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PARAMETRIC ANALYSIS OF TAPER GRINDING ATTACHMENT ON LATHE MACHINE USING RESPONSE SURFACE METHODOLOGY

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Abstract

Parametric analysis involves the determination of input variables, their control parameter range, and evaluates the outcomes of each variety of variables. In the present work parametric study was done on the performance of taper grinding operation using specially designed attachment mounted on the lathe machine using response surface methodology (RSM). The roughness of grind surface was considered as a performance measure for tapper grinding operations as the main purpose of grinding is to get a better surface finish. The experimental design was done using central composite design (CCD) under RSM with grinding wheel rotation (RPM), feed motion (mm/rev), and grinding depth cut (mm) are considered as independent variables to see the effectiveness over roughness of grind surface. It is found from the parametric analyses that, for obtaining minimum roughness of grind surface, it is important to associate high cutting speed of grinding wheel with lower feed rate and lower grinding depth. Additionally, prediction model was developed for roughness of grind surface with a correlation coefficient of 96 % which means that model can be explained with experimental values. Based on the results, it is concluded that the prediction model for getting roughness of grind surface can be helpful for the operator to select the grinding parameter for the desired roughness of grind surface. Also, the specially designed attachment mounted on lathe machine for taper grinding found to be helpful for small industries and the roughness of grind surface was analogous to the original cylindrical taper grinding machine.

Keywords: Tapper grinding attachment, central composite design, Response surface methodology, Roughness of grind surface.

1. INTRODUCTION

The taper grinding operation is performed to obtain a fine surface finish after performing a taper turning operation on a lathe machine for cylindrical jobs. This operation becomes necessary for gaining the desired low roughness of the machined surface as well as to achieve dimensions in close tolerance. Tapper grinding operation requires a separate machine that requires space, the extra time and additional cost. Therefore it will be better to have an attachment for tapper grinding on the lathe machine itself. For small-scale industrialists, tapper grinding attachment on lathe machine is a small but useful concept. Henceforth it can save a tremendous amount of time, resources, and money to increase a firm's overall efficiency. Performance of this taper grinding attachment can be evaluated using roughness of grind surface as the main objective of the grinding operation is to improve surface finish of component. The consistency and efficiency of the machined parts are directly related to the roughness of machined surface induced after machining operation [1]. The surface integrity is one of the most important criteria for achieving high product reliability. Characterization of surface integrity provides a physical basis for understanding the actions of fatigue and stress corrosion of machined components in services. Before the grinding of parts, the roughness of grind surface criteria is determined to achieve desired fatigue strength, tribological, and aesthetic corrosion resistance [2]. Therefore in the present work, one of the objectives is to develop the prediction model for roughness of grind surface based on grinding parameters. This will help to select grinding parameters i.e. Grinding wheel (RPM), feed rate (mm/rev), and penetration depth (mm) for getting the desired surface finish. Apart from this, a parametric study was performed to find out significant and non-significant grinding parameters for affecting roughness of grind surface in tapper grinding using attachment in lathe machine. The following section shows the previous work related to grinding attachment on the lathe machine.

1.1 Literature Survey on previous grinding attachment

Akash Tiwari et al. 2014 [3] performed the designing and fabrication of a multipurpose tool post for the lathe machine. The main purpose of their work is to design and fabricate a multi-operational attachment into the lathe machine in such a way that the number of operations can be carried out, without any need of shifting the work to the next machine or station. They claimed that this can reduce time and money for small scale industries.

Abhishek M. Kawade et al. 2016 [4] performed to design, analyze, and manufacture a grinding attachment on a center lathe machine for small scale industries to produce a surface finish of grade N5. They used the deterministic method of design for the components used in the attachment. They presented finite element analysis for the shaft carrying the grinding wheel for maximum loading conditions and found the proposed design as safe. The surface roughness value for the component produced using this attachment was found to be 0.63 microns i.e. desirable N5 grade surface finish.

Darshan Attarde et al. 2016 [5] showed all the procedures and components involved in fabricating grinding attachment on the lathe machine. They found good surface finish up to 0.20 micron in a production type of grinding wheels than in the conventional ones. They also found that using coolant with mixture ratio 1:20 mineral oil to water concentration, surface roughness can further be reduced in the range of 0.26 to 0.8 micrometer using a production type grinding wheel.

Pratik Chavan et al. 2015 [6] performed designing and fabrication of grinding attachment for lathe machine. According to the proposed specification, the attachment is produced and assembled successfully on a lathe machine. They claimed that using this attachment, the human effort needed to load and unload the workpiece was substantially reduced which resulted in a reduction in the lead time. The fine surface finish can be achieved by using this attachment with the precision of up to 20 microns.

