IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X
PP 39-46
www.iosrjournals.org

Prediction and Optimization of Cylindrical Grinding Parameters for Surface Roughness Using Taguchi Method

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ABSTRACT: *Recently 304 stainless steel finds many applications like Automotive, Aerospace, Nuclear, Chemical and Cryogenics. The cylindrical grinding parameters on 304 stainless steel are conducted using Taguchi design of experiments of L9 orthogonal array was selected with 3 levels with 3 factors and output parameter of Surface Roughness is measured. The quality of the surface describes the relationship between the cutting speeds, feed rate, depth of cut and surface roughness are measured. High quality of the machining is done using the cylindrical grinding operation. Quality of the surface depends on the size and shape of the workpiece used. After conducting experiment, it is optimized by S / N ratio and analyzed by ANOVA and predicted that cutting speed is a dominating parameter of cylindrical grinding.*

Keywords: *Cylindrical Grinding, Surface Roughness, Taguchi Design, ANOVA Analysis*.

I. INTRODUCTION

Cylindrical grinding is the process of final finishing of components required for smooth surfaces and close tolerances. During the cylindrical grinding operations very small size of the chips are produced. It is widely used in industry, grinding remains perhaps the least understood of all machining processes. The major operating input parameters that influence the output response of surface roughness are (i) Machine parameter (ii) Process parameter (iii) Grinding wheel parameter (iv) Work piece parameter. The present work takes the following input processes parameters of Cutting Speed, Feed Rate and Depth of Cut. The main objective of this paper is to show how our knowledge on Cylindrical grinding process can be utilized to predict the grinding behavior and achieve optimal operating processes parameters. The knowledge is mainly in the form of physical and empirical models which describe various aspects of cylindrical grinding process. A Taguchi method has been used which integrates these models to simulate what happens during cylindrical grinding processes. Predictions from this simulation are further analyzed by calibration with actual data. Various factors are involved to find the optimal value such as Chemical Composition of grinding wheel, Type of Abrasive, Cutting Speed, Feed Rate, Depth of Cut, etc. Surface finish is the important output response in the production with respect to quality and quantity.

