Comparison of DOE Approaches in Optimization of Surface Roughness in Precision Cylindrical Grinding of HCHC Steel

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Abstract:

The paper reports the comparative analysis of surface roughness in cylindrical grinding of HCHC steel using two experimental designs namely, Taguchi L_4 array and 2^k full factorial method (FFD). The surface roughness was measured on the ground specimen. The analysis of results indicates that the wheel speed has significant influence on the surface roughness when either of the approaches was used. The experimental parameters that produce lower surface roughness using FFD approach are wheel speed 1975 rpm, work speed 250 mm/min and depth of cut 0.02 mm. Besides, normal probability plot shows that the wheel speed and interaction between depth of cut × wheel speed and work speed × wheel speed has significant influence on the surface roughness as per FFD approach. It is found that the DOE approach gives better results in cylindrical grinding of HCHC steel since the process involves interactions of parameters.

Keyword: Cylindrical grinding, HCHC steel, Taguchi, Full factorial design, Surface roughness.

1. INTRODUCTION

Surface roughness is an important functional parameter of the engineering components. Better surface quality is vital for efficient performance of these components. This can be achieved through appropriate selection of the parameters during its manufacturing. The cylindrical grinding is extensively used in manufacturing of shaft like components such as automotive crankshafts, inner and outer bearing races, bogies axles, sealing surfaces, and pistons in hydraulic machines. Various advantages including good surface finish increase in hardness and high dimensional accuracy can be achieved by the grinding processes. Though, appropriate selection of grinding parameters is a prime requirement to acquire the above benefits as mentioned earlier, very few studies on cylindrical grinding are reported in the literature. Findings of some of these studies are discussed here (Heckera and Liang, 1999; Rowe and Jin, 2001; Kwak et al. 2002; Monicia and Bianchia, 2006; Hassui and Diniz 2003, Xu et al. 2003; Shaji and Radhakrishnan, 2004). Kwak et al. (2006) performed the experiments to analyze the grinding power and surface roughness in external cylindrical grinding of hardened SCM440 steel. They reported that the grinding power is linearly proportional to the depth of cut. Further, it is found that the grinding power was 1.6 times more than the depth of cut. Among the grinding parameters, the depth of cut has shown relatively more influence on grinding process than the traverse speed. Rowe and Jin (2001) investigated the dissipation of heat in grinding and the resulting influence on the workpiece surface integrity. They observed that the heat generated is proportional to the depth of cut at the contact zone and higher feed speed is always preferable to induce better surface integrity. Monicia et al. (2005) performed the experiments using different cutting fluids in plunge cylindrical grinding with conventional and super abrasive CBN grinding wheels. Thus it is understood that there are very few studies exploring the effects of grinding parameters on surface roughness, particularly in cylindrical grinding of HCHC steel. Besides, investigations which compare the results of different statistical approaches is hardly found. In view of the above, the paper attempts to compare the performance of cylindrical grinding process using Taguchi and FFD methods to arrive at the optimized conditions that lead to lower surface roughness.

2. METHODOLOGY

2.1 Taguchi Method

Taguchi method is a tool to optimize the processes, which contain multiple variables. It provides a simple, efficient and systematic approach to determine optimal machining parameters. Taguchi recommends orthogonal arrays for conducting experiments. The experimental design is combined with the quality loss during the process in terms of functional performance. The method includes three stages, namely system design, parameter design, and tolerance design. Taguchi’s parameter design has proved to be an effective approach for producing high-quality products at a relatively low cost. Parameter design can be regarded as a flexible alternative to the classical fractional factorial design and is a widely used empirical approach. The objective of the parameter design is to determine the best levels of the process parameters, thereby making the process insensitive to various sources of variation (Phadke, 2003).