Rishav Jaiswal et al. 2017 [7] performed the fabrication of grinding attachment for 2 - super lathe machines. In this relation, the design was done based on the factor of safety, normal stress, bending stress, twisting, displacement, etc. Later on, set up was the fabrication and assembled and named as “Turnery Nexus” grinding attachment on lathe machine assembly of designed products was obtained. Their set up was successfully tested on mild steel specimens.

Abhishek A. Sakhare et al. 2018 [8] also designed and fabrication of multiple tool attachment for lathe machine such that operation offset drilling, grinding, milling, and slotting operations can be performed. The multiple tool attachment is mounted by replacing the tool post from the conventional lathe machine. They performed the grinding operation at 1440 RPM and found a good surface finish.

Based on the above literature, it is found that a lot of work has been done on developing an attachment for grinding operation on the lathe machine. However, there is a lack of work found in a parametric study for the developed grinding process. Also, there is no work found in developing a prediction model for the roughness of grind surface in taper grinding attachment on the lathe machine. Therefore the following section shows the objective of present work.

1.2 Objectives of the present work:

1. Identify grinding operation control parameters and their maximum and minimum levels.
2. Performing design of experiment using central composite design used in response surface methodology.
3. Parametric study was performed using main effect plots for individual control parameters i.e. grinding wheel rotation (RPM), feed rate (mm/rev) and penetration depth (mm), over roughness grind surface.
4. Prediction model is developed and validated for roughness of grind surface based on grinding control parameters.

2. EXPERIMENTAL SET UP

Initially, tapper grinding attachment was designed and fabricated which is mounted on the center lathe machine as shown in fig. 1. An electric motor used for rotation of grinding wheel is the main part of taper grinding attachment has specifications as shown in table 1. Based on max RPM and power produced by an electric motor, shaft diameter and length are calculated are also shown in table 1.

Fig. 1. Tapper grinding attachment mounted on the center lathe

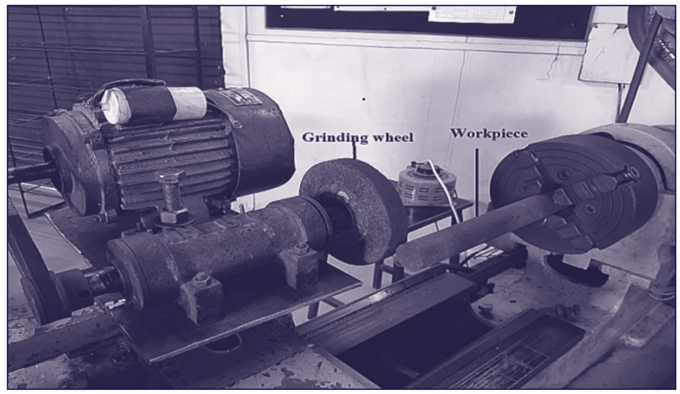


Table 1. Specification of Motor and shaft

Component	Specification
Length of Lathe machine	5 FT
Motor type	3-Phase
Motor’s rotating speed	2800 RPM
Power developed by the motor	0.75 HP
Torque	1909.0 N/MM
Shaft Diameter	10 MM
Shaft Length	210 MM

Grinding wheel used with specifications Al60P5V99 which has aluminum oxide as abrasive particles. Its grit size is 60 microns whereas workpiece material used as mild steel. Taper attachment is having an electric motor to rotate the grinding wheel with a belt and pulley arrangement as shown in fig. 1. The motor is having specifications of 1 HP, max RPM 2800, Amp 0.92, Voltage 415± 10% of A. Motor RPM is varied through voltage deamer. The roughness of grind surface was measured using Mittutoyo SJ-410 surface roughness tester.

2.1 Design of Experiments

Experiment design refers to the procedure of preparation, scheming, and analysis of the experiment so that a convincing conclusion can be drawn efficiently and effectively. The design of experiment is a method of creating a list of experiments with input variables that can vary in some range. These variables can affect some output responses of interest. In the present work grinding parameters such as grinding wheel rotation in RPM, feed rate in mm/rev, and grinding depth in mm are considered as input variables and roughness of grind surface is considered as output response. Range of maximum and minimum grinding wheel RPM varies from 2000 to 2600 RPM; feed rate varies from 0.2 to 0.5 mm/rev and grinding depth varies from 0.2 to 0.5 mm these ranges were selected based on previous literature as well as motor specifications. The list of experiment is created with the central composite design used under response surface methodology as shown in table 2. It utilizes five levels of variables with axial, center, and cubical points that allow the second-order effects to be estimated. Cubical or factorial points represent the maximum and minimum level of input variables. Center points represent mid-level of input variables whereas axial points represent the extreme minimum and extreme maximum of input variables. The distance of axial points (α) from the center of cube depends upon the number of input variables (k) through the formula $\alpha = 2^{k/4}$. Details of the design of experiment and response surface methodology are described in detail by Sahu and Andhare (2018) [9].

