IMPACT: International Journal of Research in Engineering &Technology (IMPACT: IJRET)
ISSN 2321-8843
Vol. 1, Issue 3, Aug 2013, 65-76

EXPERIMENTAL INVESTIGATIONS AND OPTIMIZATION OF JIG GRINDING PROCESS

SUDHEESH P K & GOVINDAN P

M Tech Scholar, Assistant Professor, Government College of Engineering Kannur, Kannur, Kerala, India

ABSTRACT

In this paper, an evaluation of the jig grinding process using a comprehensive experimentation is performed. There are several factors influencing the performance of the grinding performance. The performance of the process was measured in terms of MRR and Ra. The experiments were conducted based on Taguchi L_9 orthogonal array with the chosen three parameters at three levels. The statistical analysis using ANOVA indicates that none of the parameters are significant at 95% confidence level. It was observed that speed followed by depth of cut and feed influence the roughness of the ground surfaces. The MRR was influenced by feed followed by speed and depth. The AOM analysis was performed for MRR and Ra at all processing conditions. The response graphs for means and S/N rations were generated for each of the chosen input parameters. Regression equations were developed corresponding to each of these processing conditions. This comprehensive analysis has helped characterize jog grinding at an experimental level.

KEYWORDS: Jig Grinding, Optimization, Taguchi Array, Surface Roughness, MRR and ANOVA

INTRODUCTION

Jig grinding is an essential process for final machining of components requiring smooth surfaces and precise tolerances. As compared with other machining processes, grinding is costly operation that should be utilized under optimal conditions [1]. Although widely used in industry, grinding remains perhaps the least understood of all machining processes. The major operating input parameters that influence the output responses, metal removal rate, surface roughness, surface damage, and tool wear, etc. are (i) wheel parameters: abrasives, grain size, grade, structure, binder, shape and dimension, etc. (ii) Work piece parameters: fracture mode, mechanical properties and chemical composition, etc. (iii) Process parameters: work speed, depth of cut, feed rate, dressing condition, etc. (iv) machine parameters: static and dynamic Characteristics, spindle system, and table system, etc [2]. The present paper takes the following input processes parameters namely Wheel speed, feed rate and depth of cut. The main objective of this paper is to show how our knowledge on 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 grinding process [3-5]. A software package has been developed which integrates these various models to simulate what happens during Jig grinding processes. Predictions from this simulation are further analyzed by calibration with actual data. It involves several variables such as depth of cut, wheel speed, feed rate, grit size, type of abrasive, chemical composition of wheel, etc [5]. The main objective in any machining process is to maximize the metal removal rate (MRR) and to minimize the surface roughness (Ra).In order to optimize these values Taguchi method, ANOVA and regression analysis is used [6]. Demand are being placed on the automobile, aerospace, and medical component industries to produce stronger, lighter, precision parts. This in return is forcing improvement and advancement to be made in the machining processes that are used to produce these parts. Conventional machining processes are being pushed to their limits of performance and productivity [7]. Many non-traditional process such as electrical-discharge machining, electro-chemical machining, and ultrasonic machining are being used to meet industries demands. Non-traditional processes do not rely on contact between the tool