II. LITERATURE REVIEW

V. Pallavi et al. [1] used Taguchi's design of experiment and ANOVA to optimize the turning parameters for surface roughness in lathe when machining mild steel with coated carbide tool under dry cutting condition. Turning is the process used to remove the material for a workpiece to obtain specific dimension and tolerances. It is observed that surface roughness (Ra) value get reduced as signal to noise ratio increases due to the various levels of machining parameters. It is found that by increasing the signal to noise ratio, the optimal design condition was achieved. The DOE of L9 orthogonal array has been employed with cutting parameters of cutting speed, feed rate and depth of cut estimated that the minimum value of surface roughness found that 2.2 µm. In this study, Interaction Severity Index has been found between the speed and depth of cut was 18.04 %. Signal to noise ratio based on the Taguchi's design of present study was -13.78. kalidass. S et al. [2] investigated the surface roughness of Austenitic Stainless Steel (AISI 304) for end milling operation using uncoated solid carbide end mill cutter. The Artificial Neural Network and Genetic Algorithm was adopted to predict and optimize the effect of helix angle of tool geometry, spindle speed, feed rate and depth of cut on surface roughness. A source code was developed in MATLAB 7.6 and found that surface roughness value is 0.75132 µm. Surinder kumar et al. [3] developed a surface roughness prediction model for the machining of unidirectional glass fiber reinforced plastics (UD-GFRP) composite with polycrystalline diamond tool of different tool rake angle and tool nose radius using multiple regression methodology and genetic algorithm approach to predict and optimize the parameters of tool nose radius, tool rake angle, feed rate, cutting speed, cutting environment [Dry, Wet and Cooled] and depth of cut on surface roughness. It was found that Taguchi's mixed level design of L18 orthogonal array employed for the experimentation work. This material finds application in advanced structural application due to their light weight, high modulus and specific strength. The minimum value of surface roughness was found that 1.1653 µm. Suresh. P et al. [4] presented the experimental investigation of the effects of cutting speed, feed rate and depth of cut for turning of Al-SiC metal matrix composite using tungsten carbide tool for machining. All the experiments were conducted without coolant in CNC lathe as per the L9 orthogonal array. The selection of suitable machining condition essential to reduce the machining cost, reduce set up time, increase the quality and improve the efficiency of machining. The production of this Al-SiC composites using stir casting technology. In this study, taguchi L9 orthogonal array [3 level, 4 factor] was used to determine the optimal machining parameters. The factors affecting the surface roughness and material removal rate are analyzed using ANOVA and grey relational analysis based on the taguchi design of experiment. The size of the workpiece was found that 30 mm diameter and 80 mm length. In this investigation surface roughness (Ra) was measured by using the Mitutoyo surfest SJ-201 contact profilometer. Based on the analysis of optimal machining condition, the minimum surface roughness was obtained at 1.46 µm and for the metal removal rate was found that 50.81 gm/min. SEM micrograph for the machined surface shows that low speed produces high surface roughness and also metal removal rate is very low. In this study the surface roughness (Ra) with increase in feed rate, depth of cut and decrease with increase of cutting speed. Qiyong Zeng et al. [5] examined the cutting parameters affect the workpiece surface quality. Process Failure Mode and Effect Analysis (PFMEA) was conducted that cutting temperature, cutting force and mechanical vibrations are the main factors that affect the workpiece surface roughness. The cutting force, cutting temperature and vibration can be controlled by controlling cutting speed, feed rate and cutting depth. Surface roughness of the workpiece was measured by surface roughness tested. The thin film thermocouple sensor and three-dimensional piezo electric dynamometer was used to measuring the system for cutting force and cutting temperature. The piezo electric dynamometer work fast with high sensitivity is convenient for real time measuring on line. In this investigation, Polycrystalline Cubic Boron Nitride (PCBN) was used as the cutter material. Workpiece surface roughness is good under the condition of low cutting speed and low cutting depth. The thin film thermocouple is an advanced sensor used to measure the changes in temperature. It is concluded that feed rate and cutting depth affect the workpiece surface roughness than cutting speed. M. Janardhan et al. [6] has developed model to predict and optimize the process parameters using taguchi method, ANOVA and regression analysis. The main objective of this work is to maximize the metal removal rate (MRR) and to minimize the surface roughness (Ra). The design of experiments is conducted on CNC cylindrical grinding machine. The empirical models are developed using design of experiments and surface roughness methodology. Regression analysis used to determine the relationship of the input variables which affect the output responses. In this experiments, grinding wheel having aluminium oxide abrasive with vitrified bond with constant speed of 1650 rpm and water used as coolant. In this experiment L9 orthogonal array was used and tested with ANOVA. The input parameters of this work as work speed (rpm), feed rate (mm/min) and depth of cut (µm). The regression analysis was done by MINITAB 15 statistical software. In this work, EN 8 material is used to determine the effect of machining parameters. The concept of ANOVA and S/N ratio is used to determine the effect of process parameters. From the pareto analysis conclude that feed rate plays important role in the output response of surface roughness and metal removal rate. The optimized values for MRR and Ra for cylindrical process are 62.05 gm/min and 0.816 µm respectively. Deepak Pal et al. [7] investigated to predict the grinding behavior and finding optimal operating process parameters. In this paper, minimize the surface roughness (Ra) by taguchi optimization technique. The universal tool and cutter grinding machine with aluminium oxide abrasive wheel used for investigation. The workpiece material is used for this investigation is EN 24, EN 31 and Die steel. L9 orthogonal array is used for this experimental work. The input parameters used for this work is work speed, grinding wheel grades and hardness of the material. MATLAB software is used for optimization work. It is found that the optimal value of surface roughness is 1.07 µm. Thiagarajan. C et al. [8] studied the grindability of Al/SiC metal matrix composites in cylindrical grinding process. Horizontal spindle cylindrical grinding machine with Al_2O_3 grinding wheel is used for this experimental work. The experiments are carried out to study the effect of grinding parameters such as, wheel velocity, workpiece velocity, feed and depth of cut. An infra red non contact laser thermometer is used to measure the temperature generated between the grinding wheel and workpiece. Scanning Electron Microscope [SEM] is used for measure the surface integrity. They reported that good surface finish occurs at high grinding wheel velocity and workpiece velocity, low feed rate and depth of cut. Kiyak. M et al [9] studied the effect of machining parameters such as, workpiece speed, feed rate and grinding depth on AISI 1050 steel. In this research work, to optimize the surface roughness value under dry and wet conditions. This work is completed on external cylindrical grinding machine with SiC abrasive wheel is used. The Taylor Hobson Surtronic 3+ type surface test equipment is used for measuring the surface roughness. It was noticed that, in dry condition observed that high feed rate increases the surface roughness, increase workpiece speed reduces the surface roughness, in wet condition observed that high workpiece speed and high feed rate increases the surface roughness and high metal removal rate is found that 200000 mm^3/min is produced a better surface quality. Janardhan. M et al. [10] investigated the optimization of surface quality and metal removal rate using the Response Surface Methodology [RSM]. In this work, wheel speed, table speed and depth of cut as the control factors. The surface grinding machine with aluminium oxide abrasive wheel is used for this investigation. L27 orthogonal array is selected for this research work. MRR is calculated using the ratio of volume of metal removed from the workpiece to the machining time. Surface roughness was measured using the surface roughness tester. The material used for this investigation is EN 24. The Design Expert (MINITAB) software is used for finding the output responses.

