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OPTIMIZATION OF DRILLING PROCESS PARAMETERS FOR CYCLE TIME, HOLE ACCURACY AND SURFACE ROUGHNESS USING TAGUCHI METHOD

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ABSTRACT

This paper investigates the effect of process parameters during drilling deep hole in cylinder block of cast iron material. The critical parameters such as spindle speed and feed rate are varied each at three levels to study their effect on output parameters. The output parameters studied are cycle time, hole accuracy and surface roughness. For investigation Taguchi L 9 Orthogonal array is used as design of experiments. The signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) is carried out to determine which machining parameter significantly affects the output responses such as cycle time, hole accuracy and surface roughness. Also, percentage contribution of individual parameter is studied. Finally, the optimum combination of drilling parameters is searched for getting best output responses.

Keywords: ANOVA, Cycle time, Feed, Hole Accuracy, Spindle Speed, Surface Roughness, Taguchi.

I. INTRODUCTION

In manufacturing industries, metal cutting operations such as drilling, milling, turning etc. are mostly used. In that, drilling operation is important because more than 60% of all machining processes are related to drilling operation [1]. If length to diameter ratio is greater than five times tool diameter then this type of drilling is called deep drilling. The deep drilling process is quite complex because of having some difficulties such as cutting in a limited and closed space, high cutting temperature, tool overhang length and the difficulty of chip formation and removal. These conditions affect the quality of hole. Hence, from the cost and productivity point of view, the optimization of drilling process is very important for deep drilling process [2].

A special purpose horizontal and angular drilling machine is developed for drilling two deep holes in cylinder block of cast iron FG 260 material. One horizontal drill is having 178 mm depth and of diameter 14.25 mm and another angular drill at 54° to entry face with 128.89 mm depth and 14.25 mm hole diameter. In this paper horizontal drill’s process parameters and output responses are studied. The drilling process is carried out in three steps with to and fro motion.

As per customer requirement the important parameters related to the drilling operation are better surface finish and hole diameter accuracy. And as per company’s requirement the rate of production should be increased. To increase rate of production the cycle time should be minimum. Thus, cycle time, surface finish and hole diameter accuracy are the important output responses are selected for study purpose. These three parameters are affected mainly by spindle speed and feed rate [3]. Hence, critical parameters such as spindle speed and feed rate are selected for optimization by using Taguchi's method with three levels.

II. METHODOLOGY OF WORK

2.1 Introduction

Taguchi method is one of the simplest and effective approaches used for optimization of parameters. A large number of experiments have to be carried out when the number of process parameters increases. This problem is solved by Taguchi method which uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. The term 'signal' is related to the desirable value (mean) for the output characteristic and the term 'noise' is related to the undesirable value i.e. it represents standard deviation (S.D.) for the output characteristic. Hence, the S/N ratio is the ratio of the mean to the S.D [4, 5].

There are 3 types of Signal-to-Noise ratios used for optimization of Static Problems. The formulae for signal to noise ratio are designed such that high signal-to-noise ratios are always preferred. For calculating S/N ratios three characteristics are used as [6, 7],

- **Smaller-The-Better**

  In responses where smaller values are preferred then the Signal-To-Noise ratio is taken as,

  S/N = -10 *log (mean square of the response)

  $$(S/N)_{\text{Smaller is better}} = -10 \, \text{Log}_{10} \, (1/n) \sum (Y_i^2) \qquad \text{…………………. (1)}$$

- **Larger-The-Better**

  In responses where larger values are preferred then the Signal-To-Noise ratio is taken as,

  S/N = -10*log (mean square of the inverse of the response)

  $$(S/N)_{\text{Larger is better}} = -10 \, \text{Log}_{10} \, (1/n) \sum (1/Y_i^2) \qquad \text{…………………. (2)}$$

  Where n= number of measurements in trial/row, n=1, 2…, 9

  and Y_i is the value of corresponding output response for the i^{th} test in that trial

- **Nominal-The-Best**

  In responses where nominal values are preferred then the Signal-To-Noise ratio is taken as,

  S/N = 10 * log (the square of the mean divided by the variance)

  $$(S/N)_{\text{Nominal is best}} = -10 \, \text{Log}_{10} \, (Y^2/S^2) \qquad \text{…………………. (3)}$$

2.2 Steps used in Taguchi method [8]

- Identify the performance characteristics and select process parameters to be evaluated.
- Determine the suitable number of levels for the process parameters.
- Assignment of input process parameters to the selected appropriate orthogonal array.
- Conduct the experiments based on the orthogonal array.
- Calculate the S/N ratio.

