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Optimization of Surface Roughness in Cylindrical Grinding Process

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Abstract

Cylindrical grinding is a metal removing process which is used extensively in the finishing operation. Surface finish is an important output parameter in the manufacturing processes with respect to quality. Cylindrical grinding is an essential process for final machining of components requiring smooth surfaces and precise tolerances. The various process parameters of a cylindrical grinding machine include depth of cut, material hardness, work piece speed, grinding wheel grain size, and grinding wheel speed. The input process parameters considered are material hardness, work piece speed and depth of cut. The main objective is to predict the surface roughness and achieve optimal operating process parameters. For optimization process Taguchi optimization method and genetic algorithm are used. The experiments are conducted on Cylindrical Grinding Machine with L9 Orthogonal array.

Keywords: Cylindrical Grinding, Depth of cut, Material Hardness, Work Piece Speed, Taguchi Method, Genetic algorithm etc.

INTRODUCTION

Cylindrical grinding is a process used to finish grind the outside or inside diameter of a cylindrical part. Cylindrical grinding produces a high quality finish and excellent accuracy and is usually a standard requirement for high accuracy parts. Cylindrical grinding can be carried out by traversing the length of the surface, or plunge cutting can be used for narrower features. For centre grinding the work piece is either held between two centers or driven by a drive dog, or one end is driven by a chuck and the other end is located by the centre. For internal grinding the work piece is commonly held in a chuck only. Applications for cylindrical grinding are finishing bearing diameters and seal surfaces, finish grinding hard chromed hydraulic cylinder shafts and hard faced retainer pins, Sizing of hardened axles and transmission shafts.

In this paper, an attempt is made to find the effect of work material hardness, work material speed and depth of cut on surface finish of cylindrical grinded work materials.

LITERATURE REVIEW

Deepak Pal et al [1] did experimentation on cylindrical grinding. The Experiments are conducted on universal tool and cutter grinding machine with L9 Orthogonal array with input machining variables as work speed, grinding wheel grades and hardness of material. The predicted optimal values for surface roughness for cylindrical grinding are confirmed by conducting confirmation experiments.

R. Alberdi et al [2] presented two approaches aiming at the optimization of fluid application in grinding. The influence of nozzle design on the development of velocity and pressure fields is studied using CFD tools. A new nozzle design that optimizes the characteristics of the jet is introduced analyzed and manufactured. Grinding experiments show that improvements in wheel life and surface finish are possible using the new nozzle. Second, the performance of a new grinding technology that combines MQL with low-temperature CO_2 is evaluated trough industrial grinding tests. Results show an increased performance in terms of friction conditions and surface finish.

Sijo M.T and Biju.N [3] used taguchi parameter optimization methodology is applied to optimize cutting parameters in turning. The turning parameters evaluated are, cutting velocity, feed rate, depth of cut, and nose radius of tool and hardness of the material each at two levels. The results of analysis show that feed rate, cutting velocity and nose radius have present significant contribution on the surface roughness and depth of cut and hardness of material have less significant contribution on the surface roughness.

E. Brinksmeier. h. k. et al [4] described different methods for modelling and optimization of grinding processes. First the process and product quality characterizing quantities have to be measured. After-wards different model types, e.g. physical empirical basic grinding models as well as empirical process models based on neural networks, fuzzy set theory and standard multiple regression methods, are discussed for an o€-line process conceptualization and optimization using a genetic algorithm.

Y.M. Shashidhara and S.R.Jayaram [5] focused their study on the evolution of vegetable oils as cutting fluids in manufacturing sector, particularly, metal cutting and metal forming. It is observed that, most of the contributions are directed to develop and commercialise the cutting fluids based on vegetable oils. However, soyabean, sunflower and rapeseed seem to possess the relevant properties as a potential cutting fluid.

M.M.A. Khana et al [6] presented the effects of minimum quantity lubrication (MQL) by vegetable oil-based cutting fluid on the turning performance of low alloy steel AISI 9310 as compared to completely dry and wet machining in terms of chip–tool interface temperature, chip formation mode, tool wear and surface roughness. MQL machining was performed much superior compared to the dry and wet machining due to substantial reduction in cutting zone temperature enabling favourable chip formation and chip–tool interaction.

EXPERIMENTATION

Mild steel of different compositions are considered for analysis. EN 19, EN 24 and EN 31 are the different grades of the mild steels are turned on lathe and then cylindrical grinding operation is performed as per L9 orthogonal array.

EN19 alloy steel

EN19 also known as **709M40** is a high quality alloy steel, renowned for its good ductility and shock resistant and its resistance to wear properties. It is suitable for gears, pinions, shafts, spindles. It is now also widely used in the oil and gas industry. Chemical Composition of EN19 steel is shown in Table 1. Mechanical properties of EN19 steel are shown in Table 2.

