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A STUDY ON OPTIMIZATION OF CYLINDRICAL GRINDING PROCESS PARAMETERS USING TAGUCHI METHOD

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ABSTRACT

In the manufacturing sector, producing products with good quality surface finish along with dimensional accuracy and close tolerances plays an important role. Cylindrical grinding is one of the important metal cutting processes used extensively for finishing operations of cylindrical objects such as shafts, axles, spindles, studs etc. In the present study, Taguchi method along with L9 orthogonal array has been used to optimize the effect of cylindrical grinding parameters such as work speed (rpm), feed (mm/min.), depth of cut (mm) on the surface finish and material removal rate of En24 steel. En24 steel is readily machine able and combines a good high tensile steel strength with shock resistance, ductility and wear resistance. Surface roughness and material removal rate measurements were carried out during the machining process on the work piece. ANOVA is used to determine the most significant control factors affecting the surface roughness and material removal rate. From result for surface roughness the optimized parameters for surface roughness are work piece speed 145 rpm, feed rate 220 mm/min. and depth of cut 0.01 mm. For material removal rate are work piece speed 145 rpm, feed rate 220 mm/min. and depth of cut 0.015 mm.

KEYWORDS - Grinding parameter optimization, surface roughness, material removal rate, Taguchi, signal-to-noise ratio, ANOVA.

I. INTRODUCTION

Cylindrical grinding is one of the important metal cutting processes used extensively for finishing operations of cylindrical objects such as shafts, axles, spindles, studs etc. Grinding process is mostly used in which surface quality and metal removal rate are considered as an output parameters.[10] But these output parameters of grindings are influenced by several operating input parameters such as: (i) wheel parameters – type of abrasives, grain size, grade, structure, binder, shape and dimension; (ii) work piece parameters – mechanical properties, chemical composition, fracture mode; (iii) process parameters – wheel speed, depth of cut, table speed, feed, and dressing condition; (iv) machine parameters – static and dynamic characteristics, spindle system, and table system. And the metal removal rate can be maximized in very few grinding passes on work piece. The present paper takes the following input process parameters namely work speed, depth of cut and feed rate. The main objective of this paper is to achieve optimal operating process parameters of En24 steel for good quality of surface and material removal rate.

II. LITERATURE REVIEW

Sandip Kumar et al. [1] has studied the Taguchi method and was found that various input parameters of cylindrical grinding such as the work piece speed, grinding wheel speed and feed rate has more significant effect for surface roughness and depth of cut has least effect on Material removal rate of EN15 AM steel. A Taguchi L18 (21 x 33) orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters. ANOVA results shows that work piece speed contributes maximum 38.95 % percentage contribution, grinding wheel speed contributes 14.85 %, feed rate contributes 12.85% and depth of cut has least contribution about 9.80% towards the material removal rate. And finally concluded the optimized parameters for material removal rate are grinding wheel speed 1800 rpm, work piece speed 155 rpm, feed rate 275 mm/rev and depth of cut .04 mm.
Naresh Kumar et al. [2] worked on cylindrical grinding of C40E steel is done for the optimization of grinding process parameters. During this experimental work input process parameters i.e. speed, feed, depth of cut are optimized by using Taguchi L9 orthogonal array. Analysis of variance (ANOVA) used for confirmation.

And finally concluded that surface roughness is minimum at the 210 rpm, 0.11mm/rev feed, and 0.04mm depth of penetration.

M. Melwin Jagadeesh Shridhar et al. [3] analyzed optimal process parameters of cylindrical grinding to grind OHNS Steel (AISI 0-1) with high surface quality by conducting various experiments. In this work L9 orthogonal array was selected for three levels and three input parameters. The inputs parameters are considered in this experimental study are work speed, depth of cut and number of passes and response parameter is metal removal rate (MRR) during cylindrical grinding process. Higher metal removal rate is the main objective of this machining process. The different machining parameters of OHNS steel of cylindrical grinding process are optimized by Signal to noise ratio and analyzed by Analysis of variance (ANOVA's). Finally they has found that number of pass of grinding process play an important role for achieving larger metal removal rate in cylindrical grinding process and optimal parameter of OHNS steel rounds in cylindrical grinding process are 150rpm of wheel speed ,0.02 mm of depth of cut and 1 number of pass.