and the work piece to remove material in the form of chips [8]. In many cases, these processes use a tool that is softer than the work piece. Besides that, surface topography also is of great importance in specifying the function of a surface. A significant proportion of component failure starts at the surface due to either an isolated manufacturing discontinuity or gradual deterioration of the surface quality. Typically are the laps and folds which cause fatigue failures and of the latter is the grinding damage due to the use of a worn wheel resulting in stress corrosion and fatigue failure [9]. The most important parameter describing surface integrity is surface roughness. In the manufacturing industry, surface must be within certain limits of roughness. Therefore, measuring surface roughness is vital to quality control of machining work piece [10]. Grinding may be classified in to groups as rough or non precision grinding and precision grinding. Snagging and off hand grinding are the common forms of the rough grinding where the metal is removed without regard to accuracy. In precision grinding, according to type of surface to be ground, it is classified in to external or internal grinding, surface and cylindrical grinding. The achievement of desirable value is a very critical process as the parts have already passed through many machining stages. In order to maintain quality, the variables the affect the grinding process must be defined experimentally and monitored in process. The basic target of the grinding process is to achieve the required shape, size and surface topography of the finished product in the most economical way. In modern manufacturing and assemblies, high dimensional accuracy and fine surface finish play an important role [6-9]. The improvement in surface finish on the work pieces leads to higher corrosion resistance, fatigue strength and reduced power loss due to friction. The selection of the process involves: i) the material is too hard to be machined economically .The material may have been hardened in order to produce a low-wear finish, ii) tolerances required preclude machining. Jig grinder can produce tolerances of 0.0002mm with extremely fine surface finishes, and iii) machining removes excessive material [1-5]. The most important parameter describing surface integrity is surface roughness. In the manufacturing industry today, surface must be within certain limits of roughness. Therefore, measuring surface roughness is vital to quality control of machining work piece. Surface roughness also is great concern in manufacturing industrial environment. Parts such as automobile, aerospace, and medical component need high precision in surface finish. So there are problems in attempt to get high quality surface finish of product. Besides that, optimization of grinding parameter is usually a difficult work where the following aspects are requiring such as knowledge of machining and specification of machining tools capabilities [10-11]. The optimization parameters of machining are important especially in produce maximize production rate, reduce cost and production rate. Optimization parameters of machine to make good quality for surface roughness are of great concern in manufacturing environments, where economic of machining operation plays a key role in competitiveness in the market. Parameters that must identify for surface roughness and material removal rate are wheel speed, feed rate and depth of cut [8]. Other parameters of Jig grinding machine are constant. Therefore, the objectives of this study are to: i) perform experiment using jig grinding machine, ii) investigate the effect of parameter that influences the surface roughness on mild steel, and iii) to determine optimum Jig grinding process parameters.