Table 1: Chemical composition of EN19 steel

Carbon	0.36-0.44%
Silicon	0.10-0.40%
Manganese	0.70-1.00%
Sulphur	0.040 Max
Phosphorus	0.035 Max
Chromium	0.90-1.20%
Molybdenum	0.25-0.35%

Table 2: Mechanical properties of EN19 steel

Max Stress	850-1000 N/mm^2
Yield Stress	700 N/mm^2 (Min)
0.2% Proof Stress	680 N/mm^2 (Min)
Elongation	9% min
Impact KCV	55 Joules (Min)
Hardness	248-302 HB

EN24 Alloy Steel:

EN24 steel is a readily machinable material, widely used as engineering steel due to its tensile strength. The material provides a combination of high tensile strength with shock resistance, ductility and wear resistance. It is a through-hardening alloy steel which offers excellent machinability. It is used in components such as heavy duty shafts, gears, studs and bolts. Chemical Composition of EN 24 steel is shown in Table 3. Mechanical properties of EN 24 steel are shown in Table 4.

Table 3: Chemical composition of EN24 steel

Carbon	0.36-0.44%
Silicon	0.10-0.35%
Manganese	0.45-0.70%
Sulphur	0.040 Max
Phosphorus	0.035 Max
Chromium	1.00-1.40%
Molybdenum	0.20-0.35%

Table 4: Mechanical properties of EN24 steel

Max Stress	850-1000 N/mm^2
Yield Stress	680 N/mm^2 (Min)
0.2% Proof Stress	635 N/mm^2 (Min)
Elongation	13 % min
Impact KCV	50 Joules (Min)
Hardness	248/302 HB

EN31 Alloy Steel

It is High carbon alloy steel which achieves a high degree of hardness with compressive strength and abrasion resistance. It is suitable for roller bearing components such as brakes,

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cylindrical , conical & needle rollers. Chemical composition of EN 31 steel is shown in Table 5. Mechanical properties of EN 31 steel are shown in Table 6.

Table 5: Chemical composition of EN31 steel

Carbon	0.90 - 1.20%
Silicon	0.10 - 0.35%
Manganese	0.30 - 0.75%
Sulphur	0.040%
Phosphorus	0.040%
Chromium	1.00 - 1.60%

Table 6: Mechanical properties of EN 31 steel

Tensile Strength	750 N/mm²
Yield Stress	450 N/mm²
Elongation	30%
Density	7.8 Kg/m^3
Hardness	63 RC

Initially Work pieces are centre drilled and turned in lathe machine. Cylindrical grinding machine was used to grind the work pieces as per the L9 orthogonal array. The specifications of cylindrical grinding machine are shown in Table 7.

Table 7: Specifications of Cylindrical Grinding Machine

Model	DEVCO UC-150
Distance between centre	160mm
Height of centre	102mm
Swivelling angle	+/-90C
Traverse speed	140-260-370-700 mm/min
In feed of hand wheel	0.01 Division
Grinding wheel size (dxwxb)	250*25*76.2 mm
Grinding wheel speed	2300 rpm
Work head single spindle speed	90-210-360 rpm (three range)
Spindle in taper	MT-3
Total power required	3.5HP (MAX)

PROCESS VARIABLES AND THEIR LEVELS

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9orthogonal array (OA) design have been selected. In the present experimental study, three levels and three parameters such as work material hardness, work piece speed, and depth of cut have been considered as process variables. The factors and levels used are shown in Table 8.

Table 8: Factors and levels

Factors	Level 1	Level 2	Level 3
Hardness	40	47	55
Speed (rpm)	100	214	340
Depth of cut (mm)	1	3	2

Taguchi Method

Taguchi Method was used to optimize the control parameters. L9 orthogonal array was employed for optimization. L9 orthogonal array was shown in Table 9.

Experiments are conducted in the order given by Taguchi method on Cylindrical Grinding Machine as per L9 orthogonal array and the corresponding surface roughness values measured using SURFTEST SJ301 are shown in Table 10.

Table 9: L 9 Orthogonal Array

S.No	Hardness	Speed (rpm)	Depth of cut (mm)
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 10: Surface Roughness Values as per L9 Orthogonal Array

S.No	Hardness	Speed (rpm)	Depth of cut (mm)	Roughness (Ra)
1	40	100	1	0.81
2	40	214	2	0.78
3	40	340	3	1.25
4	47	100	2	1.06
5	47	214	3	1.08
6	47	340	1	1.20
7	55	100	3	1.60
8	55	214	1	1.04
9	55	340	2	1.54

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value for the output characteristic. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. Smaller is better S/N ratio was used in this study because less surface roughness was desirable. Quality characteristic of the smaller is better is calculated in the following equation.

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

S/N values are calculated using Taguchi Method and are shown in Table 11.

Table 11: S/N values for machining the EN 19,24,31 work pieces at nine runs

S.No	Hard-ness	Speed (rpm)	Depth of cut (mm)	Ra	S/N ratio
1	40	100	1	0.81	1.83
2	40	214	2	0.78	2.15
3	40	340	3	1.25	-1.93
4	47	100	2	1.06	-0.50
5	47	214	3	1.08	-0.66
6	47	340	1	1.20	-1.58
7	55	100	3	1.60	-4.08
8	55	214	1	1.04	-0.34
9	55	340	2	1.54	-3.75

After calculating S/N Ratios, the effect of control parameters on S/N ratio is found and shown in Fig.1.

