Taguchi based Optimization of Cylindrical Grinding Process

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Abstract— Cylindrical grinding is one of the important metal cutting processes used extensively in the finishing operations. To enrich the eminence of machined parts, and to reduce the machining expenditures and to increase the production rate, it is very important to select the optimal machining parameters. This article discusses the optimization of cylindrical grinding of austenitic steel SS316 and effect of operating parameters (wheel speed, feed rate and depth of cut) towards surface roughness. Taguchi analysis is employed to identify optimum machining parameters for grinding of austenitic steel. A L9 orthogonal array, signal to-noise ratio and analysis of variance have been applied to study the performance characteristic of machining parameters with consideration of surface roughness.

Key words: Cylindrical Grinding, Optimization, Taguchi, S/N ratio, ANOVA

I. Introduction

Cylindrical grinding is an essential process for final machining of components requiring smooth surfaces and precise tolerances. Grinding is one of the most important and widely used manufacturing processes for surface finish in engineering industry .Grinding is a finishing process employed for producing close dimensional and geometric accuracies and smooth surface finish .Although widely used in industry, grinding remains perhaps the least understood of all machining processes .The success of any grinding operation is influenced by the proper selection of various operating conditions like wheel speed, work speed, traverse feed, area of contact, grinding fluids, balancing of grinding wheels, dressing, etc. The optimization of operating parameters is an important step in machining. Optimization of machining parameter will reduce the machining cost and ensure the quality of final product. Optimization of grinding process still remains one of the most challenging problems because of its high complexity and non-linearity while solving it. The main objective of this paper is to predict the grinding behavior and achieve optimal operating processes parameters by Taguchi method.

II. Literature review

T.J. Choi et al. [1] developed generalized grinding process models for cylindrical grinding processes based on the systematic analysis and experiments. The relationships for power, surface roughness, G-ratio and surface burning are presented for various steel alloys and alumina grinding wheels. C. Thiagarajan et al. [2] evaluated the significance of the cylindrical grinding variables on the selected responses by conducting experiments and the effect of grinding variables on tangential grinding force (F_T), surface roughness (Ra) and grinding temperature (G_T) are observed. The surface roughness decreases with an increase in wheel velocity and work piece velocity. J.S. Kwak et al. [3] tested the machinability of the fabricated MMCs using the surface grinding process. The surface roughness and the grinding force were measured using the Taguchi's design of experiments, and the effect of the grinding parameters was analyzed with the S/N ratio. The optimal sets to enhance the surface roughness and to reduce the grinding force were also determined. Leonardo Roberto da Silva et al. [4] analyzed the surface integrity (roughness, residual stress, microstructure and micro hardness) by implementing MQL technology in cylindrical plunge grinding. It was found that the surface roughness values were substantially reduced with the use of the MQL technique. N.Baskar et al [5] has proposed an Ants Colony Algorithm based optimization procedure to optimize grinding conditions, viz. wheel speed, work piece speed, depth of dressing, and lead of dressing, using a multi-objective function model with a weighted approach for surface grinding. The optimal grinding conditions subjected to constraints such as thermal damage, wheel-wear parameters and machine-tool stiffness are determined. Sanjay Agarwal et al. [6] investigated the machining characteristics and the material removal mechanism in the grinding of silicon carbide by diamond-grinding wheel. Grinding induced surface and subsurface damage have also been assessed and characterized using scanning electron microscope (SEM).

G. Akhyar et al. [7] implemented Taguchi optimization methodology to optimize cutting parameters in turning Ti-6%Al-4%V extra low interstitial with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed and analyzed the effect of process parameters on surface roughness. Gopalasamy et al. [8] implemented Taguchi method for optimizing process parameters for end milling while hard machining of hardened steel and analyzed the effect of process parameters using S/N ratio and ANOVA. Jae-Seob Kwak et al [9] evaluated the effect of grinding parameters on the geometric error using Taguchi method. The depth of cut was a dominant parameter for geometric error and the next was the grain size. Optimal grinding conditions to minimize the geometric error were also determined. Ilhan Asilturk et al. [10] determined the multi-objective optimal cutting conditions and established mathematic models for surface roughness (Ra and Rz) on a CNC turning and the influence of cutting speed, feed rate and depth of cut on the surface roughness was examined. K. Palanikumar et al. [11] measured the surface roughness in the turning process for machining of GFRP composites under different cutting conditions with a PCD tool using Taguchi's orthogonal array. The effect of machining parameters on the surface roughness has been evaluated with the help of Taguchi method and optimal machining conditions to minimize the surface roughness have been determined. Filleti Rap et al. [12] the developed dynamic method was applied to real case study and the results are compared with a conventional grinding process available on the Gabi software. Fratila D et al. [13] this method of parameter design can be performed with lesser number of experimentations as compared to that of full fractional analysis and yields similar results. Kara S