LITERATURE REVIEW

M.Janardhan *et al.* [1] proposed that in cylindrical grinding metal removal rate and surface finish are the important responses. The Experiments were conducted on CNC cylindrical grinding machine using EN8 material (BHN-30-35) and he found that the feed rate played vital role on responses surface roughness and metal removal rate than other process parameters. M.A. Kamely *et al.* [2] have been developed a mathematical model of the surface roughness by using response surface methodology (RSM) in grinding of AISI D2 cold work tool steels. M.N. Dhavlikar *et al*. [3] have done a project on Combined Taguchi and dual response method for optimization of a centerless operation. This paper presents a successful application of combined Taguchi and dual response methodology to determine robust condition for minimization of out of roundness error of work pieces for center less grinding operation. From the confirmation runs, it was observed that this approach led to successful identification of optimum process parameter values. The application of combined Taguchi and dual response methodology has resulted in a solution, which has led to almost zero defect situation for the centerless grinding process. The concept of S/N ratio from Taguchi methodology was used to measure the variance of out of roundness error. The dual response methodology was used to formulate an objective function to obtain optimum condition for the process. Regression analysis was done on the experimental runs to obtain equations for S/N ratio and average out of roundness error. These equations were then used in the objective function formulated using dual response methodology. The primary objective was to minimize the S/N ratio while keeping the out of roundness error below 5 mm. Monte Carlo simulation procedure was used to determine the optimum condition by sequentially narrowing down the search range of the variables around the best solution obtained at every run. S. Shaji *et al*. [4] studied with the analysis of the process parameters such as speed, feed, infeed and mode of dressing as influential factors, on the force components and surface finish developed based on Taguchi's experimental design methods. Taguchi's tools such as orthogonal array, signal-to-noise ratio, factor effect analysis, ANOVA, etc. have been used for this purpose and an optimal condition has been found out. The results have been compared with the results obtained in the conventional coolant grinding. It has been observed that, with the graphite application, the tangential force and surface roughness are lower and normal force is higher compared to those in the conventional grinding. Jae-Seob Kwak [5] applied Taguchi and response surface methodologies for geometric error in surface grinding process. The effect of grinding parameters on the geometric error was evaluated and optimum grinding conditions for minimizing the geometric error were determined. A second-order response model for the geometric error was developed and the utilization of the response surface model was evaluated with constraints of the surface roughness and the material removal rate. Suleyman Neseli *et al* [6] applied combined response surface methodology (RSM) and Taguchi methodology (TM) to determine optimum parameters for minimum surface roughness (Ra) and vibration (Vb) in external cylindrical grinding. First, an experiment was conducted in a CNC cylindrical grinding machine. The three input parameters were work piece revolution, feed rate and depth of cut; the outputs were vibrations and surface roughness. Second, to minimize wheel vibration and surface roughness, two optimized models were developed using computer-aided single-objective optimization. The experimental and statistical results revealed that the most significant grinding parameter for surface roughness and vibration is work piece revolution followed by the depth of cut. The predicted values and measured values were fairly close, which indicates that the developed models can be effectively used to predict surface roughness and vibration in the grinding. Kundan Kumar *et al*. [7] proposed Optimal material removal and effect of process parameters of cylindrical grinding machine by Taguchi method. This research outlines the Taguchi's Parameter Design Approach, which has applied to optimize machining parameters in Cylindrical Grinding Process. The grinding parameters evaluated are cutting speed and depth of cut. An orthogonal array, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to analyze the effect of these grinding parameters. An orthogonal array has used to plan the experiments. Kirankumar Ramakantrao Jagtap [8] proposed that for Surface Roughness (Ra), the work speed (Nw) was the most influencing factor for AISI 1040 work material followed by grinding wheel speed, number of passes and depth of cut. So, to achieve the minimum surface roughness of AISI 1040 steel, they employed low depth of cut. Alao Abdur-Rasheed *et al*. [9] aims at Optimization of Precision Grinding Parameters of Silicon for Surface Roughness Based on Taguchi Method. This study investigated the effect and optimization of grinding parameters using Taguchi optimization technique during precision grinding of silicon. Experimental studies were conducted under varying depths of cut, feed rates and spindle speeds. An orthogonal array (OA), signal-to-noise (*S/N*) ratio and the analysis of variance (ANOVA) were employed to find the minimum surface roughness value and to analyze the effect of the grinding parameters on the surface roughness. Confirmation tests were carried out in order to illustrate the effectiveness of the Taguchi method. The results show that feed rate mostly affected the surface roughness.

The predicted roughness (*Ra*) of 34 nm was in agreement with the confirmation tests. Massive ductile streaked surface was also found corresponding to the minimal surface finish determined from the optimal levels. Mustafa Kemal Külekcý [10] aims Analysis of process parameters for a surface Grinding process based on the Taguchi method. In this study the wheel speed (*V*), the rate of feed (*F*) and the depth of cut (*D*) were selected as variable parameters. Other process parameters were fixed.

Deepak Pal et al [11] aims at Optimization of Grinding Parameters for Minimum Surface Roughness by Taguchi Parametric Optimization Technique. In this study, 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 developed model can be used by the different manufacturing firms to select right combination of machining parameters to achieve an optimal surface roughness (Ra).

EXPERIMENTAL WORK

A set of experiments were conducted on MOORE Jig grinding machine on 150X100 mm dimension Mild steel bar material to determine effect of machining parameters namely feed rate (mm/sec) , Wheel speed (rpm), depth of cut (mm) on metal removal rate and surface finish (μm). The experimental set-up is shown in Figure 1. Three levels and three factors L9 Orthogonal array used to design the orthogonal array by using design of experiments (DOE) and relevant ranges of parameters .Grinding wheel used for the present work is the Diamond abrasive with verified bond with varying speed of 48000, 51300 and 56200 RPM and air coolant was supplied in all grinding experiments.