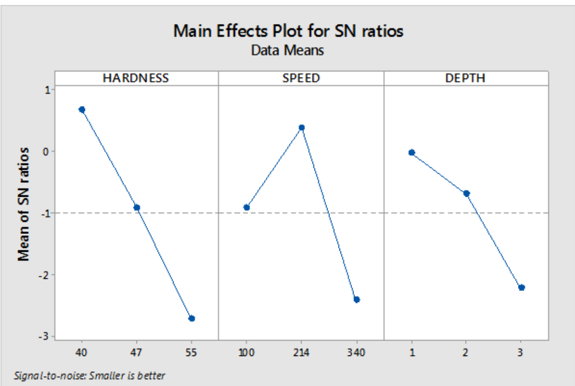

Figure 1: Effect of Control parameters on S/N ratio

According to Taguchi design, Factor levels for minimum surface roughness are obtained and shown in Table 12.

Table 12: Optimum Control parameters for minimum surface roughness

Hardness	Speed	Depth of Cut	S/N ratio
40	214	1	3.00873

Predicted S/N Ratio as per Taguchi method= 3.00873

Predicted Surface roughness value corresponding to S/N ratio of 3.00873 is 0.707 µm

Experimental surface roughness value as per work piece hardness of 40, speed of 414 rpm, Depth of cut of 1mm = 0.712 µm.

Regression Equation

Ra = -0.723 + (0.02990 * Hardness) + (0.000760* Speed) + (0.1467 *Depth Of Cut)

Analysis of Variance is carried out to find the most contributing factor for surface roughness. The result of analysis of variance is shown in Table 13.

Table 13: Result of ANOVA

Source	DF	Adj SS	Adj MS	F value	P value	SS %
Hardness	1	0.30	0.16	9.24	0.06	46.8
Speed	1	0.05	0.30	1.53	0.029	7.7
Depth of Cut	1	0.13	0.05	3.95	0.271	20
Error	5	0.16	0.13		0.104	25.3
Total	8	0.65	0.03			

From the ANOVA analysis, it can be under stood that Hardness is the most contributing factor for surface roughness.

Optimization by Genetic algorithm using MAT LAB

Using MATLAB Software, genetic algorithm is applied to find the optimum factors to get minimum surface roughness. The problem is formulated as single objective optimization function. The aim to find the optimum surface roughness value in the given bounds. The optimization algorithm used was Genetic algorithm. Control parameters are left to default value and are as shown in Table 14.

Table 14: Default values of Control Parameters

S NO	CONTROL PARAMETERS	VALUE/TYPE
1	Population size	20
2	Creation function	Uniform
3	Scaling function	Rank
4	Selection function	Stochastic uniform
5	Elite count	2
6	Crossover fraction	0.8
7	Mutation function	Constraint dependent
8	Crossover fraction	scattered

From genetic algorithm, minimum surface roughness is found to be as per control factors shown in Table 15.

Table 15: Optimum control factors as per genetic algorithm

Hardness	Speed	Doc	Surface Roughness
40	100 rpm	1 mm	0.6957

The variation for best fittest vale is shown in Fig.2.

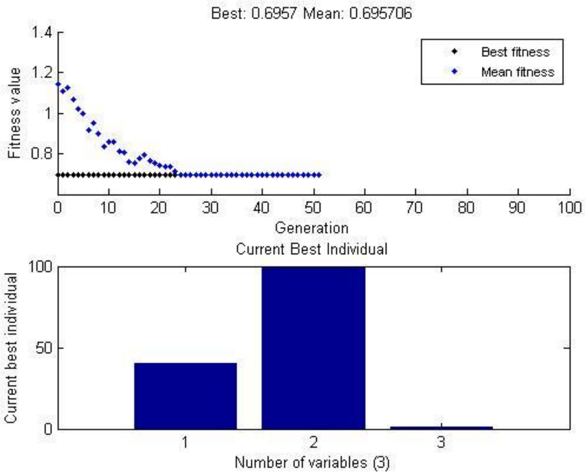

Figure 2: Variation for best fittest value

CONCLUSIONS

The study proposes an integrated optimization approach using Taguchi method and genetic algorithm.

Optimum combination of process parameters (hardness of 40, speed of 214 rpm and depth of cut of 1mm) for minimum surface roughness has been calculated using Taguchi method.

It has been found that the hardness contributes more than 45% in minimization of surface roughness whereas depth of cut and speed affects the surface roughness to 20% and 7.74% respectively.

The predicted range of surface finish is 0.707 µm at 95% consistency level for optimum combination of process parameters as per taguchi method.

Conformational experiment has also been performed at the optimum combination of process parameters and the resultis found within the calculated range of surface roughness i.e. 0.712 µm.

As per genetic algorithm, optimum combination of process parameters are hardness of 40, Speed of 100 rpm, Depth of cut of 1mm and the results found within the calculated range of surface roughness is 0.6957 µm. But experimental value for this set of input parameters is 0.81 µm which is closer. The variation is due to vibrations and noise factors .

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