- Analyze the experimental results using the S/N ratio and ANOVA.
- Select the optimal levels of process parameters.

2.3 Experimental details

Parameters affecting surface finish and hole diameter are coolant, type of drill, spindle speed, feed rate etc. Although many factors affect the drilling process, the important machining parameters which affect the accuracy of hole and surface roughness are spindle speed and feed rate. Hence, we select spindle speed and feed rate for this investigation as input parameters with three levels [9, 10].

The experiments are performed on special purpose horizontal and angular drilling machine. For experimentation High speed cobalt coated drill of diameter 14.25 mm is used. The diameter of drill is 14.25 mm and material is cast iron. So, for these conditions standard range of spindle speed and feed rate is selected from design data hand book [11]. For conducting experiments a L9 orthogonal array was chosen. Table 1 shows the drilling input parameters and its symbol and level.

Table 1 Experimental parameters and levels

Code	Input factor	Levels		
		1	2	3
A	Spindle Speed (rev/min)	500	550	600
B	Feed Rate (mm/rev)	0.17	0.20	0.23

The output responses are cycle time, hole diameter accuracy, and surface roughness which are studied for improvement in productivity. Actual drilling process time is measured for different levels of experiments by using stopwatch. This time is taken as cycle time for output response.

Second output response is hole diameter accuracy. The required hole diameter with tolerance is $14.25^{+0.200}$ mm. Thus deviation from the mean value is calculated for each reading and it is taken as hole diametral error (HDE) in micrometer. For checking hole diameter, Co-ordinate measuring machine of Spectra make having specification 600 × 800 × 500 mm is used. Set up for measuring hole diameter is shown in Fig. 1.

Fig.1 set up for measuring hole diametral error

Third output response is Surface roughness of hole and it is checked by surface finish tester with model Mititoyo SJ-400. Surface roughness is checked at three locations and its average value is taken. The surface roughness measuring set up is shown in Fig. 2

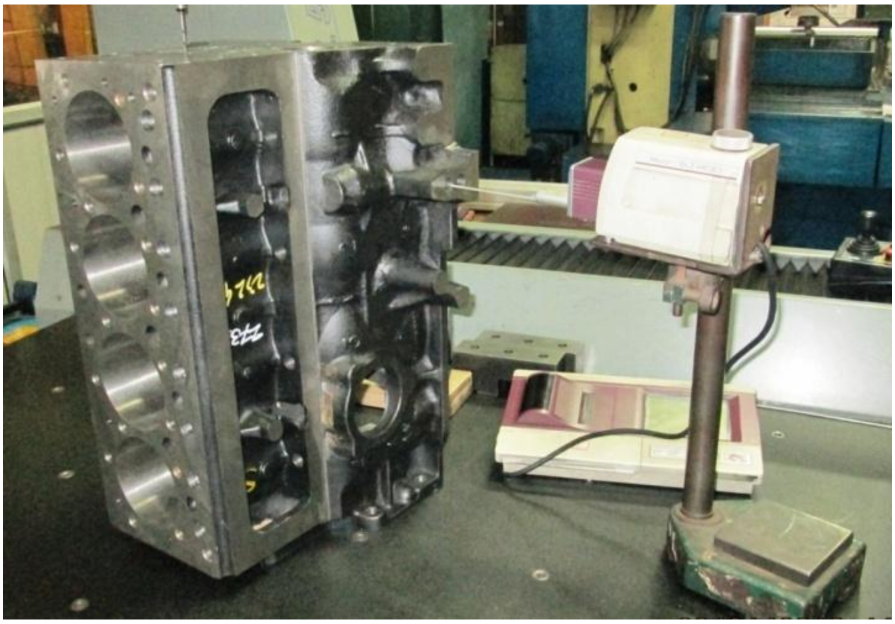

Fig. 2 Set up for measuring surface roughness

2.4 Experimental Results

Experiments were conducted as per L9 orthogonal array. The Taguchi L9 array with coded and actual values is shown in Table 2.