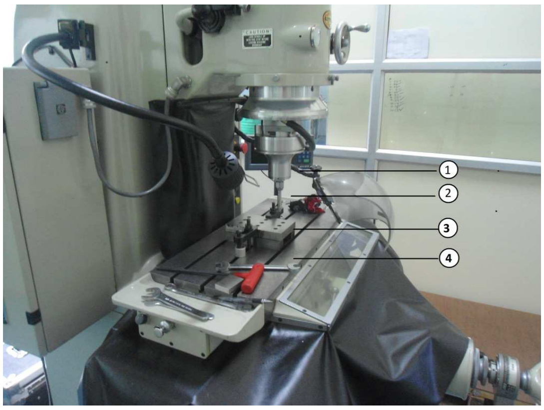

Figure 1: Experimental Set-up for Jig Grinding (1. Spindle, 2.Tool 3.Workpiece, 4.Work Table)

The jobs have undergone milling, drilling and reaming processes before grinding. Hardening is done for better output response and the BHN is maintained at 50 BHN.

He surface roughness (Ra) of the jobs is evaluated on the Taylor/Hobson Taly surf surface test instrument. The average of nine readings is taken to determine the reading of surface roughness value for the experiment.MRR is taken by evaluating rate of machining time.

Model : MOORE Jig Grinder
Serial No : G2987
ID Code : JG-54
Table size :11"X24"
Table Travel, Longitudinal: 18"
Table Travel cross: 11"
Table size: 610x280
Spindle vertical Travel: 3.62"
Main spindle speed(variable):7000-175000 RPM
Grinding diameter capacity: 0.015"-3.5"
Max.Angular adjustment of spindle: 1.5 DEG
Tool used : 10mm dia.Diamond Tool
Workpiece Used: Mild Steel

Figure 2: Specifications of the Jig Grinding Machine

The specifications of the jig grinding machine are shown in Figure 2. The tool used for jig grinding is presented in Figure 3.

Figure 3: A Photograph of the Grinding Tool

Roughness measurement has been done using a portable stylus-type profilometer, Talysurf (Taylor Hobson, Surtronic 3+, UK) shown in Figure 4. The Talysurf instrument (Surtronic 3+) is a portable, self-contained instrument for the measurement of surface texture. The parameter evaluations are microprocessor based. The measurement results are displayed on an LCD screen and can be output to an optional printer or another computer for further evaluation. The instrument is powered by non-rechargeable alkaline battery (9V).

It is equipped with a diamond stylus having a tip radius 5 μm. The measuring stroke always starts from the extreme outward position. At the end of the measurement the pickup returns to the position ready for the next measurement. The selection of cut-off length determines the traverse length. Usually as a default, the traverse length is five times the cut-off length though the magnification factor can be changed.

The profilometer has been set to a cut-off length of 0.8 mm, filter 2CR, traverse speed 1 mm/sec and 4 mm traverse length. Roughness measurements, in the transverse direction, on the work pieces have been repeated four times and average of four measurements of surface roughness parameter values has been recorded. The measured profile has been digitized and processed through the dedicated advanced surface finish analysis software Talyprofile for evaluation of the roughness parameters. Surface roughness measurement with the help of stylus has been shown in Figure 4.

Figure 4: A Photograph of the Surface Roughness Tester

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array design have been selected. In this experimental study, wheel speed, feed and depth of cut have been considered as Process parameters as shown in Table 1.

Table 1: Input Parameters and Their Levels

Levels	Wheel Speed(rpm)	Feed (mm/s)	Depth of Cut(mm)
1	48000	50	0.01
2	51300	75	0.02
3	56200	100	0.03

Table 2: Design of Experiment Using L_9 Orthogonal Array

Trail No.	L_9 array		
	Speed (rpm)	Feed (mm/sec)	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

In the present study, surface roughness values are taken by using Taylor/Hobson Talysurf (Surtronic 3+) instrument.

