	7,2	46,7	6,4	13,8
f	2	7,9	3,4	1,3	3,9	1,7	0,64	-	-	-	7,9	3,4	1,3	19,6	2,8	2,5
a	2	9,5	106,0	38,7	4,7	53,0	19,4	-	-	-	9,5	106,0	38,7	23,4	89,5	74,5
b	2	4,2	1,5	4,8	2,1	0,7	2,41	-	-	-	4,2	1,5	4,8	10,3	1,3	9,2
Other errors	8	0														
Total		40,46	118,51	51,98										100	100	100

5. CONCLUSION

This paper has discussed dependence of the orthogonal cutting forces of the four ball-end milling parameters. Taguchi method has been used to determine the main effects, significant factors and optimum machining conditions to the value of the cutting forces F_x, F_y and F_z. From analysis using Taguchi's method, results indicate that among the all-significant parameters, depth of cut is the most significant on cutting forces F_y and F_z, but cutting speed is the most significant on cutting force F_x. Results obtained from Taguchi method closely match with ANOVA.

7. REFERENCES

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