Table 2 Taguchi L9 array

Trial	Spindle Speed (A) rev/min		Feed rate (B) mm/rev	
	Coded	Actual	Coded	Actual
1	1	500	1	0.17
2	1	500	2	0.20
3	1	500	3	0.23
4	2	550	1	0.17
5	2	550	2	0.20
6	2	550	3	0.23
7	3	600	1	0.17
8	3	600	2	0.20
9	3	600	3	0.23

III. ANALYSIS OF RESULTS AND DISCUSSION

3.1 Determination of optimal process parameters for cycle time

For optimization of process parameters the experimental results are transferred to signal to noise ratio (S/N ratio, dB) and the quality characteristics deviating from the desired values are measured. To increase rate of production cycle time should be minimum. Hence, smaller the better criterion is used for calculating S/N ratio. The output response of cycle time and its S/N ratio value are tabulated in Table 3.

Table 3 Observed values of cycle time and its S/N ratio

Trial	Level (A)	Level (B)	Cycle Time (Sec.)	S/N ratio for Cycle time (dB)
1	1	1	191.83	-45.66
2	1	2	168.00	-44.51
3	1	3	153.39	-43.72
4	2	1	177.42	-44.98
5	2	2	155.75	-43.85
6	2	3	142.74	-43.09
7	3	1	165.35	-44.37
8	3	2	145.50	-43.26
9	3	3	135.83	-42.66

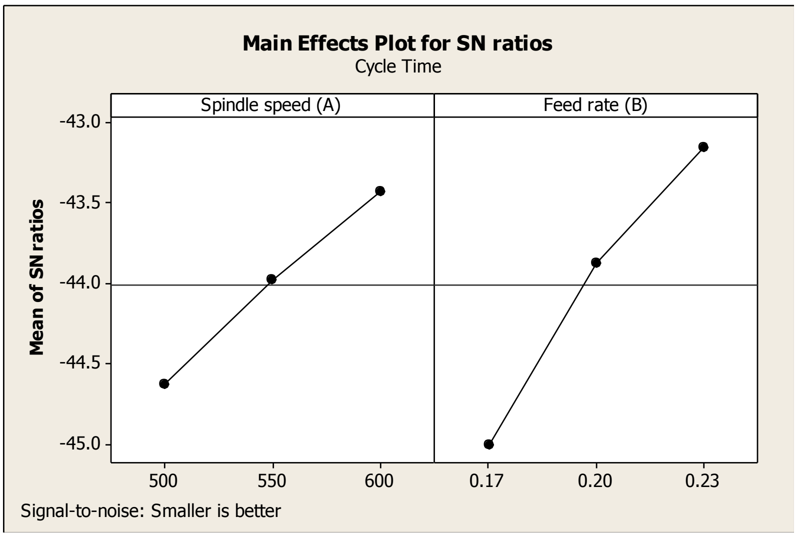

Fig. 3 Means of S/N ratio graph for Cycle time

The largest S/N ratio is selected as optimal solution; hence from Table 3 it is clear that trial no 9 is the optimal solution for getting minimum cycle time. Also, from Fig. 3 largest S/N ratio value is for A3-B3 combination. Hence optimal process parameters are spindle speed with 600 rpm and feed rate with 0.23 mm/rev for getting minimum cycle time.

3.2 Analysis of variance (ANOVA) for cycle time [4, 12]

The purpose of ANOVA is to investigate which drilling parameter significantly affects the performance characteristics. First, the total sum of the squared deviations from the total mean of the S/N ratio is calculated.

The total sum of squared deviations is divided into two sources. First is the sum of squared deviations due to each process parameter and second is the sum of squared error. Next step is to calculate mean of standard deviations. It is calculated as the sum of squared deviations divided by the number of degrees of freedom associated with the process parameter. Afterwards the F value is calculated by taking the ratio of the mean of squared deviations to the mean of squared error. Finally, the percentage contribution is calculated by taking ratio of the sum of squared deviations due to each process parameter to the total sum of squared deviations.

