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INVESTIGATING THE EFFECT OF MACHINING PARAMETER ON MILLING PRODUCT SURFACE QUALITY USING DOE APPROACH

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ABSTRACT

Machining process is one of the complex processes which have numerous factors contributing towards the quality of the finished product. Milling process is one among the machining process in which quality of the finished product depends on the tool geometry, accuracy of machine tool and cutting condition. The research was done to investigate the effect of machining parameters on product surface quality in milling process. The experiments conducted on a conventional milling machine use of cutting fluid. Material AISI 1050 and HSS end mill cutting tool used for the experiments. Three cutting parameters such as spindle speed, feed rate and depth of cut at two-level was planned using design of experiment (DoE) methodology. The result show that the better surface quality of milling process is obtained for the minimum value of surface roughness (Ra = 1.481 μm). The Analysis of Variance inferred that the spindle speed cutting parameter has significant effect on the surface roughness (Ra).

KEY WORDS: DoE; cutting_parameters; surface_roughness

INTRODUCTION

In general, the purpose of any material cutting operation is to produce a part of the required shape and dimensions with the specified quality and surface finish. Surface roughness plays an important role in evaluating quality of machined products. The quality of surface is of utmost important for the correct functioning of machine parts which directly affect the attributes of product such as friction, fatigue, wear resistance, coating and dimensional accuracy (Groover, 2010). There are many factors that affect surface roughness of any machined parts, these factors among others includes: machining parameters, tool geometry, workpiece material, nature of chip produced, machine rigidity and cutting fluids used (Boothroyd and Knight, 2006).

Milling is one of the fundamental machining processes, especially for the finishing of machined parts. Usually, the selection of appropriate machining parameters is difficult and relies heavily on the operator's experience and the machining parameters tables provided by the machine-tool manual for the target material. Proper selection of cutting tools, cutting parameters and conditions for optimal surface quality requires a more methodical approach by using experimental methods and mathematical and statistical models.

Surface roughness as affected by the cutting conditions on milling operation has been investigated by engineers and researchers for many years on different of materials and methods (Stephenson and Agapiou, 2006; Yusuf et al., 2012; Rashid and Lani, 2010; Denkena and Hasselberg, 2015; Tseng et al., 2016). In this study, investigate the effect of machining parameters include spindle speed, feed rate and depth of cut on the surface quality of milling product using Design of Experiment Method.

EXPERIMENTAL SET UP

The steel AISI 1050 material was used in the experiment. The machining was done on a conventional vertical milling machine use of cutting fluid, Figure 1. The HSS end mill cutting tool which is 16 mm in diameter and has four teeth was used in the experiment. The surface roughness (R_a) was measured using TR-200 surface roughness tester. Spindle speed (n), feed rate (vf) and depth of cut (a) were selected as the cutting parameters to analyze their effect on the surface roughness. The combination of spindle speed, feed rate and depth of cut as the cutting parameter model was designed based on design of experiment (DoE) methodology. Eight cutting parameters models represent a full factorial design (2^3) to carry out the experiments (Myers and Montgomery, 2002; Bass, 2007). The factors and levels each parameter was set as shown in Table 1.

Fig. 1. Conventional vertical milling machine

Table 1. The cutting parameters set up and levels for the experiment.

Cutting parameter	Unit	Levels	
		Low (-1)	High (+1)
Spindle speed (*n*)	r min^{-1}	587	1551
Feed rate (*vf*)	mm min^{-1}	15	167
Depth of cut (*a*)	mm	0.5	1.5

DESIGN OF EXPERIMENT

Design of experiments (DoE) is used extensively in machining investigation. DoE is powerful analysis tool for modeling and analyzing of the process effect. The application design of experiment is able to reduce the experiment expenses. DoE method is an effective approach to optimize the various cutting parameters on machining processes. There are some methods in the design of experiment including factorial design, response surface design, mixture design and Taguchi method used in experiment studies (Myers and Montgomery, 2002).