Table 2. List of grinding operation and measured roughness of grind surface

Std Order	Run Order	Wheel RPM	Feed Rate (mm/rev)	Grinding depth (mm)	Roughness grind surface (µm)
15	1	2300	0.35	0.35	0.593
8	2	2600	0.5	0.5	0.475
10	3	2804.5	0.35	0.35	0.387
6	4	2600	0.2	0.5	0.458
14	5	2300	0.35	0.60	0.609
18	6	2300	0.35	0.35	0.593
3	7	2000	0.5	0.2	0.767
20	8	2300	0.35	0.35	0.542
16	9	2300	0.35	0.35	0.584
2	10	2600	0.2	0.2	0.405
11	11	2300	0.10	0.35	0.555
12	12	2300	0.60	0.35	0.603
1	13	2000	0.2	0.2	0.748
9	14	1795.5	0.35	0.35	0.820
4	15	2600	0.5	0.2	0.484
7	16	2000	0.5	0.5	0.846
13	17	2300	0.35	0.10	0.534
17	18	2300	0.35	0.35	0.560
19	19	2300	0.35	0.35	0.583
5	20	2000	0.2	0.5	0.748

2.2 Response Surface Methodology

The Response Surface Methodology (RSM) is an importan t method in the statistical design of experiments and is a set of mathematical and statistical techniques that are useful for modeling and analyzing problems where a response of interest is affected by several variables. The model developed between control parameters and response as shown in eq. 1

$$\sigma_{c\ max} = \frac{2*F}{\pi*b*L}\ \text{, where } F=W*9.81 \qquad \text{(a)}$$

Where S_w is output; ω_0, ω_i are constants established after regression; y_i are input factors; ε error in measurement. The least-squares approach is used for estimating the parameters in the approximating polynomials. The surface analysis of the response is then done using the fitted surface. The model parameters can be estimated most effectively if the data are gathered using proper experimental designs. In the present work model for the roughness of grind surface was developed using grinding input parameters as shown in eq. 2

$$S_w = 2.53 - 0.001275\times R + 0.002\times f + 0.165\times d + 0.337\times f^2 + 0.223\times d^2 - 0.000055\times R\times f - 0.0001\times R\times d + 0.087\times f\times d \qquad (2)$$

Where S_w = roughness of grind surface R = RPM of grinding wheel; f =feed rate in mm/rev; d=grinding depth mm.

Analysis of variance was performed to find out which parame ters are relevant based on p values as shown in table 4. Non-significant parameters are eliminated using a stepwise backward elimination method. Parameters having p-value greater than 0.1 are remove from the model. The correlation coefficient (R^2) of 96 % shows that model can be well explained by the developed model. From table 3 it is clear that terms interaction terms and square terms are insignificant on the response.

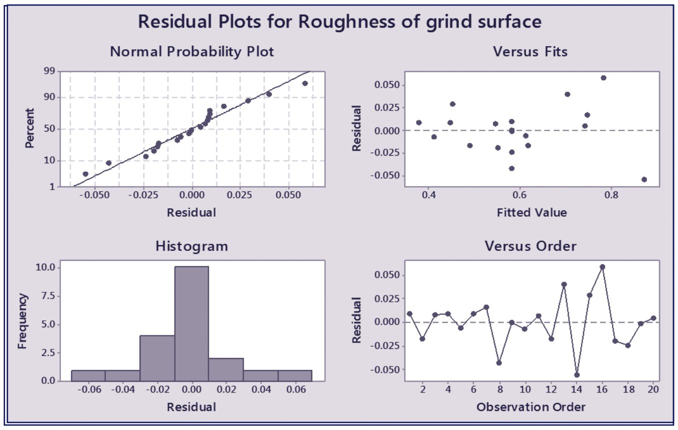
Table 3. Estimated statistical constant for the roughness of grind surface

Term	Effect	Coef	SE Coef	T-Value	P-Value
Constant		0.5738	0.0140	41.12	0.000
R	-0.29505	-0.14753	0.00926	-15.93	0.000
f	0.04283	0.02141	0.00926	2.31	0.043
d	0.03623	0.01811	0.00926	1.96	0.079
R*R	0.03275	0.01638	0.00901	1.82	0.099
f*f	0.01517	0.00758	0.00901	0.84	0.420
D*D	0.01004	0.00502	0.00901	0.56	0.590
R*f	-0.0049	-0.0025	0.0121	-0.20	0.843
R*D	-0.0090	-0.0045	0.0121	-0.37	0.716
f*D	0.0039	0.0019	0.0121	0.16	0.875