Table 4 ANOVA for Cycle time

Source	DF	Adj. SS	Adj. MS	F Value	% Contribution
Speed	2	741.56	370.78	73.23	28.95
Feed	2	1799.57	899.79	177.72	70.26
Error	4	20.25	5.06		0.79
Total	8	2561.38			100

Analysis of variance for cycle time is shown in Table 4. The large F value indicates the change of the machining parameter has a significant effect on the performance characteristic. From Table 4, the F value is greater for feed rate hence, feed rate significantly affects to the output response cycle time. The percent contribution for affecting cycle time due to feed rate is 70.26% and due to spindle speed is 28.95%.

3.3 Determination of optimal process parameters for Hole diametral error

For better quality of product, the error in hole diameter should be minimum hence, smaller the better criterion is used for HDE. The observed values of error and corresponding S/N ratio are shown in Table 5. And graph of S/N ratio for HDE is shown in Fig. 4.

Table 5 Observed values of Hole diametral error and its S/N ratio

Trial	Level (A)	Level (B)	HDE µm	S/N ratio for HDE (dB)
1	1	1	29.8	-29.48
2	1	2	33.4	-30.47
3	1	3	71.8	-37.12
4	2	1	33.4	-30.47
5	2	2	40.2	-32.08
6	2	3	75.3	-37.54
7	3	1	35.3	-30.96
8	3	2	41.2	-32.30
9	3	3	83.5	-38.43

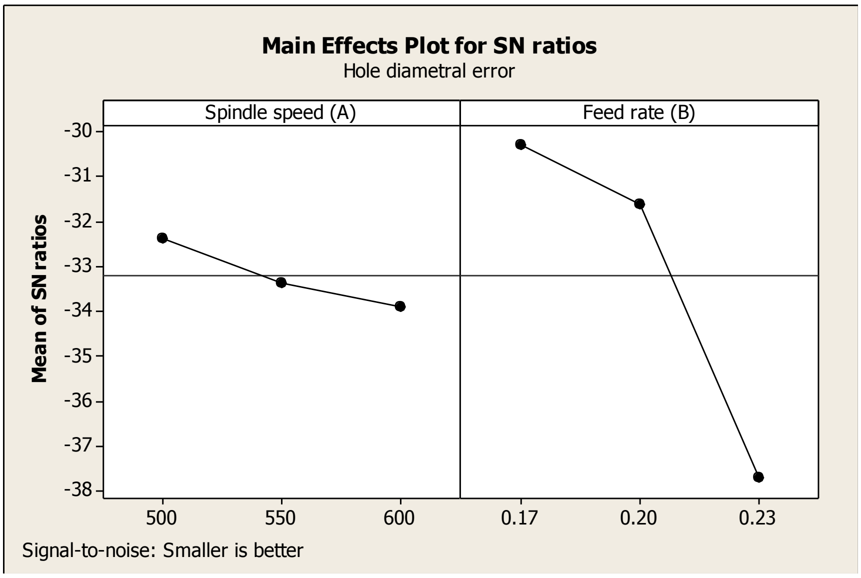

Fig. 4 Means of S/N ratio graph for HDE

From Table 5, largest S/N ratio is for trial no 1. And from Fig. 4 largest S/N ratio is for A1-B1 level of combination. Hence, trial no 1 is the optimal solution for getting minimum hole diametral error i.e. minimum HDE is achieved when spindle speed is 500 rpm and feed rate is 0.17 mm/rev.

3.4 Analysis of variance (ANOVA) for HDE

ANOVA for hole diametral error is shown in Table 6. The F value for feed rate is very large as compare to F value of spindle speed, hence feed rate significantly affects the output response namely HDE. Also, the percent contribution for affecting HDE due to feed rate is 96.54% and due to spindle speed is 2.92% which is negligible.