Factorial design was employed for modeling and analyzing the influence of cutting parameters on the surface roughness, three principal cutting parameters, including spindle speed (*n*), feed rate (v*f*) and depth of cut (*a*) were specified as cutting parameters. In the milling process, these cutting parameters were selected as the independent input variables. The surface roughness was assumed to be affected by the above three principal cutting parameters as the output response. The quantitative form of relationship between the output response and input variables can be represented as the following:

$$Y = F\,(n\;\; vf\;\; a) \qquad (1)$$

where *Y* is the desired response, and *F* is the response function. The approximation of *Y* has been proposed by first-order regression model expressed in the following form:

$$Y = a_0 + \sum_{i=1}^{3} a_i X_i + \sum_{i=1}^{3} a_{ij} X_i X_j \qquad (2)$$

where a_0 is a constant and a_i and a_{ij} are the coefficients of main and interaction effects of *Y*, respectively. The X_i reveals the coded variables corresponding to studied cutting parameters (*n*, *vf*, and *a*).

The necessary data required for developing the response models have been collected by the experimental. In this study, the collection of experimental data base on the factorial design. The levels and cutting parameters were selected as shown in Table 1.

RESULT AND DISCUSSION

Based on design of experiment method, eight cutting parameters models represent a full factorial design (2^3) to carry out the experiments. The combination of spindle speed, feed rate and depth of cut as the cutting parameter model developed with the help of a software package MINITAB. The test models and the experiment results are given in Table 2. From the Table 2, the better surface quality of milling process is obtained for the minimum value of surface roughness (*Ra* = 1.481 µm).

Figure 2 is shows the main effects plot for surface roughness (*Ra*), the better surface quality achieved at high spindle speed, low feed rate and low depth of cut. The surface roughness increases with increasing feed rate and depth of cut.

Figure 3 is shows a two-cutting parameters interaction effect plot for surface roughness. The plot show that the lines are not parallel to each other, there may be an interaction between the cutting parameters

Table 2. The test model and experiment results based on full factorial design (2^3)

Test model	Cutting parameters			*Ra* (µm)
	n	*vf*	*a*	
1	-1	-1	-1	2.637
2	+1	-1	-1	1.596
3	-1	+1	-1	2.603
4	+1	+1	-1	2.408
5	-1	-1	+1	3.505
6	+1	-1	+1	1.659
7	-1	+1	+1	3.534
8	+1	+1	+1	1.481