K. Mekala et al. [4] analyzed that an optimization of cylindrical grinding parameters of austenitic stainless steel rods (AISI 316) by Taguchi method to have maximum MRR with good surface quality. In this, Taguchi design of experiments of L9 orthogonal array was selected with 3 levels with 3 factors and output parameters of Metal removal rate are measured. After conducting experiment optimized by S/N ratio and analyzed by ANOVA and predicts Cutting speed is a dominating parameter of cylindrical grinding. The optimal process parameters for AISI 316 austenitic stainless steel were found 560 m/min of cutting speed, 0.130 mm/rev of feed and 0.005 mm of depth of cut.

Lijohn P George et al. [5] conducted experiment to study the working of cylindrical grinding machine and effects of grinding process parameters on Surface roughness. The experiments are conducted on MILANO RICEN RUM 1 Cylindrical Grinding Machine with L9 Orthogonal array with input machining variables as work speed, depth of cut and hardness of material. In this EN 24, EN 31, EN 353 alloy steels are used. Surface roughness is measured using MITUTOYO Surf test SJ-400 surface roughness tester. He also formulated an empirical relationship between the surface roughness values and the input parameters. Taguchi parametric optimization is used for the optimization process. Then results are further confirmed by conducting confirmation experiments on ANOVA.

III. EXPERIMENTAL SETUP

The En24 steel is selected for the study since it has very wide industrial applications although the researches done on this material is less. En24 is used in applications such as components for the aircraft, automotive and general engineering industries like propeller shafts, connecting rods, gear shafts, and other automobile parts. In this study, ϕ 25 mm × 150 mm round bar of En24 steel is taken as specimens. And grinding length is kept up to 100 mm.

Table 1 Chemical composition of En24 Steel (in weight %)

Carbon (C)	Silicon (Si)	Manganese (Mn)	Phosphorous (P)	Sulphur (S)
0.386	0.239	0.549	0.023	0.033

The experimental runs are done on the Jones-Shipman 1310 Universal Cylindrical Grinding Machine. The specimen which is to be ground is held in between supporting centers. Depth of cut is given manually by the cross feed wheel. The work speed as well as feed rate is varied by gearing arrangement. The wheel speed is kept constant at 2100 rpm. Machining is done in three numbers of passes. For all three level factors are attempted with an overall number of 9 trials completed.

The surface roughness of the work piece is measured after grinding with the help of MITUTOYO Surftest SJ-400 Tester. MRR is measured with an electronic weight machine and calculated by following formula.

$$MRR = (W_b - W_a)/T_m$$

Where,

W_b: Weight of work piece material before grinding (gm)

W_a: Weight of work piece material after grinding (gm)

T_m: Machining times (sec)

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IV. EXPERIMENTATION

A. Taguchi Design

Taguchi method is a powerful tool in quality Optimization makes use of a special design of Orthogonal Array (OA) to examine. Taguchi method is a powerful tool of the DOE which gives best results in lowest possible runs. In this study, a three factor three level setup is chosen with an overall nine numbers of trials to be conducted and hence the OA L9 be there selected.

The levels of experiment parameters are shown in Table as shown in table below.

Table 2 levels of experiment parameters

Machining Parameter	Unit	Levels		
		Level 1	Level 2	Level 3
Work speed	rpm	51	86	145
Depth of cut	mm	0.01	0.015	0.02
Feed rate	mm/min	150	170	220

Taguchi design of experiment by the L9 array is obtained by MINITAB 17 and accordingly experiments are carried out on the machine. During the experimentations, the observations are noted down. The Taguchi's design of experiment along with the observations is given in following table.