2.1.1 Stages in Taguchi Method

Taguchi recommends three types of S/N ratio to deal with the quality characteristics. These are smaller-the-better, higher-the-better and nominal-the-best. Regardless of the quality characteristic, and the transformations, the S/N ratio is always interpreted as: a larger S/N ratio is better for higher process performance. The steps involved in Taguchi's robust design are (Phadke, 2003) -

- To identify and select the independent input parameters
- Determine their levels and the possible interactions
- To select the appropriate orthogonal array
- To assign the factors, interactions and their levels to orthogonal array
- Conduct the experiments as per the orthogonal array
- Perform the analysis of variance (ANOVA) and analysis of means (ANOM)
- To conduct the confirmation experiment to check the adequacy of the model

2.2 Full Factorial Design of Experiment

It is one of the classical experimental designs identified by b^{a}, where *‘a’* represents the number of variables and *‘b’* represents the levels of input parameters when conventional experimental design technique was applied to industrial experimentation (Montgomery, 2003). Design generated by the two methods appears to be similar. The classical DOE and Taguchi’s DOE can be used for optimization of process variables in any machining operation. As compared with other machining processes, grinding is a costly operation that should be utilized under optimal processing conditions so as to achieve high quality and productivity. It is known that the number of process parameters influence the grinding process performance. Few of them are - depth of cut, wheel speed, and work speed.

3. EXPERIMENTAL DETAILS

3.1 Plan of Experiment

The experimental plan consists of selection of independent input parameters, their levels, the type of design and the experimental array, selection of response variable and S/N ratio. As evident from the literature, the parameters such as, wheel speed, work speed, and depth of cut influence the surface roughness in grinding operation. Therefore these three parameters were selected in this investigation. The factors considered for both Taguchi as well as 2^k FFD are listed in Table 1 with their corresponding levels.

Table 1. Input parameters and their levels

Level	Depth of cut (mm)	Work speed (mm/min)	Wheel speed (rpm)
1	0.01	125	1975
2	0.02	250	2400

The experimental layout employed for the experiments along with the measured response variable is shown in Tables 2 and 3 for Taguchi L_4 and 2^3 full factorial design respectively. After experiments, the ground surfaces were measured using a portable surface roughness tester (Perthometer, M2). The R_a values were noted at three locations separating 120^o on the periphery of the ground surface. Then the average is considered for the analysis.

Table 2. L_4 Taguchi orthogonal array with independent parameters and response

Expt. Run	Depth of cut (mm)	Work speed (mm/min)	Wheel speed (rpm)	Surface roughness R_a (µm)			Average R_a (µm)
				1	2	3	
1	0.01	250	2400	0.62	0.78	0.63	0.67
2	0.02	125	1975	0.63	0.69	0.59	0.63
3	0.01	250	1975	0.50	0.58	0.59	0.55
4	0.02	125	2400	0.77	0.89	0.66	0.77

Table 3. 2^3 Full factorial (FFD) array with independent parameters and response

Expt. Run	Depth of cut (mm)	Work speed (mm/min)	Wheel speed (rpm)	Surface roughness R_a (µm)			Average R_a(µm)
				1	2	3	
1	0.01	125	1975	0.51	0.40	0.50	0.47
2	0.02	125	1975	0.53	0.50	0.49	0.50
3	0.01	250	1975	0.58	0.55	0.64	0.59
4	0.02	250	1975	0.90	0.73	0.60	0.74
5	0.01	125	2400	0.48	0.68	0.69	0.61
6	0.02	125	2400	0.58	0.58	0.74	0.63
7	0.01	250	2400	0.69	0.84	0.80	0.77
8	0.02	250	2400	0.50	0.53	0.86	0.63

3.2 Experimental Procedure

The work piece material used in the present study was HCHC steel in the form of cylindrical bar 35 mm dia and 120 mm long. It has nominal composition (wt. %) as - C 2.35; Cr 12; W 1; Mo 1 and V 4. The grinding wheel used was bonded SiC abrasive type. Before grinding, one end of the workpiece was held in the headstock chuck and another end was held with revolving center of lathe and turned to 30 mm diameter using tungsten carbide insert. The turning conditions were kept constant as - spindle speed of 1200 rpm; feed 0.01mm/rev, DoC 0.05 mm for all the workpieces. The experiments were carried out on PARISHUDH cylindrical grinding machine (see Fig.(1a-b).