RESULTS AND DISCUSSIONS

The experimental observations for surface roughness and MRR are shown in Table 3 and 4 respectively.

Table 3: The Results for Surface Roughness, Ra (µm)

Trail No.	L_9 Array			
	Speed (rpm)	Feed (mm/sec)	Depth of Cut(mm)	Roughnes s(µm)
1	48000	50	0.01	0.44
2	48000	75	0.02	0.58
3	48000	100	0.03	0.45
4	51300	50	0.02	0.82
5	51300	75	0.03	0.50

Table 3: Contd.,

6	51300	100	0.01	0.81
7	56200	50	0.03	0.45
8	56200	75	0.01	0.49
9	56200	100	0.02	0.40

Table 4: The Results for MRR (gm/min)

Trial No.	L9 Array			
	Speed (rpm)	**Feed (mm/sec)**	**Depth of Cut (mm)**	**MRR (gm/min)**
1	48000	50	0.01	0.117
2	48000	75	0.02	0.029
3	48000	100	0.03	0.060
4	51300	50	0.02	0.060
5	51300	75	0.03	0.060
6	51300	100	0.01	0.050
7	56200	50	0.03	0.080
8	56200	75	0.01	0.050
9	56200	100	0.02	0.090

Discussion is done by determination of signal to noise ratio(S/N ratio) based on the experimental data. The S/N ratio is a simply a quality indicator by which the effect of a changing a particular process parameter on the processes performance. A better signal is obtained when the noise is smaller so that a larger S/N ratio is used for surface roughness and higher is better characteristic is used for metal removal rate. The surface roughness and metal removal rate(MRR) for nine trail conditions with two measurement locations along with average response values and corresponding S/N ratios were determined, shown in Table 5 and Table 6 respectively. The average values of surface roughness and metal removal rate (MRR) at different levels were computed. As a sample calculation, the average effect of work speed at first level was determined for surface roughness using the average of surface roughness from the experimental values 1-3 of Table 2 viz. [(0.44+0.58+0.45)/3=0.49].

Table 5: Experimental Observations and S/N Ratio for Surface Roughness Ra (µm)

Trial No.	L9 Array				
	Speed (rpm)	**Feed (mm /sec)**	**Depth of Cut (mm)**	**Roughness (µm)**	**S/N Ratio (dB)**
1	48000	50	0.01	0.44	7.130
2	48000	75	0.02	0.58	4.731
3	48000	100	0.03	0.45	6.9357
4	51300	50	0.02	0.82	1.723
5	51300	75	0.03	0.50	6.020
6	51300	100	0.01	0.81	1.830
7	56200	50	0.03	0.45	6.935
8	56200	75	0.01	0.49	6.1960
9	56200	100	0.02	0.40	7.9588

For the case of minimizing the performance characteristic, ie surface roughness the following definition of the S/N ratio should be calculated from equation (1).

$$SN_i = -10\log\left(\sum_{u=1}^{N_i}\frac{y_u^2}{N_i}\right) \qquad (1)$$

Table 6: Experimental Observations and S/N ratio for MRR

Trial No.	L9 Array				
	Speed (rpm)	Feed (mm/sec)	Depth of Cut (mm)	MRR (gm/min)	S/N Ratio (dB)
1	48000	50	0.01	0.117	-18.6363
2	48000	75	0.02	0.029	-30.7520
3	48000	100	0.03	0.060	-24.4370
4	51300	50	0.02	0.060	-24.4370
5	51300	75	0.03	0.060	-24.4370
6	51300	100	0.01	0.050	-26.0206
7	56200	50	0.03	0.080	-21.9382
8	56200	75	0.01	0.050	-26.0206
9	56200	100	0.02	0.090	-20.9151

For the case of maximizing the performance characteristic , i.e., MRR the following definition of the S/N ratio should be calculated from eqn (2).

$$SN_i = -10\log\left[\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{y_u^2}\right] \quad (2)$$

Analysis of variance (ANOVA) using MINITAB15 software was performed to determine the significance of process parameters on the output responses namely surface roughness and metal removal rate (MRR) listed in Table 6 and Table 7 and reveals that both models are significant.