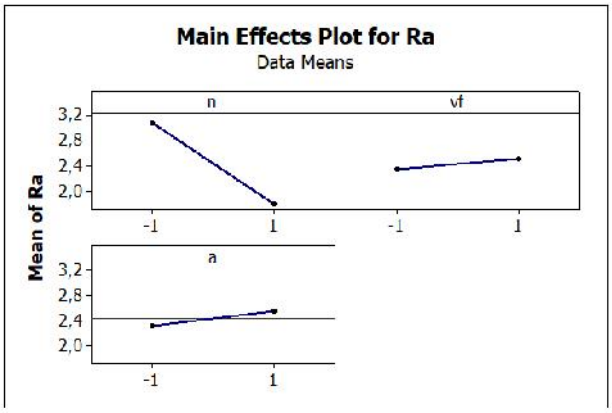

Fig. 2. Main effects plot for surface roughness

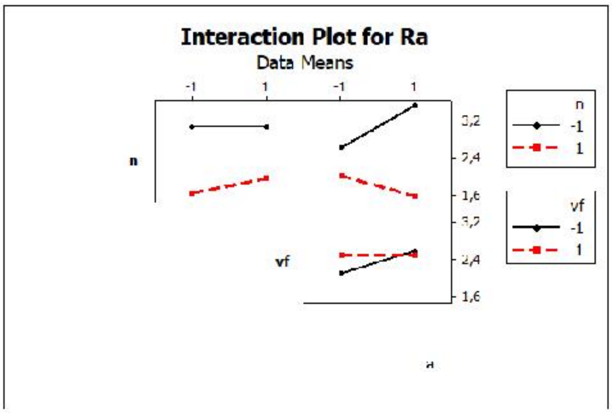

Fig. 3. Interaction plot for surface roughness

The relation of surface roughness to two cutting parameters shown in the three dimensional surface plots in Figures 5, 6 and 7, respectively. These plots shows how a response variable relates to two factors based on a model. The plot in the Figure 5 shows how spindle speed and feet rate are related to surface roghness. To minimize surface roughess, choose high setting for spindle speed and low setting for feet rate while holding depth of cut at lowest (-1). The surface roughess decrease with increasing of spindle speed and depth of cut while holding feet rate at lowest (-1) (Fig. 6). Figure 7 shows that the surface roughess decrease with decreasing of depth of cut and feet rate while holding spindle speed at lowest (-1).

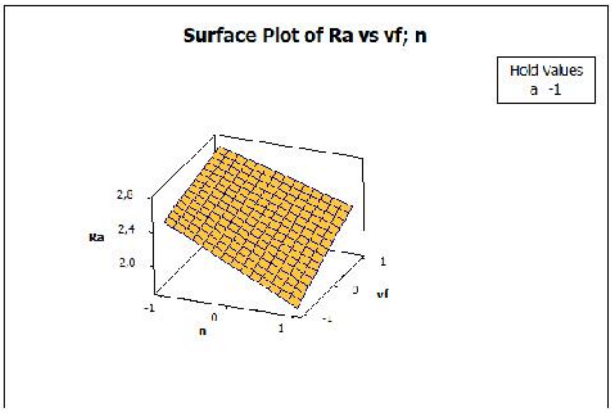

Fig. 5. Surface roughness plot for spindle speed vs feed rate

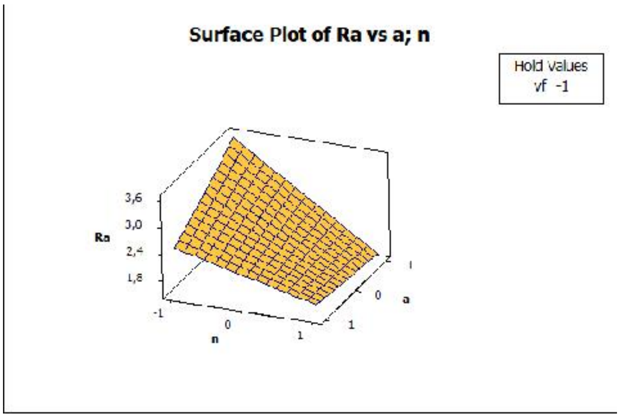

Fig. 6. Surface roughness plot for spindle speed vs depth of cut

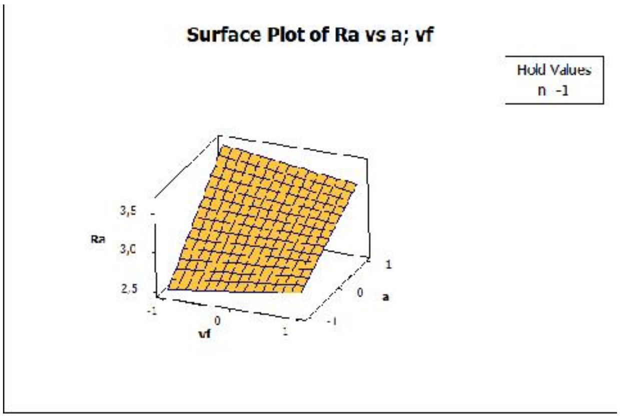

Fig. 7. Surface roughness plot for depth of cut vs feet rate

The analysis of variance used for the purpose of identifying the significant parameters, which affects the surface roughness. The analysis of variance for surface roughness (*Ra*) are shown in Tables 3. This analysis is carried out for a significant level of α = 0.05 (confidence level of 95%). The comparisons between *P*-value and level of significance (α-level) to determine which of the effects in the model are statistically significant. The effect is significant if the *P*-value is less than or equal to α-level. Based on the Table 3, the ANOVA inferred that the spindle speed cutting parameter (*n*) has significant effect on the surface roughness.