The main objective of my work is to minimize the Surface Roughness (Ra). In order to optimize the Ra value Taguchi method, ANOVA and regression analysis is used to predict the optimal value. This research work is to study the relationship between the cylindrical grinding parameters [cutting speed, feed rate, depth of cut] and the surface roughness value.

III. PROBLEM IDENTIFICATION

The cylindrical grinding process parameters such as cutting speeds, feed rate and depth of cut are the main factors that affect the quality of the surface finish. The main objective of this study is to find the minimum surface finish. The Figure 1 that shows the structure of the model to predict the surface roughness.

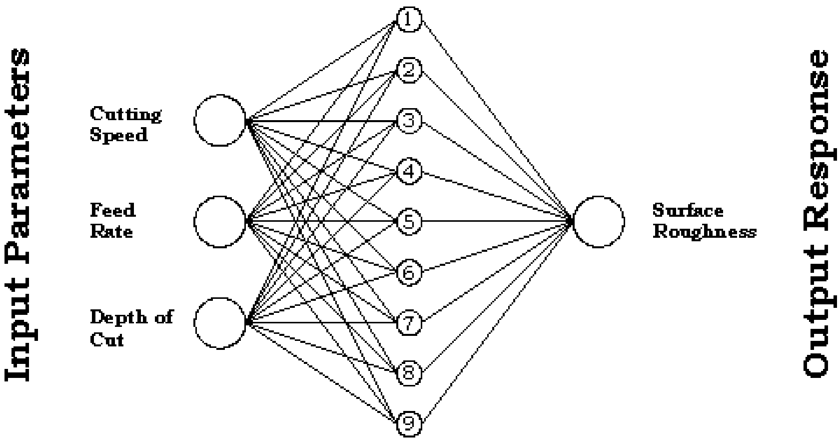

Figure 1 Structure of the model to predict the surface roughness

The identification of machining and grinding problem for 304 stainless steel which cannot be tackled using conventional technique because of the following problems occurs in grinding process**.**

- Poor Chip Breaking.
- High Work hardened.
- Tendency to sticky.
- Transformation Induced plasticity.
- Affect the passive surface.
- Machining distortion.

The above problems are to overcome during cylindrical grinding to achieve good surface finish and close dimensional accuracy.

Special Features

Cylindrical grinding of 304 stainless steel have the following special features.

- Grinding of 304 stainless steel rods to produce good surface finish with optimum parameters.
- Grinding can improve Integrity and Quality Defects are also reduced.
- Achieve for Micro machining.
- High dimensional Accuracy can be Achieved
- Close tolerance can be achieved.

IV. EXPERIMENTAL PROCEDURE WORKPIECE MATERIAL

The workpiece material selected for investigation is 304 stainless steel. This steel is also called as corrosion resistant steel but having greater strength compared with low carbon steel having the dimensions of 20 mm diameter and 100 mm length as shown in Figure 2.