Table 7: ANOVA Analysis for Ra, Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Rank
Speed	2	0.1196	0.1196	0.0598	2.49	0.287	1
feed	2	0.0033	0.0033	0.0016	0.07	0.935	3
depth	2	0.0310	0.0310	0.0155	0.65	0.608	2
Error	2	0.0480	0.0480	0.0240			
Total	8	0.2020					

Table 8: ANOVA Analysis for MRR, Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Rank
Speed	2	0.00044	0.00044	0.00022	0.19	0.841	2
feed	2	0.00232	0.00232	0.00116	0.99	0.504	1
depth	2	0.00024	0.00024	0.00012	0.10	0.907	3
Error	2	0.00235	0.00235	0.00117			
Total	8	0.00536					

From Table (6), it is evident that speed and depth of cut are significant process parameters as their F values are greater than P values for the output response where as other process parameter feed is not significant as its F value is less than the P value. From Table (7) it is evident that feed rate is significant process parameter and speed and depth of cut are not significant. The regression equations for output responses in terms of process parameters are given below. The results if multiple regression analysis is shown in Table 8.

Table 9: Results from Multiple Regression Analysis

Trial No	Experimental Values		Results from Multiple Regression Analysis	
	Ra (μm)	MRR (gm/min)	Ra (μm)	MRR (gm/min)
1	0.44	0.117	0.64	0.072
2	0.58	0.029	0.58	0.062
3	0.45	0.060	0.50	0.053

Table 9: Contd.,

4	0.82	0.060	0.56	0.075
5	0.50	0.060	0.50	0.065
6	0.81	0.050	0.60	0.056
7	**0.45**	**0.080**	**0.46**	**0.079**
8	0.49	0.050	0.56	0.069
9	0.40	0.090	0.50	0.060

Regression Equation for surface roughness,

Ra=1.15393 - 9.00398e-006 speed - 0.000333333 feed - 5.66667 depth. (3)

Put the values of speed, feed and depth of cut for each level in the above shown equation. Then we will get Ra values for each levels. Then compare these Ra values with the experimental values. The above shown regression Equation will get when we done a general regression analysis by MINITAB16 software. Regression Equation for MRR,

MRR=0.0537404 +7.86502e-007speed - 0.00038feed + 0.000212675 depth. (4)

Put the values of speed, feed and depth of cut for each level in the above shown equation. Then we will get MRR values for each level. Then compare these MRR values with the experimental values. The above shown regression Equation will get when we done a general regression analysis by MINITAB16 software.

Response Graphs for the average values and S/N ratios of surface roughness and metal removal rate are shown in Figures 5 and 6.