Table 6 ANOVA for HDE

Source	DF	Adj. SS	Adj. MS	F Value	% Contribution
Speed	2	104.60	52.30	10.92	2.92
Feed	2	3458.42	1729.21	361.05	96.54
Error	4	19.16	4.79		0.54
Total	8	3582.18			100

3.5 Determination of optimal process parameters for Surface Roughness [13, 14]

For getting quality product the surface roughness should be minimum hence, smaller the better criterion is used for calculating S/N ratio. The observed values of Surface Roughness and its corresponding S/N ratios are shown in Table 7. And graph of S/N ratio for surface roughness is shown in Fig. 5. From Table 5, the largest S/N ratio of surface roughness is for 7th experiment. And from Fig. 5, the largest S/N ratio is for A3-B1 level of combination. Hence trial no 7 is the optimal solution for getting minimum surface roughness i.e. at spindle speed 600 rpm and feed rate 0.17 mm/rev we can achieve better surface finish.

Table 7 Observed values of Surface Roughness and its S/N ratio

Trial	Level (A)	Level (B)	SR Ra in µm	S/N ratio for SR (dB)
1	1	1	3.213	-10.14
2	1	2	3.446	-10.75
3	1	3	3.876	-11.77
4	2	1	3.083	-9.78
5	2	2	3.163	-10.00
6	2	3	3.896	-11.81
7	3	1	2.823	-9.01
8	3	2	3.120	-9.88
9	3	3	3.966	-11.97

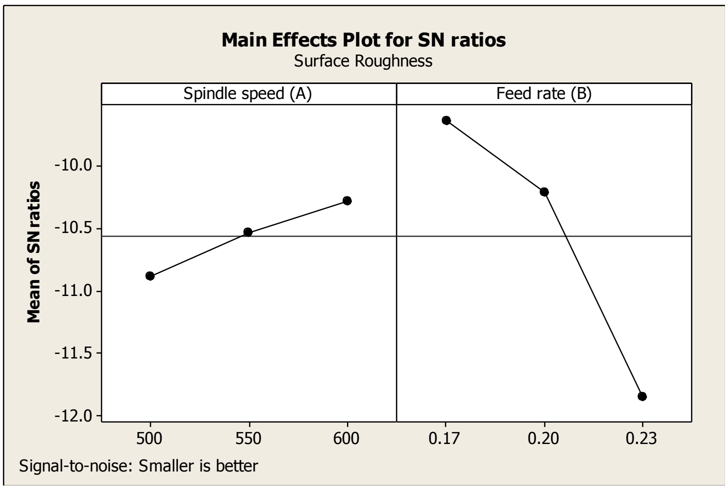

Fig. 5 Means of S/N ratio graph for SR

3.6 Analysis of variance (ANOVA) for Surface Roughness

ANOVA for surface roughness is shown in Table 8. From the Table, the F value for feed rate is large as compare to F value of spindle speed which shows feed rate significantly affects the surface roughness. The percent contribution for affecting SR due to feed rate is 89.55% and due to spindle speed is 4.77%. Hence surface roughness value largely depends on feed rate.

Table 8 ANOVA for Surface Roughness

Source	DF	Adj. SS	Adj. MS	F Value	% Contribution
Speed	2	0.06673	0.03337	1.68	4.77
Feed	2	1.25193	0.62596	31.56	89.55
Error	4	0.07934	0.01983		5.68
Total	8	1.3980			100

IV. CONCLUSION

This paper is focused on the optimization of drilling parameters for deep drilling in cast iron block. Based on the different experimental results, following conclusions are drawn.

- In this investigation Taguchi method is used to study the effect of spindle speed and feed rate on cycle time, hole accuracy and surface roughness.
- In Taguchi method, two input parameters with three levels, L9 orthogonal array is selected for design of experiments.
- For minimum cycle time, the spindle speed should be 600 rpm and feed rate should be 0.23 mm/rev.
- For better hole diameter accuracy, the spindle speed should be 500 rpm and feed rate should be 0.17 mm/rev.
- For minimum surface roughness, the spindle speed should be 600 rpm and feed rate should be 0.17 mm/rev.
- ANOVA is used to measure which parameter significantly affects the output responses. The results of ANOVA shown that feed rate is the main parameter which affects significantly to all three output responses.

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