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et al [14] a methodology is provided to support the description, modeling, evaluation and improvement of the grinding process, system with the goal of achieving higher eco efficiency.

The literature review above indicates that there is only limited work on optimization of process parameters of cylindrical grinding for a minimum surface roughness. It is also predicted that the Taguchi method is useful for studying the interactions between the parameters, and it is a powerful design of experiments tool, which provides a simple, efficient and systematic approach to determine optimal cutting parameters.

III. PROPOSED METHODOLOGY

In the present work, Taguchi L9 orthogonal array is employed to determine the optimal machining parameters for minimum surface roughness of austenitic steel in the grinding operation. Using S/N ratio and ANOVA the experimental data are analyzed to investigate the influence of operating parameters on the surface roughness and the results are compared.

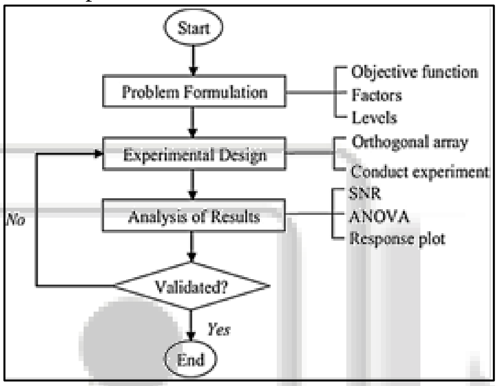

Fig. 1: Flow chart for optimization using Taguchi

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A. *Taguchi Approach*

Taguchi method is the process of engineering optimization in a three step approach namely system design, parameter design and tolerance design. In the system design, a basic functional prototype design will be produced by applying scientific and engineering knowledge. With such an arrangement completely randomized experiments can be conducted. This method is useful for studying the interactions between the parameters, and also it is a powerful design of experiments tool, which provides a simple, efficient and systematic approach to determine optimal cutting parameters.

B. *Signal to Noise Ratio (S/N)*

Generally, signal to noise (S/N) ratio represents quality characteristics for the observed data in the Taguchi design of experiments. A smaller value of surface roughness is normally required in metal machining. Therefore, the smaller-the-better methodology of S/N ratio is employed for the aforesaid responses. Heedless of the category of the performance characteristics, the high value of S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The smaller-the-better type of the S/N ratio is defined as follows:

$$\eta = -10 \log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \qquad (3.2.1)$$

Where y_i is the observed data at the i^{th} trial and n is the number of trials. From the S/N ratio, the effective parameters having influence on process results can be seen and the optimal sets of process parameters can be determined.

C. *Analysis of variance for S/N ratio*

ANOVA is a statistically based, objective decision making tool for detecting any differences in the average performance of groups of items tested. In the analysis the sum of squares and variance are calculated. With signal to noise (S/N) ratio and ANOVA analyses, possible combination of optimum parameters can be predicted.

IV. EXPERIMENTAL DETAILS

A series of experiments have been conducted on the cylindrical grinding machine on austenitic steel SS316 to determine the effect of machining parameters on surface finish. Grinding wheel used for the experimental work has silicon carbide abrasives with vitrified bond. The wheels used have initial dimensions of 580 mm in diameter and 50 mm in width. A single point diamond dresser was used with a water-soluble coolant. The surface roughness (Ra) of the jobs is evaluated on the Taly surf surface test instrument. The average of ten readings is taken to determine the reading of surface roughness value for the experiment.