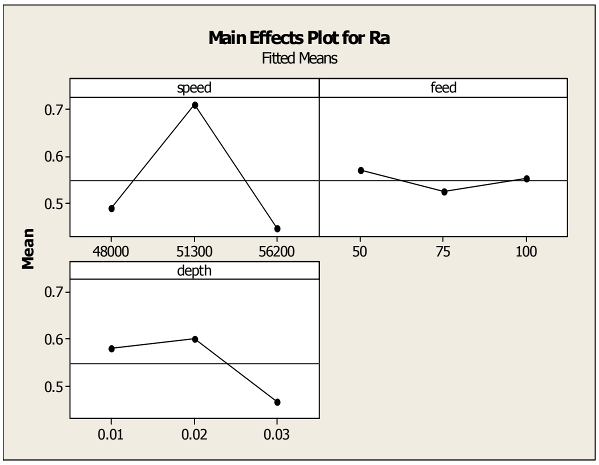

Figure 5: Response Graph for Ra

Figure 5 shows the response graph of Ra value for two significant parameters namely speed and depth of cut Figure 6 shows the response graphs of S/N ratio for Ra with two significant parameters namely speed and depth of cut followed by feed ratio. Figure 7 shows the response graph of MRR for significant parameter namely feed only and Figure 8 shows the response graph of S/N ratio for MRR with significance parameter namely feed followed by speed and depth of cut. It reveals that highest S/N ratio values of speed and depth of cut are highest and produced minimum variation in surface roughness at that level and highest S/N ratio value of feed rate are highest followed by speed and depth of cut and produced maximum variation in MRR at that level. At optimal setting conditions, the surface roughness and metal removal rate are determined using the below equations (5) & (6) respectively. The level selected for surface roughness and Metal removal rate are A3B2C3 and A3B1C1. Where A3 is third level of speed value,B2 is second level of feed value and C1 is first level of depth of cut value and A3 is third level of speed value, B1 is first level of feed value and C1 is first level of depth of cut.

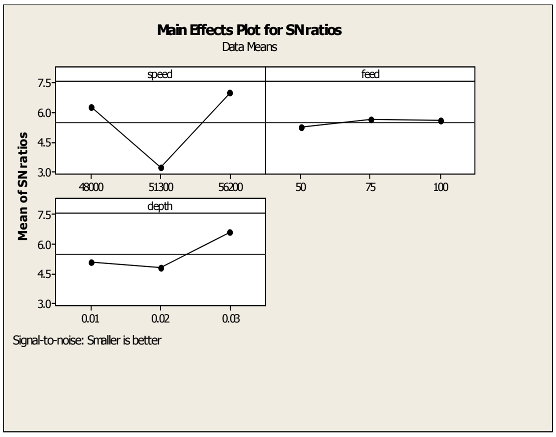

Figure 6: Response Graph for S/N ratio of Ra

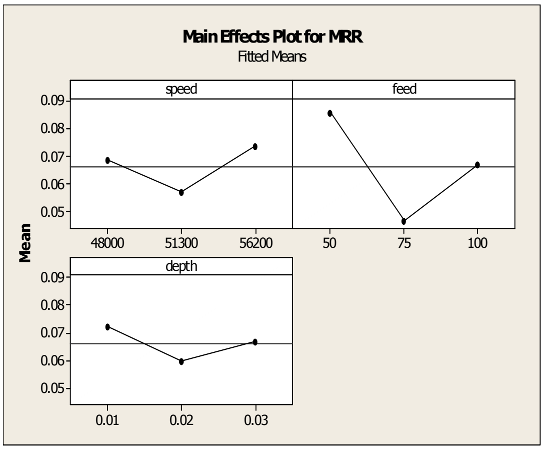

Figure 7: Response Graph for MRR

For surface roughness, the optimal value is

$Ra=A_{3R}+C_{3R}-Y_1$ (5)

Where A_{3R} &C_{3R} = Avg Ra value for 3rd level of speed and depth of cut

Y1= Mean of average value of Ra

Here, Ra== 0.55+0.46-0.546

=0.47µm

For Material Removal Rate, the optimal value is

$MRR=A_{3M}+B_{1M}-Y_2$ (6)

Where A_{3M} & B_{1M} =Average MRR value for 3rd level of speed and 1st level of feed value

