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An Optimization of Machine Parameters for Modified Horizontal Boring Tool Using Taguchi Method

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***Abstract*—**This paper presents the findings of an experimental investigation of important machining parameters for the horizontal boring tool modified to mouth with a horizontal lathe machine to bore an overlength workpiece. In order to verify a usability of a modified tool, design of experiment based on Taguchi method is performed. The parameters investigated are spindle speed, feed rate, depth of cut and length of workpiece. Taguchi L9 orthogonal array is selected for four factors three level parameters in order to minimize surface roughness (Ra and Rz) of S45C steel tubes. Signal to noise ratio analysis and analysis of variance (ANOVA) is performed to study an effect of said parameters and to optimize the machine setting for best surface finish. The controlled factors with most effect are depth of cut, spindle speed, length of workpiece, and feed rate in order. The confirmation test is performed to test the optimal setting obtained from Taguchi method and the result is satisfactory.

***Keywords*—**Design of Experiment, Taguchi Design, Optimization, Analysis of Variance, Machining Parameters, Horizontal Boring Tool.

I. Introduction

DESIGN of experiment is a powerful tool for parameters analysis and process optimization in many disciplines such as agriculture, petrochemical, and manufacturing. It enables engineers to simultaneously analyze many different factors that affect the interested output at a time. However, with an increase in the number of factors, the number of experiments also increases and so does the cost to run experiments. Taguchi method reduces the number of experiments drastically while remains statistically informative by using predefined orthogonal arrays. It is also a major tool in robust design to obtain a product or process which is insensitive to various noise conditions. In manufacturing, Taguchi method is widely used to optimize machine parameters such as cutting speed, cutting depth, or machine feed. The three characteristics to obtain signal to noise ratio are nominal the best to achieve target result, smaller the better to minimize the output and larger the better to maximize the output. The equations for said characteristics are as follows;

Nominal the best characteristic;

$$S/N = 10log\,\frac{\bar{y}}{S_{\bar{y}}^2} \quad (1)$$

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Smaller the better characteristic;

$$S/N = -10log\,\frac{1}{n}\left(\sum y^2\right) \quad (2)$$

Larger the better characteristic;

$$S/N = -10log\,\frac{1}{n}\left(\sum \frac{1}{y^2}\right) \quad (3)$$

Previous works have been done by many engineers and Taguchi technique was successfully used to obtain optimal machine parameters in their studies. Youssef et al. [1] made a comparison between different methods of design of experiment namely full factorial design, fractional factorial design and Taguchi design. They found that Taguchi design and fractional factorial design were sufficient for screening process parameters and was able to reduce experiments from 288 trials of full factorial design to only 16 trials. The data analyzed by Taguchi method was reliable without losing valuable information and at the same time was more economical than full factorial design. Said et al. [2] compared between Taguchi method and response surface methodology (RSM) to optimize machining condition for aluminum silicon alloy (AlSic) and found that Taguchi method required less number of experiments than RSM while accurately optimized machining condition. Taguchi method was recommended due to time and cost advantages over RSM. Asilturk and Akkus [3] used Taguchi approach to determine optimum condition for hard turning of hardened AISI 4140 alloy steel. The signal to noise ratio (S/N ratio) and analysis of variance (ANOVA) were used to determine effect of machine parameters i.e. cutting speed, feed rate, and depth of cut and their interactions. Optimum cutting parameters for hard turning process to achieve minimum surface finish was found. Kirby et al., [4] used Taguchi design to optimize machine parameters in turning operation. The control parameters in their study were spindle speed, feed rate, depth of cut and tool nose radius. They also set up noise factors by observing at different room temperature and using different cutting tool dimensions. Taguchi approach was effectively used and optimum turning parameters was found for various operating temperature and tool dimensions. Other experiments using Taguchi approach are listed in [5]-[11].

