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Optimization of Turning Process by Using Taguchi Method

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Abstract

In this study, AISI 1040 steel is machined on CNC lathes. Taguchi L_{16} ortogonal array was used as experimental design. Experiments were carried out with selected the three cutting parameters. These parameters were determined as feed rate, cutting speed and cutting depth. Turning operation was carried out in dry conditions with diamond cutting tools. At the end of experiments, the values of surface roughness (Rz) on samples were found. Signal/Noise (S/N) rates were found with using the Taguchi method. According to the results, feed rate had the most significant effect on Rz among three factors. In ANOVA analysis, respectively feed rate, cutting depth and cutting speed are effective at 95% confidence level at Rz value. In repetition experiments carried out for parameters chosen in Taguchi prediction, it was identified that Taguchi works with nearly 94% accuracy.

Keywords: AISI 1040, turning, Taguchi, surface roughness.

1. INTRODUCTION

The purpose of the machining is to manufacture the part according to a certain degree of accuracy, not only to give a shape, but also to the geometry, size and surface shown in the part figure. The surface quality, including the surface accuracy of the part, is the most important feature that guides the determination of the chip removal process. In machining, multiple parameters affect the shear forces [1-3]. The machining method is the parameters that influence the surface quality of the cutter, the mechanical properties of the cutter, the material being processed, the physical factors, the chemical factors, the thermal factors, the cooling fluid, the cutting fluid and the interrupted fluid [4-6].

Turning is the removal of metal from the outside diameter of a rotating cylindrical part. Turning is generally used to reduce the diameter of the workpiece to a certain size and to obtain a smooth metal surface [7].

The steel materials used in the manufacturing industry are gradually improving and are among the most preferred materials in the machining industry. Steel material; food industry, healthcare, automotive and aerospace industries [8].

Surface roughness decreases with increasing cutting speed in researches, increasing with progress and increasing chip depth values [9]. In machining, generally better surface quality is obtained at high cutting speeds [10]. However, the same surface quality can not be maintained for a long time because the high cutting speed accelerates tool blunting [11].

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The most effective way to achieve maximum industrial efficiency during production is to determine and apply optimum production parameters. The material and vehicle manufacturer informs the manufacturer about the use of the product, but this information does not include materials, tools and processing conditions [12]. Here, different statistical methods, artificial intelligence methods, simulation methods are introduced and assist the user in selecting the optimum process [13, 14]. Data obtained during processing by many investigators are analyzed using different statistical methods such as ANOVA (variance analysis), Taguchi methods, factorial design and response surface method (RSM) [15]. The Taguchi experiment design method emerges as a successful method of solving optimization problems by increasing processing performance with fewer experiments and less cost. The biggest advantage of the Taguchi method is that it can predict the end result. The Taguchi method avoids unnecessary experiments and saves time and cost [16].

In this study, we analyzed the obtained surface roughness with Taguchi analysis. The optimal values, the most effective parameters and ANOVA analysis were examined by Taguchi analysis. As the last phase of our work, repeat experiments were performed and Taguchi estimation results and absolute error amount were found in percent.

2. EXPERIMENTAL DESIGN

In our study, the material of AISI 1040 steel was used as workpiece. This material is generally used in the automotive, machine and mold industries. The chemical content of material was given in Table 1.

Table 1. Chemical content of material

Element	Mn	C	Si	S	P
%	0,6-0,9	0,38-0,45	0,15-0,35	≤0,05	≤0,04

Hardness of the material was increased by applying the heat treatment. At the end of this operation, material hardness was seen about 46 HRc by BMS Digirock hardness measurement machine.

The turning diameter and turning size of the samples were selected as 80 mm and 135 mm. The surfaces of the samples were cleaned before turning.

In our experiments, we used ACE LT-20C brand CNC lathe. In our machining, no cutting fluid was used. Samples were machined in dry cutting conditions. For turning operations, Teknik 2525 M15 brand tool holder was used. Also we selected the DNMG 15 06 08 diamond cutting tool for turning the samples. We selected the 50 mm for machining distance. Cutting tool, tool holder and CNC lathe were given in the Figure 1.