Y2= Mean of average value for MRR

So here MRR=0.056+0.056-0.067

= 0.045 gm/min

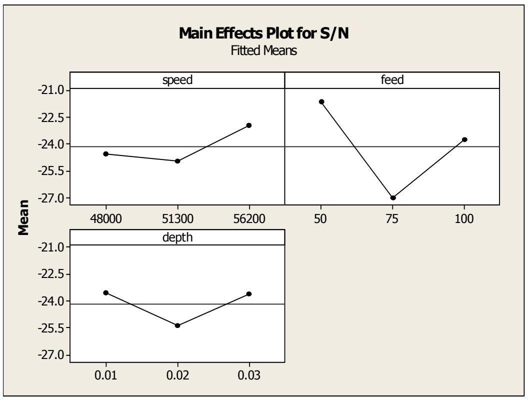

Figure 8: Response Graph for S/N Ratio of MRR

CONCLUSIONS

This paper has presented application of Taguchi method to determine the optimal process parameters for Jig grinding process. The concept of ANOVA and S/N ratio is used to determine the effect and influence of process parameters namely wheel speed, feed rate and depth of cut is studied on output responses, and found that the developed model is significant. MINITAB16 software is used is for analysis of response graphs of average values and S/N ratios. From the analysis it is evident that the speed and depth of cut played vital role on output responses surface roughness and feed rate on metal removal rate (MRR) than other process parameters. The model predicted in the present work is useful for selecting the right set of process parameters variables for optimal value of the MRR and Surface roughness. Confirmation Test at the optimum set of process parameters for surface roughness and MRR has to be done for the remaining work. Future work can be done by including more parameters like work speed, No. of passes etc.

ACKNOWLEDGMENTS

The authors wish to acknowledge support for this work from Dr. T. D. John, The Principal, Dr. K. M. Peethambaran, HOD (Mechanical), Faculty and Staff of Mechanical Engg. Dept. and all faculty/staff members of Government College of Engineering, Kannur, Kerala.

REFERENCES

1. M.Janardhan and Dr.A.Gopala Krishna, “Determination and Optimization of Cylindrical Grinding Process parameters using Taguchi method and Regression analysis”, International Journal of Engineering Science and Technology (IJEST) Vol. 3 No. 7 July 2011.

2. M.A. Kamely, S.M. Kamil, and C.W. Chong Mathematical Modeling of Surface Roughness in Surface Grinding Operation, international journal of engineering &natural sciences 5:3 2011(146-149).

3. M.N. Dhavlikar, M.S. Kulkarni, V. Mariappan, “Combined Taguchi and dual response method for optimization of a centerless grinding operation”, Journal of Materials Processing Technology 132 (2003) 90–94.

4. S. Shaji, V. Radhakrishnan, “Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method” Journal of Materials Processing Technology 141 (2003) 51–59.

5. Jae-Seob Kwak, “Application of Taguchi and response surface methodologies for geometric error in surface grinding process”, International Journal of Machine Tools & Manufacture 45 (2005) 327–33.

6. Suleyman Neseli, Đlhan Asilturk and Levent Celik, “Determining the optimum process parameter for grinding operations using robust process”, Journal of Mechanical Science and Technology 26 (11) (2012) 3587-359.

7. Kundan Kumar, Somnath Chattopadhyaya, Hari Singh,” Optimal material removal and effect of process parameters of cylindrical grinding machine by Taguchi method”, International Journal of Advanced Engineering Research and Studies E-ISSN2249–897, IJAERS/Vol. II/ Issue I/Oct.-Dec., 2012/41-45.

8. Kirankumar Ramakantrao Jagtap,”Optimization of Cylindrical Grinding process parameters for AISI 1040 steel using Taguchi Method”,IJMET Volume 3, Issue 1, January- April (2012), pp. 226-234.

9. Alao Abdur-Rasheed and Mohamed Konneh,” Optimization of Precision Grinding Parameters of Silicon for Surface Roughness Based on Taguchi Method”, *Advanced Materials Research Vols. 264-265 (2011) pp 997-100*

10. Mustafa Kemal Külekcý,”Analysis of process parameters for a surface Grinding process based on the Taguchi method”, Materials and technology 47(2013) 1,105-109.

11. Deepak Pal, Ajay Bangar, Rajan Sharma, Ashish Yadav,” Optimization of Grinding Parameters for Minimum Surface Roughness by Taguchi Parametric Optimization Technique” (IJMIE), ISSN No. 2231 –6477, Volume-1, Issue-3, 2012.