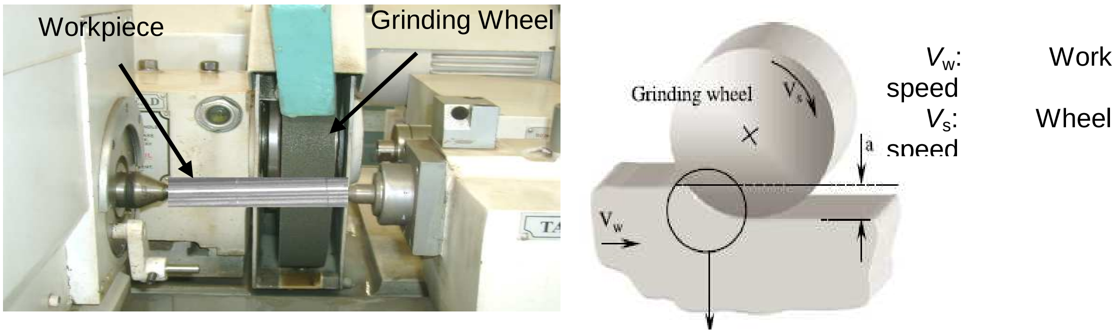


Fig. 1 (a) Close view of the grinding operation, and (b) grinding parameters V_w, V_s, *a*

4. RESULTS AND DISCUSSION

In the following section, the experimental results are analysed and discussion on the effect of various grinding parameters on surface roughness in grinding of HCHC steel is presented.

4.1. Analysis of Surface Roughness using Taguchi Method

The surface roughness was analysed by performing S/N ratio analysis. The following expression was used to determine the S/N ratio:

$$\text{S/N ratio } (\eta) = -10 \log_{10} [(1/n) \times \sum(y_i^2)] \qquad (1)$$

where η is the resultant S/N ratio; n is the number of observations in the experiments and y is the response variable, average surface roughness R_a. The effects of independent parameters are discussed below using main effects plots as shown in Fig. 2.

Effect of depth of cut

It is found that the surface roughness increases with an increase in the depth of cut. It is obvious as the depth of cut increases the volume of deformation involved in the grinding zone also increases. Hence more defects might get exposed due to restructuring of the near surface layers. Therefore the ground surface shows higher roughness.

Effect of work speed

It is observed that when the work speed increases from 125 m/min to 250 m/min the surface roughness increases substantially. It is found that the temperature in the grinding zone increases with an increase in the work speed. It leads to higher thermal oriented deformations and therefore the surface roughness increases (Malkin, 2001). However as the speed crosses certain value, chatter marks are produced on the workpiece surface and thus increase in surface roughness is relatively more than the earlier.

Effect of wheel speed

It is observed from the main effects plots that when the wheel speed increases from 1975 rpm to 2450 rpm, the surface roughness decreases. This might be due to reduction in the contact area between the abrasive cutting points and the work surface (Malkin, 2001). Thus the surface roughness reduces.