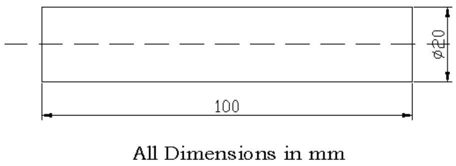

Figure 2 Dimensions and Shape of Specimen

The chemical composition of the work material is shown in Table 1

Table 1 : Chemical Composition of 304 Stainless Steel

Cr	Ni	Mn	S	Si	C	P
18	8	2.0	0.03	1	0.08	0.045

Machining Process

Normally machining is the important term used to explain the removal of material from the workpiece. The cutting process is the one of the important manufacturing operations. The grinding is the one of the metal removal process to produce good surface finish in the manufactured product. This cylindrical grinding operation is used to improve the quality of the surface finish and also improves the appearance of the workpiece after machining process. The grinding process is performed on cylindrical grinding machine as shown in Figure 3 using silicon carbide as grinding wheel in the room temperature. The coolant is used to remove the large amount of heat produced during the cylindrical grinding operation and also improve the surface finish of the machined workpiece. The actual working of tze cylindrical grinding operation is explained in Figure 4.

Figure 3 Cylindrical Grinding Machine

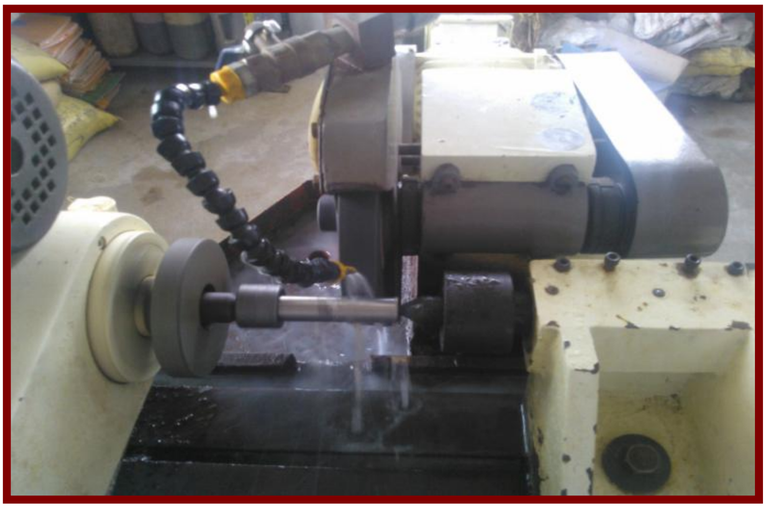

Figure 4 Cylindrical grinding machine with workpiece actual setup

Dimensions are the main factor described by the customer for the quality of the machined surface. The experiments are conducted as per the orthogonal array and roughness of various combinations of parameters was measured using the surface roughness tester [surftest SJ-201P] as shown in Figure 4. It is a shop-floor type surface roughness measuring instrument, which traces the surfaces of workpieces, calculates their surface roughness based on roughness standards and displays the results. This instrument has a maximum measurement range of 350 μm and can represent surface texture using various surface roughness parameters. It has a light weight [0.5 Kg] design for excellent portability. It is made compact so that it can be held and operated in one hand. An AC adapter and a built-in battery are provided to supply power to this instrument. This instrument used to determine the surface roughness of the material after completing the grinding operations.

Figure 4 Surface Roughness Tester

DESIGN OF EXPERIMENTS

The Design of Experiments (DOE) is an important statistical technique for improving the product design and solving production problems. Dr. Genichi Taguchi (1980) has prescribed a standard way to utilize the DOE to enhance the quality of product and process for the design and manufacturing and also reduces the cost.

In this present work three levels at three factors has been employed to predict the optimal values, as shown in Table 2.

Table 2 : Details of Process Parameters

S. No.	Input Factors	Levels		
		1	2	3
1.	Cutting Speed (rpm)	560	780	1000
2.	Feed Rate (mm/rev)	0.178	0.128	0.100
3.	Depth of Cut (mm)	0.003	0.004	0.005

L9 orthogonal array for three factors and three levels is used in the present investigation. This L9 orthogonal array is selected to check the interactions between the factors as shown in Table 3.

Table 3 : Taguchi's Design of Experiments

Experiment	Cutting speed	Feed rate	Depth of Cut
	rpm	mm/rev	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

V. RESULT AND DISCUSSIONS

The selection of abrasive and process variable is the important factor that affects the quality and surface finish of the workpiece. A silicon carbide grinding wheel is used for cylindrical grinding operations of 304 stainless steel workpiece as shown in Figure 5.

Figure 5 Actual Workpiece after Cylindrical Grinding process

Surface Roughness

- Cutting speed is a dominating parameter of cylindrical grinding.
- The optimum parameter of cylindrical grinding of 304 Stainless Steel rods were 780m/min of cutting speed, 0.093mm of feed rate and 0.05mm of depth of cut.
- However 304 Stainless Steel is good machinabilty characteristic and Produce excellent surface finish.
- 304 stainless steel produce good surface finish and get minimum crack tendency.
- Cylindrical grinding improves surface integrity and accuracy.