In this study, Taguchi method is used to analyze and optimize machine parameters for a boring tool modified to mount on a horizontal lathe machine. The tool is designed to bore inner surface of a cylindrical tube by mounting a mandrel equipped with carbide insert to machine spindle while holding workpiece in place. In contrast with normal turning process,

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the mandrel with carbide insert is a moving part and the workpiece is tightly clamped. With this unique setup, normal machine parameters for turning process cannot be used and experiments are required to validate the usability of modified machine. Taguchi L9 orthogonal array is selected to analyze four machine parameters with three levels namely cutting speed, feed rate, depth of cut, and length of workpiece. An arithmetic average surface roughness (Ra) and average maximum height of the profile (Rz) are considered for quality inspection with smaller the better characteristic.

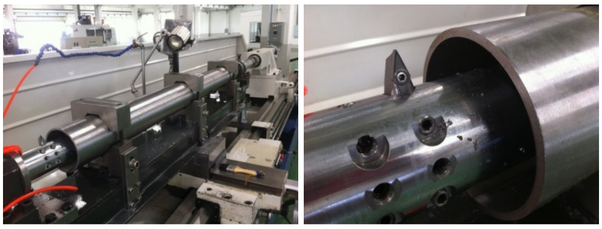
II. Experimental Details

A. Material and Equipment

The tested material is S45C cylindrical tubes with a length of 1,500 mm, inner diameter of 110 mm, and thickness of 5 mm. The standard chemical composition of tested material is shown in Table I. The mandrel is equipped with Kennametal V-shaped carbide cutting insert ISO coding VBGT-160408HP with nose radius of 0.8 mm. The machine set up is shown in Fig. 1.

TABLE I
CHEMICAL COMPOSITION OF S45C STEEL

	C	Si	Mn	P	S	Cr	Ni	Cu
%Weight	0.42-0.48	0.15-0.35	0.6-0.9	≤0.03	≤0.03	≤0.2	≤0.2	≤0.2



(a) (b)

Fig. 1 (a) Workpiece and machine setup for modified boring tool on lathe machine, (b) V-shaped carbide cutting insert equipped on a spinning mandrel

The boring tool is modified to mount on a six meter lathe machine brand Evorex model H840. The mandrel equipped with carbide cutting insert is tightly attached to the machine spindle with head and tail stock. The workpiece is hold in place with three clamps.

B. Taguchi Design of Experiment

In this study, four machine parameters which are cutting speed, feed rate, depth of cut, and length of workpiece are analyzed. The four factors with three levels are assigned to L9 (3^4) orthogonal array as shown in Table II. The experiment is done with two replications with a total number of 18 trials using sequences shown in Table III, then, an arithmetic average surface roughness (Ra) and average maximum height of the profile (Rz) are measured for outputs. Taguchi criteria for smaller the better characteristic is used to calculate signal to noise ratio for each factors. Analysis of variants (ANOVA) is also performed to analyze each main effect and compare with Taguchi method.

TABLE II
FACTORS AND LEVELS USED IN THE EXPERIMENT

		Levels		
	Factors	1	2	3
A:	Feed rate (mm/rev)	0.1	0.2	0.3
B:	Spindle speed (rpm)	76	86	115
C:	Length of workpiece (mm)	0-500	500-1,000	1,000-1,500
D:	Depth of cut (mm)	0.4	0.8	1.2

mm = millimeter, rpm = round per minute, rev = revolution

TABLE III
EXPERIMENTAL SEQUENCE USING CODING

Run No.	A	B	C	D	Run No.	A	B	C	D
1	2	2	3	1	10	1	3	3	3
2	3	3	2	1	11	2	1	2	3
3	1	1	1	1	12	3	2	1	3
4	3	2	1	3	13	3	1	3	2
5	2	1	2	3	14	1	2	2	2
6	1	3	3	3	15	2	3	1	2
7	3	1	3	2	16	1	1	1	1
8	1	2	2	2	17	3	3	2	1
9	2	3	1	2	18	2	2	3	1

III. Results and Discussion

A. Surface Roughness Measurement

Surface roughness measurement is one of the most important requirements in many engineering applications, as it is considered an important index of product quality. [12] In this study, an arithmetic average surface roughness (Ra) and average maximum height of the profile (Rz) are used as quality criteria. The lower the value of both profiles means the better surface finish and resulting in higher quality of finished parts. In order to measure inner surface, each finished tube is cut into three pieces according to the level assigned by Taguchi design and marked accordingly.