3. VALIDATION OF PREDICTION MODEL FOR ROUGHNESS OF GRIND SURFACE

Residual graphs represent statistical validation of the developed model based on experimental values as shown in fig. 2. It consists of mainly four graphs through which adequacy of the model is checked [10]. The first graph i.e. normal probability plot gives residual versus its expected values when the distributions are normal. The data lies along the straight line means that the data complies with the guidelines for sample size and confidence intervals and correct values of p. In the second graph i.e. residual versus fitted plot, if the sample is correct then all points on both sides of zero will fall randomly along with a recognizable pattern. From fig. 2, it is obvious that all points are settled on both sides of zero, and no non-constant or outlier variation is observed. It tests that residuals are distributed randomly, with constant variance. The residual versus order plot shows the order of collecting experimental values and illustrates the order and pattern of observation in the lines. Ideally, the residual on the plot will fall around the middle line at random. From fig. 2 it is clear that the residuals close to each other are associated and thus not independent.

Fig.2 Residual plot for prediction of the roughness of grind surfaces

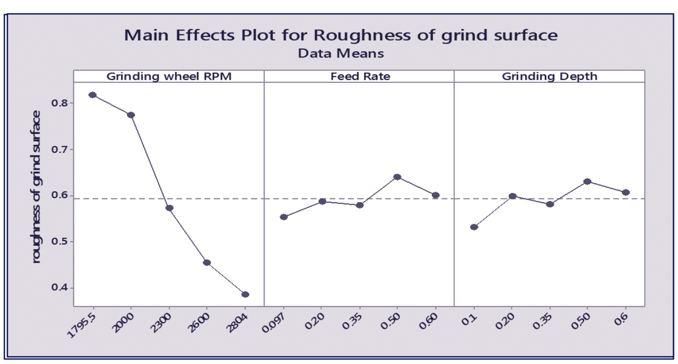


Hence, based on residual plots based on a statistical test on developed model and value of correlation coefficient (R^2) i.e. 96 %, it can be concluded that the model is adequate to predict the roughness of grind surface. However, it should also be noted that this model is valid only in ranges of grinding parameters (table 2) selected for grinding operation.

Main effect plot of grinding parameters on the roughness of grind surface (Parametric study)

The principal plots of effects demonstrate how each factor influences the character of the response. This uses line plots to illustrate the reaction effect of the variables and to compare the relative strength of the results. The points in the plot are the means of a variable answer at the different levels of each factor, and the points for each factor are linked by rows. A line of reference is drawn at the great mean of the response data. The main effect may be positive or negative, depending on whether the line slopes as the factor level rises upwards or downwards. Main effect plot was drawn as input factors with wheel RPM, feed rate in mm/rev, grinding depth in mm, and roughness of grind surface (µm) as response as shown in fig. 3. The main effect plot for each input factor is plotted while other input factors are keeping at the mean level.

Fig. 3 Main effect plot for the roughness of grind surface



From fig. 3 it is clear that as roughness value decreases with an increase in wheel RPM whereas it increases with an increase in feed rate and grinding depth. The possible reason for the above trend is that as the cutting speed increases, due to high temperature generated at grinding zone thermal softening of workpiece dominates strain hardening. And material deforms smoothly with low cutting force and better surface finish is achieved. On the other hand as feed rate increases, due to higher feed forces, vibration increases, and chattering of workpiece occur. Also As feed rate increases large quantities of material come into contact with grinding wheel in less time which leaves feed marks on the grind surface. As grinding depth increases due to more material removal, rough finish surface produced. However, high-temperature generation is correlated with the fast wear of the grinding wheel. Therefore, for obtaining minimum roughness of grind surface, it is important to associate the high cutting speed of the grinding wheel with a low feed rate. The main reason is that less friction between the grinding wheel and workpiece surface can control the temperature in the grinding zone at a low feed rate, along with lower feed forces. Therefore, for obtaining minimum roughness of grind surface, it is important to associate high cutting speed of grinding wheel with lower feed rate and lower grinding depth.

CONCLUSION

The present work successfully installed a tapper grinding attachment on the lathe machine. Experiment design and RSM-based ANOVA evaluate significant and non-substantial parameters for the performance of roughness of grind surfaces. Later on, the parametric study was done with response surface methodology to see the effect of each grinding parameter on the roughness of the grind surface and found that roughness value decreases with an increase in wheel RPM whereas it increases with an increase in feed rate and grinding depth. Also, a model is developed to predict roughness of grind surface which can predict the response with a correlation coefficient of 96 %. The model is also validated using residual plot or statistical tests. It is also found that grinding parameters affect uniformly to the roughness of grind surface. This prediction model for getting roughness of grind surface can be helpful for the operator to select the grinding parameter for the desired roughness of grind surface.

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