ANOVA

The ANOVA procedure performs **Analysis of Variance (ANOVA)** for balanced data from a wide variety of experimental designs. In analysis of variance, a continuous response variable, known as a dependent variable, is measured under experimental conditions identified by classification variables, known as independent variables. The variation in the response is assumed to be due to effects in the classification, with random error accounting for the remaining variation.

Response Table for Signal to Noise Ratios of surface roughness values (Smaller is better)

LEVEL	A	B	C
1	1.2216	0.6744	-1.1483
2	-1.2282	-1.2581	0.9132
3	-0.8885	-0.3114	-0.6601
DELTA	2.4499	1.9325	2.0615
RANK	**1**	**3**	**2**

Table 4 S/N ratio of cylindrical grinding parameters of surface roughness

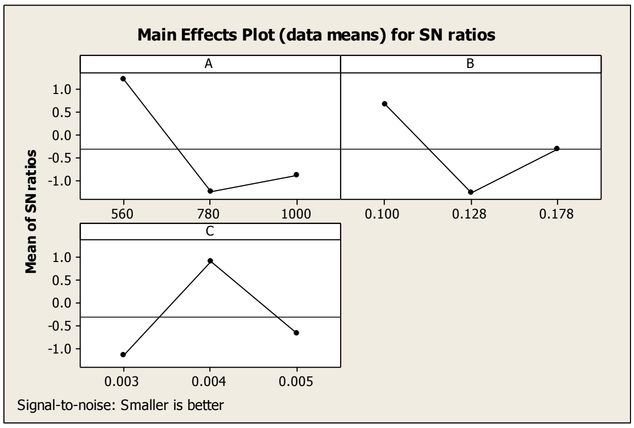

Figure 6 Main effect plots for Ra in 304 Stainless Steel Workpiece

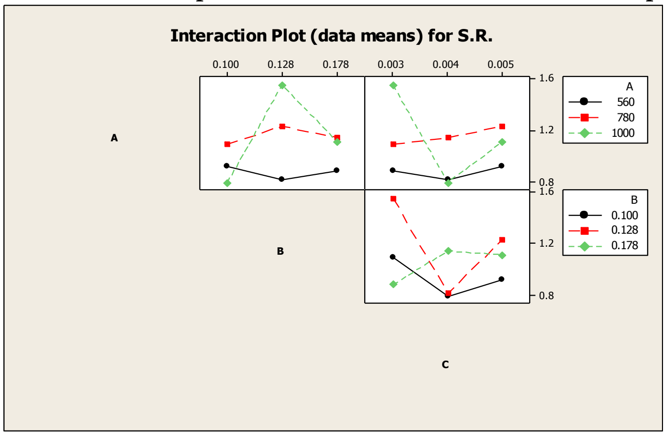

Figure 7 Interaction plot for Ra in 304 Stainless Steel Workpiece

VI. CONCLUSIONS

On the basis of this investigation, the following conclusions can be drawn.

1. It was found that good surface finish is obtained during the cylindrical grinding process with optimum grinding conditions.
2. Cutting Speed, Feed Rate and Depth of Cut plays an important role in the cylindrical grinding parameters.
3. The optimum parameters of cylindrical grinding process to overcome the problem of poor surface finishing.
4. Close tolerance can be achieved.
5. Increase in cutting parameters affects the vibration of the grinding machine, grinding wheel, more metal removal and excessive heat on the workpiece. The above causes will results in poor surface finish.

This study is valuable for the Researchers to develop their basic knowledge about fundamental methodology and procedures are conducted.

ACKNOWLEDGEMENTS

First of all I would like to express my deepest gratitude and sincere thanks to my guide, Dr. P. Paulraj, Professor & Head of the Department, J.J. College of Engineering and Technology, Trichy, Tamilnadu, India his valuable time and keep interest in my research work. His intellectual advice has helping me in every step of my research work.

I express my sincere thanks to our beloved Chairman Dr. P. Selvaraj, Director Dr. E. Ramasamy, Respected Principal Dr. S. Ganesan Shanthi and Head of the Department Prof. K. Anand for given valuable suggestions and Motivate this Efforts

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