Table 3 Taguchi design and observations

Run no.	Process parameters			Output responses	
	Work speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)	Avg. surface roughness (Ra) (µm)	Avg. MRR (gm/sec)
1	51	0.01	150	0.636	0.0583
2	51	0.015	170	0.422	0.0692
3	51	0.020	220	0.436	0.1151
4	86	0.01	170	0.527	0.0831
5	86	0.015	220	0.539	0.1110
6	86	0.020	150	0.267	0.0766
7	145	0.01	220	0.591	0.1463
8	145	0.015	150	0.567	0.1089
9	145	0.020	170	0.572	0.0859

V. RESULT AND DISCUSSION

In this chapter, we are discussing about influence of machining parameters i.e. work speed, depth of cut and feed rate on material removal rate (MRR) and surface roughness (SR) & also find out which parameter is most important during an experiment.

A. Taguchi Analysis for S/N ratio of surface roughness

The S/N ratios for SR are calculated as given in below Equation. Taguchi method is used to analysis the result of response of machining parameter for "smaller is better" criteria.

$$SB : S/N\ Ratio = -10 \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$

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Table 4 Table for S/N ratios

Run nos.	Work speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)	Surface roughness (Ra) (µm)	S/N Ratio for Ra	S/N Ratio for MRR
1	51	0.01	150	0.636	3.9309	-24.687
2	51	0.015	170	0.422	7.4938	-23.198
3	51	0.02	220	0.436	7.2103	-18.778
4	86	0.01	170	0.527	5.5638	-21.608
5	86	0.015	220	0.539	5.3682	-19.094
6	86	0.02	150	0.267	11.4698	-22.315
7	145	0.01	220	0.591	4.5683	-16.695
8	145	0.015	150	0.567	4.9283	-19.259
9	145	0.02	170	0.572	4.8521	-21.32

Following graph shows the main effect plot for S/N ratios of process parameters viz. work speed, depth of cut and feed rate on surface roughness.

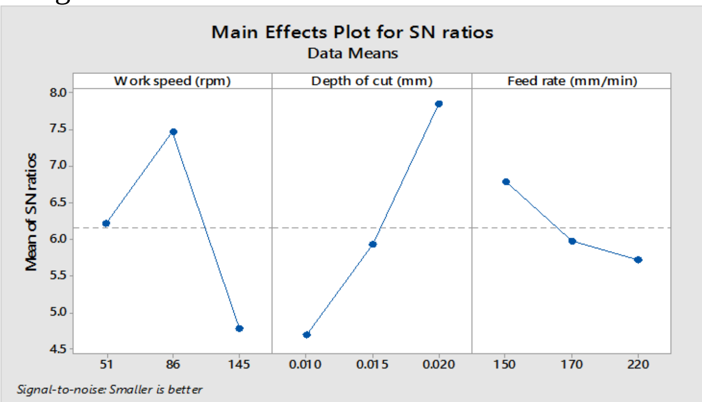

Fig. No. 1 Main effect plot for S/N ratio for surface roughness

Table 5 Response Table for Signal to Noise Ratios - Smaller is better

Level	Work speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	6.212	4.688	6.776
2	7.467	5.93	5.97
3	4.783	7.844	5.716
Delta	2.684	3.156	1.061
Rank	2	1	3

From above results it is clear that, the main influencing parameter for surface roughness is depth of cut. Whereas feed rate and work speed are less influencing parameters. The optimized parameters for surface roughness are, work piece speed 145 rpm, feed rate 220 mm/min. and depth of cut 0.01 mm.

B. Analysis of Variance for S/N ratio of surface roughness

Following table shows the analysis of variance for S/N ratios of surface roughness.