Each piece is then cut again in the middle along the length to open the inner surface for roughness testing.

(a) (b)

Fig. 2 (a) Surface roughness measuring system (b) Surface roughness measuring probe and tested workpiece

TABLE IV
RESULTS OF SURFACE ROUGHNESS MEASUREMENT

	Coded Unit				Uncoded Unit				Ra (µm)		Rz (µm)	
No.	A	B	C	D	A	B	C	D	Rep1	Rep2	Rep1	Rep2
1	1	1	1	1	0.1	76	0-500	0.4	10.257	9.338	76.076	72.782
2	1	2	2	2	0.1	86	500-1,000	0.8	13.237	14.389	96.675	98.331
3	1	3	3	3	0.1	115	1,000-1,500	1.2	3.548	2.832	24.948	19.050
4	2	1	2	3	0.2	76	500-1,000	1.2	9.316	10.668	70.984	60.285
5	2	2	3	1	0.2	86	1,000-1,500	0.4	2.398	2.520	19.210	24.397
6	2	3	1	2	0.2	115	0-500	0.8	11.750	10.763	90.940	82.422
7	3	1	3	2	0.3	76	1,000-1,500	0.8	16.693	14.142	113.896	95.532
8	3	2	1	3	0.3	86	0-500	1.2	2.576	3.028	14.893	23.298
9	3	3	2	1	0.3	115	500-1,000	0.4	9.313	9.764	68.704	69.125

TABLE V
SIGNAL TO NOISE RATIO FOR RA AND RZ

No.	Coded Unit				Ra (µm)		S/N ratio for Ra	Rz (µm)		S/N ratio for Rz
	A	B	C	D	Rep1	Rep2		Rep1	Rep2	
1	1	1	1	1	10.257	9.338	-19.8318	76.076	72.782	-37.4370
2	1	2	2	2	13.237	14.389	-22.8133	96.675	98.331	-39.7807
3	1	3	3	3	3.548	2.832	-10.1302	24.948	19.050	-26.9254
4	2	1	2	3	9.316	10.668	-20.0129	70.984	60.285	-36.3714
5	2	2	3	1	2.398	2.520	-7.8178	19.210	24.397	-26.8315
6	2	3	1	2	11.750	10.763	-21.0364	90.940	82.422	-38.7690
7	3	1	3	2	16.693	14.142	-23.7899	113.896	95.532	-40.4334
8	3	2	1	3	2.576	3.028	-8.9775	14.893	23.298	-25.8240
9	3	3	2	1	9.313	9.764	-19.5920	68.704	69.125	-36.7663

The surface roughness is measured using surface roughness measuring system brand Mitutiyo Model Surftest SV-2000/3000 as shown in Fig. 2. The measured result of surface roughness Ra and Rz is shown in Table IV.

B. Analysis of Signal to Noise Ratio

Signal to noise ratio (S/N ratio) is a measurement scale normally used in communication and electrical engineering. It is a ratio of output signal and noise. The higher the S/N ratio means the more strength of the output signal to ambience noise. Taguchi applied this concept along with orthogonal array to his approach to design of experiments. By comparing S/N ratio between each control factors, the one with higher value is the one which has more effect to the output. S/N ratio can be characterized into three characteristics which are nominal the best, smaller the better, and larger the better and they represent the ratio of sensitivity to variability of experimental results. In this experiment, S/N ratio with smaller the better characteristic is used in order to minimize the surface roughness of finished products. Signal to noise ratio of surface roughness Ra and Rz calculated using Minitab 16 is shown in Table V. Main effect plots for S/N ratio of Ra and Rz are shown in Figs. 3 and 4 respectively.

In this experiment, the machine parameter which has most effect on surface roughness both Ra and Rz listed from maximum effect to minimum effect is Depth of Cut, Spindle Speed, Length of workpiece, and Feed Rate as shown in Table VI and VII. An optimal level for each factor is the level with highest S/N ratio, thus, an optimal level is A2B2C3D3. The main effect plots for means of surface roughness Ra and Rz shown in Fig. 5 and 6 illustrate that surface roughness Ra and Rz is at minimum when controlled factors are at A2B2C3D3 in accordance with S/N ratio analysis.