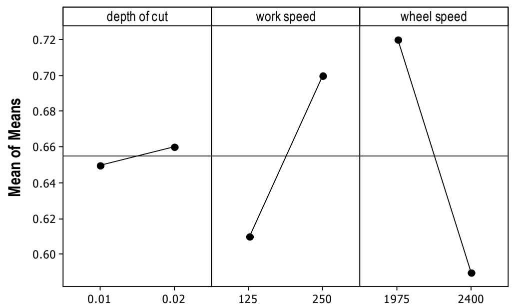


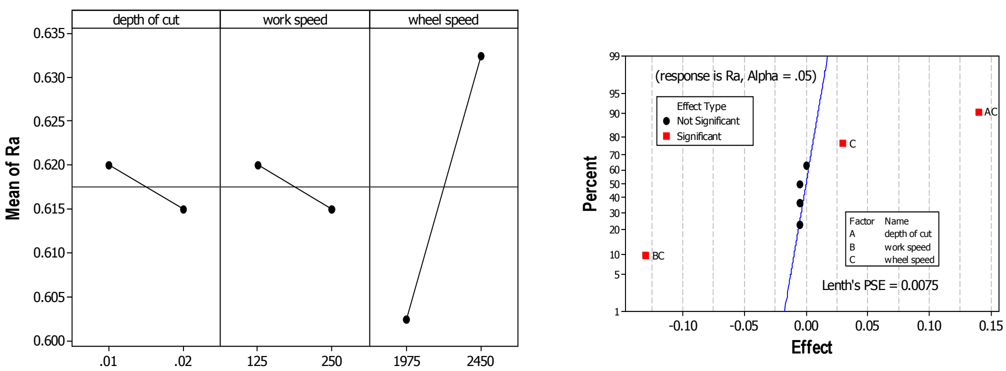
Fig.2 Main effects plots of surface roughness

4.2 Analysis of Surface Roughness using Full Factorial Design

The surface roughness of the ground workpiece is analyzed using main effects plots, normal probability plot, pareto diagram and interactions plots. The effect of input parameters on surface roughness based on the main effects plots is discussed in this section.

Effect of depth of cut

It is noted from Fig. 3 that as the depth of cut increases, the value of the surface roughness decreases. This might be due to increased temperature in the grinding zone, which causes restructuring of the near surface layer.



(a) (b)

Fig. 3 (a) Main effects plots, and (b) Normal probability plot of the surface roughness

Effect of work speed

It is found that the surface roughness decreases with an increase in the work speed. It can be concluded that (see Fig. 3) as work speed increases from lower value i.e. 125 mm/min to higher value i.e. 250 mm/min, the surface roughness decreases hence the quality of the ground surface increases.

Effect of wheel speed

As the wheel speed increases from 1975 rpm to 2400 rpm, the ground surface shows higher roughness value, see Fig.3 (a).

The effects of selected factors and their significance on the surface roughness also can be estimated using normal probability plot as shown in Fig. 3 (b). It is noted that the factor C (wheel speed) and two interactions i.e. AC and BC (interaction between depth of cut x wheel speed and work speed x wheel speed) have statistically significant effect on the surface roughness. However no other factors and remaining interactions have found to be significant on surface roughness in cylindrical grinding of HCHC steel. The effects of various selected factors on the surface roughness after cylindrical grinding of HCHC steel can also be explained using the pareto diagram shown in Fig.4.

It is observed from the Pareto diagram that the interaction between depth of cut and wheel speed has the highest contribution on the surface roughness produced during cylindrical grinding operation.

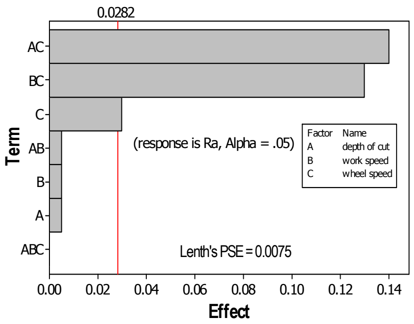


Fig. 4 Pareto diagram of the effects

Fig.5 Interactions plots for surface roughness

Following the interaction AC, other interactions between work speed and wheel speed also have significant contribution on the surface roughness generated during cylindrical grinding operation. It is noted that none of the remaining factors and their interactions have significant effect on the surface roughness produced during grinding of HCHC steel.

The effects of interactions between wheel speed and work speed is also shown using interactions plots presented in Fig. 5. It is observed from the interactions plots that at work speed of 125 mm/min, a change of wheel speed from 1975 rpm to 2450 rpm causes significant increase in the surface roughness. However, the trend is reversed at 250 mm/min work speed, in which the surface roughness reduces with the increase in wheel rpm.

5. CONCLUSIONS

The following conclusions are noted based on statistical analysis of surface roughness in cylindrical grinding of HCHC steel.

(e) Both methods show that the wheel speed has more influence on the surface roughness of the ground workpiece.

(f) Interaction AC (depth of cut and wheel speed) and BC (work speed and wheel speed) have found to be the major effects on the surface roughness, R_a.

(g) Taguchi's method is efficient, systematic with a small number of tests and provides relatively large amount of information using a simple analysis when the interactions are not important. However, full factorial method (FFD) is more efficient when interactions between the process variables are absent.

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