The chemical composition of the work piece (SS316) is listed in Table 1. Type 316 is an austenitic chromium nickel stainless steel containing molybdenum. This addition increases general corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at elevated temperatures.

SS316	C	0.08
	Mn	2.0
	Si	0.75
	P	0.045
	S	0.03
	Cr	18.0
	Mo	3.0
	Ni	14.0
	N	0.10

Table 1: Chemical composition of the work piece

The grinding parameters selected for investigation are cutting speed (V_s), feed rate (V_f) and depth of cut (D). Each factor has three levels (process ranges). The other factors such as type of abrasive, workpiece, coolant, and spark out are constant. The controllable factors (grinding parameters) and their levels considered in this study are listed in the Table2. Taguchi L_9 Orthogonal array is used to design the orthogonal array by using design of experiments (DOE) as shown in Table 3.

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Factors	Cutting Parameters	Levels		
		1	2	3
A	cutting speed (rpm)	560	780	1000
B	feed rate (mm/rev)	0.13	0.093	0.073
C	Depth of cut (mm)	0.003	0.004	0.005

Table 2: The controllable factors and their levels

V. RESULTS AND DISCUSSIONS

From results, it is observed that there is decreases surface roughness as material hardness increased. The main objective of the experiment is to optimize the grinding parameters (cutting speed, feed rate and depth of cut) to achieve low value of the surface roughness.

Exp. Run	Factors		
	A	B	C
1.	1	1	1
2.	1	2	2
3.	1	3	3
4.	2	1	2
5.	2	2	3
6.	2	3	1
7.	3	1	3
8.	3	2	1
9.	3	3	2

Table 3: L_9 Orthogonal array for experiments

A. *Taguchi L_9 Orthogonal array*

The experiments were conducted with three factors at three levels. L_9 Orthogonal array was used for the elaboration of the plan of experiments, which has 9 rows corresponding to the number of tests as shown in Table 3. The measured surface roughness and its corresponding S/N ratio are shown in Table 4.

The average surface roughness (Ra), which is mostly used in industrial environments, is taken-up for the present study. The roughness was measured number of times and averaged.

Sl. No	A	B	C	SR	S/N Ratio
1.	560	0.13	0.003	0.79	2.04746
2.	560	0.093	0.004	0.76	2.38373
3.	560	0.073	0.005	0.84	1.51441
4.	780	0.13	0.004	0.60	4.43697
5.	780	0.093	0.005	0.58	4.73144
6.	780	0.073	0.003	0.67	3.47850
7.	1000	0.13	0.005	0.71	2.97483
8.	1000	0.093	0.003	0.75	2.49877
9.	1000	0.073	0.004	0.73	2.73354

Table 4: Experimental results for surface roughness and S/N ratio

B. *Signal to Noise Ratio (S/N)*

The significance of controllable factors is investigated using S/N ratio approach. Analysis of the influence of each control factor (V, f, a) on the surface roughness has been performed with a signal-to-noise ratio response table shown in Tables 5 and 6. The tables show the S/N ratio at each level of the control factors and how it is changed when settings of each control factor are changed from one level to another.

Level	A	B	C
1	1.982	3.153	2.675
2	4.216	3.205	3.185
3	2.736	2.575	3.074
Delta	2.234	0.629	0.510
Rank	1	2	3

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

Level	A	B	C
1	0.7967	0.7000	0.7367
2	0.6167	0.6967	0.6967
3	0.7300	0.7467	0.7100
Delta	0.1800	0.0500	0.0400
Rank	1	2	3

Table 6: Response Table for Means

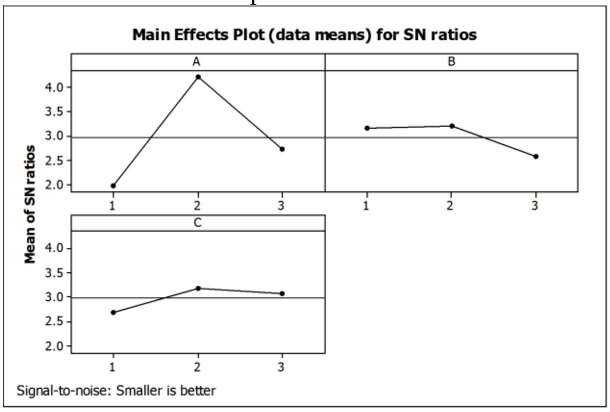

Fig. 2: Main effects for factors machining verse S/N ratio of surface roughness.