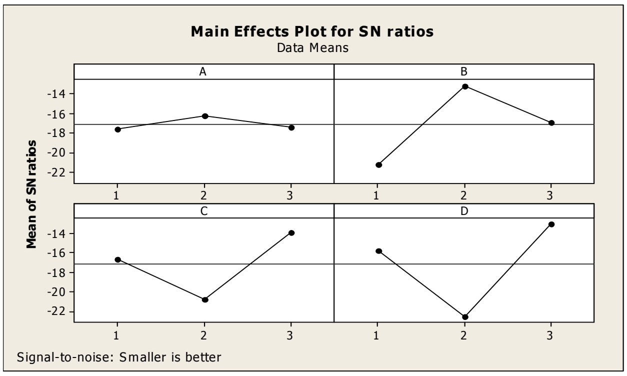


Fig. 3 Main effect plots for signal to noise ratio of Ra

TABLE VI
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO OF RA

Level	A	B	C	D
1	-17.59	-21.21	-16.62	-15.75
2	-16.29	-13.20	-20.81	-22.55
3	-17.45	-16.92	-13.91	-13.04
Delta	1.30	8.01	6.89	9.51
Rank	4	2	3	1

TABLE VII
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO OF RZ

Level	A	B	C	D
1	-34.71	-38.08	-34.01	-33.68
2	-33.99	-30.81	-37.64	-39.66
3	-34.34	-34.15	-31.40	-29.71
Delta	0.72	7.27	6.24	9.95
Rank	4	2	3	1

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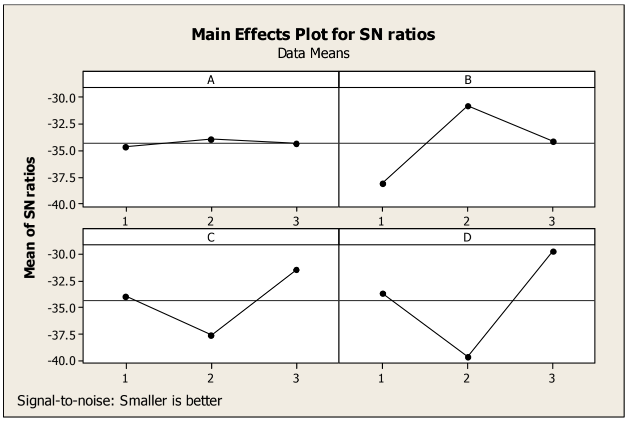