Figure 1. The cutting tool, tool holder and CNC lathe

We determined the cutting parameters from catalogue of manufacturer company. Three different parameters were selected as feed rate, cutting speed and cutting depth. Also four different levels were determined for each parameters according to catalogue. Selected the parameters and levels of these parameters were given in Table 2.

If we have done 64 experiments with full factor, this will cause both waste of time and serious costs. L16 orthogonal array was designed using the taguchi method to reduce production time and reduce costs. After the experiments performed by applying the parameters and levels given in Table 2, the Rz values formed on the workpiece surface were measured. Mitutoyo Surftest SJ-210 device was used for surface roughness (Rz) measurements.

The experiments were carried out in five times. Rz values of experiments were determined by calculating the average of the measured Rz values of each experiment. the cutting tool we selected can cut through four different edge. But we used only one edge for each experiment. Designed experiment list in Taguchi and measured Rz are given in Table 3.

Table 2. Cutting parameters and their levels

Cutting parameters	Level-1	Level-2	Level-3	Level-4
Cutting speed(m/min)	200	225	250	275
Feed rate(mm/rev)	0,15	0,25	0,35	0,45
Cutting depth(mm)	1,5	2,5	3,5	4,5

3. RESULTS

We aimed the optimal cutting conditions for desired surface quality. For the best surface quality, minimum surface roughness is wanted. Therefore, we choosed “the smaller is better” S/N ratio in MINITAB program.

In this program, Rz values were converted to S/N ratios with “smaller is better” equivalent. S/N rates obtained by using this equation are given in Table 3.

Table 3. L_{16} orthogonal experimental design, experimental results and S/N ratios

Experimental number	Cutting speed (m/min)	Feed rate (mm/rev)	Cutting depth (mm)	Rz (μm)	S/N
1	1	1	1	5,83	-15,31
2	1	2	2	12,01	-21,59
3	1	3	3	21,36	-26,59
4	1	4	4	33,06	-30,39
5	2	1	2	7,42	-17,41
6	2	2	1	12,35	-21,83
7	2	3	4	23,10	-27,27
8	2	4	3	31,77	-30,04
9	3	1	3	5,18	-14,29
10	3	2	4	12,81	-22,15
11	3	3	1	20,09	-26,06
12	3	4	2	30,82	-29,78
13	4	1	4	8,69	-18,78
14	4	2	3	12,38	-21,85
15	4	3	2	21,25	-26,55
16	4	4	1	30,41	-29,66

In Taguchi, Signal/Noise(S/N) ratio is the most effective thing for the evaluation of the test results is. In our work, so as to obtain the most appropriate cutting parameters and levels using Taguchi, maximum value of the S/N ratio must be taken. In these conditions, in the L_{16} orthogonal array optimal cutting condition for Rz was found as -14,29 S/N ratio in Table 3. 250 m/min cutting speed, 0.15 mm/rev feed rate and 3.5 mm cutting depth; in these values optimal cutting conditions were determined for the smallest Rz value. the Level values of the factors found from MINITAB 14 for Rz as using the Taguchi method are shown in Table 4. In

Figure 2, the graphic of the level values given in Table 4 is shown. In the determination of the optimal cutting conditions of the experiments that will be carried out from now on, the interpretations are made according to the level values of the selected parameters specified in Table 4 and Figure 2. In this case, it can be seen in Figure 2 and Table 4 that the third level of the cutting speed factor, the first level of the feed rate factor and the third level of the cutting depth factor are high. Therefore, the optimal cutting parameters were seen in 313 ortogonal array (250 m/min, 0,15 mm/rev, 3,5 mm). Moreover, the effect of the cutting parameters to the surface roughness were respectively obtained for each parameters in Table 4.