The response graphs present more clearly the influence of each control factor, which is given in figure 2. These figures reveal the level to be chosen for the ideal cutting parameters (the level with the highest point on the graphs), as well as the relative effect each parameter has on the S/N ratio (the general slope of the line). As seen in the S/N ratio effects graphs (Figure 2), the slope of the line which connects between the levels can clearly show the power of influence of each control factor. Especially the cutting speed is shown to have a strong effect on surface roughness and its S/N ratios. The feed rate and depth of cut has a smaller effect, as evidenced by the shallow slope of the lines.

C. *Analysis of variance for S/N ratio*

The analysis of variance for surface roughness is shown in Table 7, which consists of DF (degree of freedom), S(sum of square), V (variance), F (variance ratio)and P (significant factor) . In most engineering cases, the significant value selected was 5% (α = 0.05). Table 7 shows that the significant value of the cutting speed (P) is 0.027. It means that the cutting speed influences significantly on the surface roughness value at significant value of 0.05. In addition, P value for the feed rate and depth of cut are insignificant.

Source	DF	Sum of Sq	Mean Sq	F- ratio	P- value
A	2	0.0496889	0.0248444	36.66	0.027
B	2	0.0046889	0.0023444	3.46	0.224
C	2	0.0024889	0.0012444	1.84	0.353
Error	2	0.0013556	0.0006778		
Total	8	0.0582222			

Table 7: ANOVA table for SR

Source	DF	Sum of Sq	Mean Sq	F- ratio	P- value
A	2	7.7482	3.8741	40.21	0.024

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B	2	0.7321	0.3661	3.80	0.208
C	2	0.4312	0.2156	2.24	0.309
Error	2	0.1927	0.0963		
Total	8	9.1042			

Table 8: ANOVA table for S/NRatio

The analysis of variance for S/NRatio is shown in Table 8, in which the significant value of the S/N ratio of the cutting speed (P) is 0.024. It means that the cutting speed influences significantly on the surface roughness value at significant value of 0.05. In addition, P value for the S/N ratio of the feed rate and depth of cut are insignificant. Figure 3 shows the interaction between the cutting speed and feed rate (AxB), the cutting speed and depth of cut (AxC) and the feed rate and depth of cut (BxC). It indicates that the effect of factor B on surface roughness is dependent on factor C and vice versa whereas the effect of factor A is independent of the other two factors.

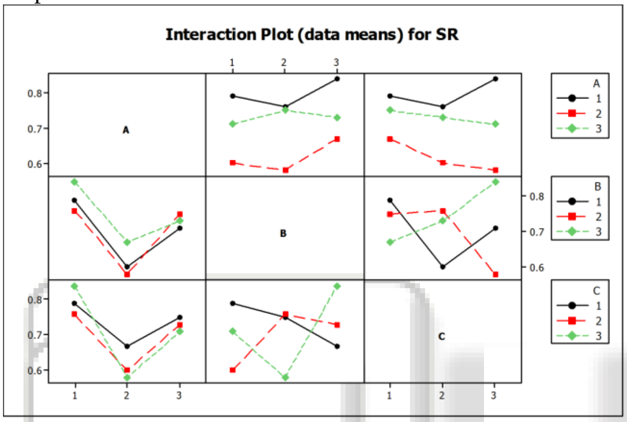

Fig. 3: Interaction plot for surface roughness

VI. Conclusion

In this study, an application and adaptation of the Taguchi optimization and quality-control method were established for the optimization of the surface roughness in a grinding process. The effect of grinding parameters on the surface roughness was evaluated with help from the Taguchi method. The concept of ANNOVA and S/N ratio is used to determine the effect and influence of process parameters namely cutting speed, feed rate and depth of cut on surface roughness. The cutting speed was found to be a dominant parameter for surface roughness. Optimal grinding conditions to minimize the surface roughness were determined. Confirmation experiments are conducted to verify the optimal machining parameter combinations as predicted by Taguchi analysis.

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