Fig. 4 Main effect plots for signal to noise ratio of Rz

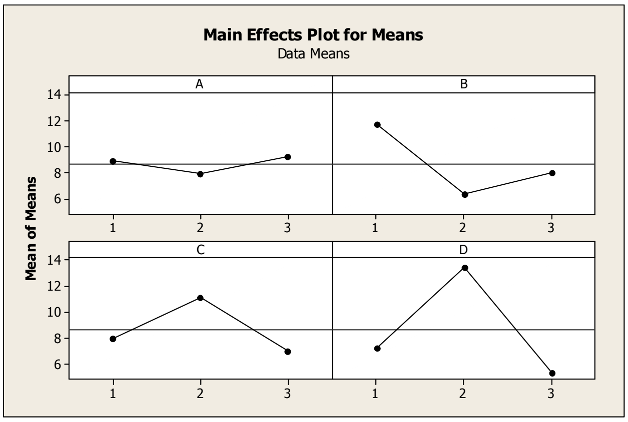

Fig. 5 Main effect plots for mean of surface roughness Ra

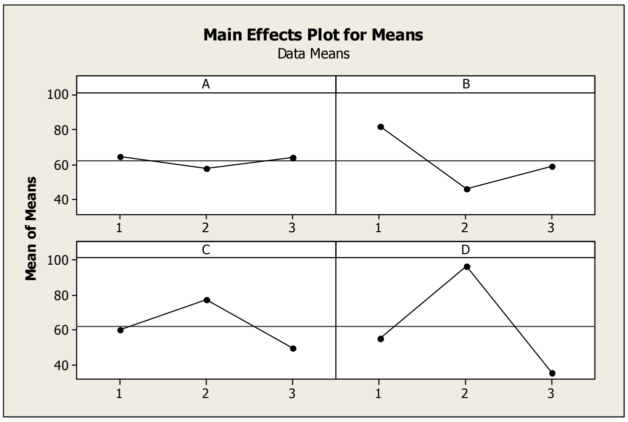

Fig. 6 Main effect plots for mean of surface roughness Rz

C. Analysis of Variance

Analysis of variance (ANOVA) is performed in order to investigate which controlled factor has a significant effect on the output response. The analysis is carried out with a significance level of $\alpha = 0.05$ (confidence level of 95%). Thus, for P-value greater than 0.05, the contribution of that factor is insignificant or negligible. ANOVA tables are constructed for surface roughness Ra and Rz as shown in Table VIII and IX.

TABLE VIII
ANOVA TABLE FOR SURFACE ROUGHNESS RA

Source	DOF	SS	MS	F ratio	P value	PCR (%)
A	2	5.976	2.988	4.33	0.048	1.58
B	2	91.183	45.592	66.09	0.000	24.18
C	2	55.226	27.613	40.03	0.000	14.64
D	2	218.568	109.284	158.43	0.000	57.95
Error	9	6.208	0.690			1.65
Total	17	377.161				100

DOF = Degree of Freedom, SS = Sum of Squares, MS = Mean Squares, PCR = Percent Contribution Ratio

TABLE IX
ANOVA TABLE FOR SURFACE ROUGHNESS RZ

Source	DOF	SS	MS	F ratio	P value	PCR (%)
A	2	164.5	82.2	2.21	0.166	0.90
B	2	3859.0	1929.5	51.81	0.000	21.13
C	2	2371.2	1185.6	31.83	0.000	12.98
D	2	11536.1	5768.1	154.88	0.000	63.16
Error	9	335.2	37.2			1.84
Total	17	18265.9				100

The result from ANOVA is coherent with analysis of S/N ratio with depth of cut having the most significant effect to surface roughness both Ra and Rz followed by spindle speed, and length of workpiece while the effect of feed rate is negligible. A graphical representation for percent contribution ratio of each controlled factor is shown in Fig. 7.

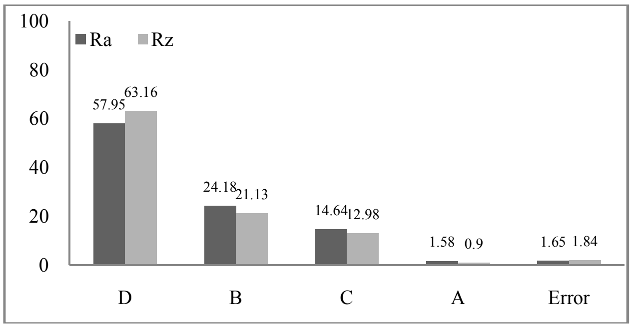

Fig. 7 Percent contribution of controlled factors

Based on S/N ratio analysis and ANOVA, in order to optimize machining condition, controlled factors with significant effect and their optimal level to minimize surface roughness Ra and Rz is considered. In this experiment, an optimal surface finished is obtained from using depth of cut of 1.2 mm, spindle speed of 86 rpm, and feed rate of 0.2 mm/rev. Best surface finish is at the end part of workpiece at length 1,000 – 1,500 mm.

D. Confirmation Test

In order to verify the usability of the modified tool, a confirmation test with optimal machine parameter obtained from Taguchi method is performed. The test is setup with factor level of A2B2C3D3 and run two times. The result of confirmation test is shown in Table X.

TABLE X
CONFIRMATION TEST RESULTS

Condition				Ra (µm)		Rz (µm)	
A	B	C	D	Rep1	Rep2	Rep1	Rep1
2	2	3	3	2.438	2.363	13.472	14.836

IV. CONCLUSION

Design of experiment based on Taguchi method is successfully used for a verification of the horizontal boring tool modified to mouth with a horizontal lathe machine to bore an overlength workpiece. The machine parameter which has significant effect on the surface roughness of finished product is found to be depth of cut, spindle speed, length of workpiece and feed rate respectively. The confirmation test is run and the result from the optimal set up is satisfactory.

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