Table 4. Surface roughness factor for S / N answer table

Level	A	B	C
1	-23,47	-16,45	-23,22
2	-24,14	-21,86	-23,83
3	-23,07	-26,62	-23,19
4	-24,21	-29,97	-24,65
Delta	1,14	13,52	1,45
Rank	3	1	2

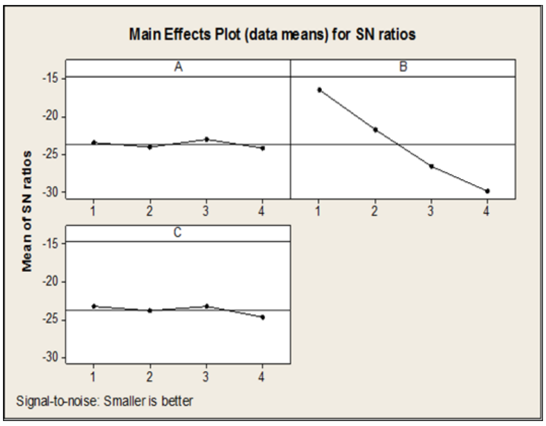

Figure 2. Factor level's graphic of Rz according to S/N ratios

The relation between analysis of variance and cutting parameters were determined. The relations of the S/N with selected cutting parameters were assessed. The results of the S/N rates according to ANOVA are shown in Table 5. According to the ANOVA results, the significance level must be $p<0.01$ or $p<0.05$. According to these results, the most significant value order is respectively feed rate, depth of cut and cutting speed. The cutting speed, feed rate and cutting depth displayed activity at 95% confidence level.

Table 5. The relationship among the S/N rates of factors

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	3,61	3,61	1,203	1,67	0,270
B	3	415,087	415,087	138,362	192,47	0,000
C	3	5,612	5,612	1,871	2,6	0,147
Residual Error	6	4,313	4,313	0,719		
Total	15	428,623				

Taguchi aims at lowering the number of design experiments and at acquiring the correct results in short period of time. The estimation experiments carried out in this study did not take the time and the cost into consideration, these experiments were carried out to prove that Taguchi estimation is close to the real values. In the last stage of the Taguchi analysis, estimations were made for the levels given in the Table 6. In Table 6, the results of the Taguchi estimation, experiment results and the absolute error between these estimations were given in percentages. Under the light of these results Taguchi estimation is 94% correct.

Table 6. Absolute error (%) among the predicted results and Rz results

Cutting speed (m/min)	Feed rate (mm/rev)	Cutting depth (mm)	Experimental Rz (µm)	Taguchi estimated Rz(µm)	Absolute difference	Absolute error(%)
1	1	4	6,74	7,19	0,45	6,65
3	2	2	10,79	11,42	0,63	5,80
2	3	1	20,71	21,21	0,50	2,42

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, the analysis of the Rz values was made for the optimisation of the turning process by using Taguchi experiment design. The results of the study are given below.

For the four different level of the cutting speed, feed rate and cutting depth that are the cutting factors. Also we designed L_{16} array in MINITAB 14 by using the Taguchi method. Thanks to this, instead of 64 full factorial experiments, 16 experiments were carried out. In the result, S/N ratio of Rz was found. By using "smaller is better" S/N ratio rule, the highest value was searched in S/N value. The highest S/N values gives us the most available parameters. For the lowest surface roughness in the turning operation, the optimal cutting conditions that correspond to Rz value's maximum -14,29 S/N value were emerged in 9th experiment. This experiment was carried out with using 313 ortogonal array (250 m/min, 0,15 mm/rev, 3,5 mm).

By applying the analysis of variance to the S/N ratios, relation levels of the cutting parameters on Rz were determined. In ANOVA, respectively feed rate, cutting depth and cutting speed are effective at 95% confidence level at Ra value.

By comparing the Taguchi estimation with experiment result, it was found in Taguchi estimation is about 94% accurate.

In the subsequent studies, different materials, different cutting tools, different process methods, tool wears, cutting force, vibration and acoustic emission measurements are advised.

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