Table 6 Analysis of Variance for S/N ratio of Surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Work speed (rpm)	2	0.026581	0.013290	0.73	0.578
Depth of cut (mm)	2	0.038281	0.019140	1.05	0.487
Feed rate (mm/min)	2	0.001538	0.000769	0.04	0.959
Error	2	0.036409	0.018204		
Total	8	0.102808			

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Above values are obtained from MINITAB-17 software. It shows that depth of cut is the significant parameter for surface roughness and other parameters i.e. feed rate and work speed has less impact on surface quality of work piece.

C. Taguchi Analysis for S/N ratio of MRR

Now for the MRR, the S/N ratios for MRR are calculated as given in below Equation. Taguchi method is used to analysis the result of response of machining parameter for "Higher is better" criteria.

$$HB : S/N\ Ratio = -10 \log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^{-2}\right]$$

Following graph shows the main effect plot for S/N ratios of process parameters viz. work speed, depth of cut and feed rate on MRR.

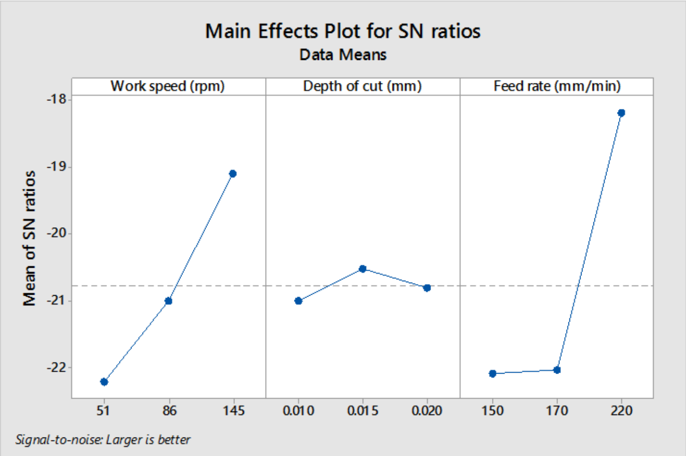

Fig. No. 1 Main effect plot for S/N ratio for MRR

Table 7 Response Table for Signal to Noise Ratios – Larger is better

Level	Work speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	-22.22	-21.00	-22.09
2	-21.01	-20.52	-22.04
3	-19.09	-20.80	-18.19
Delta	3.13	0.48	3.90
Rank	2	3	1

From above results it is clear that, the main influencing parameter for MRR is feed rate. Whereas depth of cut and work speed are less influencing parameters. The optimized parameters for MRR are material removal rate are work piece speed 145 rpm, feed rate 220 mm/min. and depth of cut 0.015 mm.

D. Analysis of Variance for S/N ratio of MRR

Following table shows the analysis of variance for S/N ratios of surface roughness.

Table 8 Analysis of Variance for S/N ratio of MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Work speed (rpm)	2	0.001716	0.000858	3.61	0.217
Depth of cut (mm)	2	0.000026	0.000013	0.06	0.948
Feed rate (mm/min)	2	0.003842	0.001921	8.08	0.110
Error	2	0.000476	0.000238		
Total	8	0.006060			

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Above values are obtained from MINITAB-17 software. It shows that feed rate is the significant parameter for MRR. And other parameters viz. depth of cut and work speed has less impact on MRR of work piece.

VI. CONCLUSION

Based on the analytical and experimental results obtained in this study following conclusions can be drawn.

1. The depth of cut is the significant parameter for surface roughness and other parameters i.e. feed rate and work speed has less impact on surface quality of work piece.
2. The optimized parameters for surface roughness are, work piece speed 145 rpm, feed rate 220 mm/min. and depth of cut 0.01 mm.
3. The feed rate is the significant parameter for MRR and other parameters i.e. depth of cut and work speed has less impact on surface quality of work piece.
4. The optimized parameters for MRR are material removal rate are work piece speed 145 rpm, feed rate 220 mm/min. and depth of cut 0.015 mm.

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