Table 3. Analysis of variance for *Ra*

Source	DF	Seq SS	Adj SS	Adj MS	F	P
n	1	3,2960	3,2960	3,2960	26,80	0,035
vf	1	0,0495	0,0495	0,0495	0,40	0,591
a	1	0,1093	0,0495	0,1093	0,89	0,445
*n * vf*	1	0,0510	0,1093	0,0510	0,41	0,585
*n * a*	1	0,8864	0,8864	0,8864	7,21	0,115
Error	2	0,2460	0,2460	0,1230		
Total	7	4,6383				

The estimation of effects and coefficients for surface roughness are shown in Table 4. The sign of the effect determines which factor setting results in a higher response measurement. A positive sign indicates that the high factor setting results in a higher response than the low setting, and a negative sign indicates that the low factor setting results in a higher response than the high setting. From the Table 4 shows that the depth of cut has the greatest effect (0.2337) on surface roughness. In addition, setting depth of cut high produced higher surface roughness than setting the depth of cut low. The feed rate has the second greatest effect (0.1572) on surface roughness. In addition, setting the feet rate high produced higher surface roughness than setting the feet rate low. The spindle speed has the smallest effect (-1.2837) on surface roughness. It has a negative sign, therefore, setting the spindle speed high produced weaker surface roughness than setting the spindle speed low. The other important coefficient, R^2, which is called determination coefficients in the resulting ANOVA table, the higher of R^2 is better to determine the coefficient of regression equation.

The relationship among the factors i.e. spindle speed, feed rate and depth of cut and performance measure (*Ra*) are obtained. Based on the coefficient value in the Table 4, the approximation of surface roughness (*Ra*) by the regression model Equation (2) is presented as follow:

$$Ra = 2.4279 - 0.6419\,(n) + 0.0786\,(vf) + 0.1169\,(a) + 0.0799\,(n*vf) - 0.3329\,(n*a)$$

The above model obtained can be used to predict the surface roughness within the limits of factors studied. The differences between experimental results and predicted of surface roughness are illustrated in Figure 8.

Table 4. Estimated effects and coefficients for surface roughness (*Ra*)

Term	Effect	Coefficient
Constant		2.4279
n	-1.2837	-0.6419
vf	0.1572	0.0786
a	0.2337	0.1169
*n * vf*	0.1597	0.0799
*n * a*	-0.6658	-0.3329
Standard deviation (*S*)		= 0.350726
Predicted residual error of sum of square (PRESS)		= 3.93628
R^2		= 94.70%
R^2 adjusted		= 81.44%

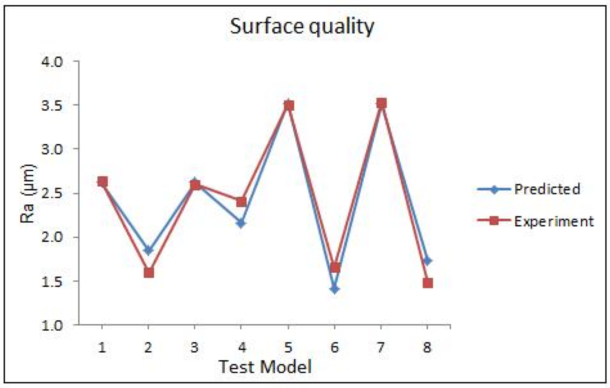

Fig. 8. The comparison between experimental and predicted value for *Ra*

CONCLUSIONS

In this research, investigation of the effect of machining parameter on milling product surface quality has been carried out. The surface roughness response *Ra* has been modelled and analysed through design of experiment (DoE) method. Factorial design was used to carry out the experimental study. Analysis of variance (ANOVA) was used to analyse the effect of the parameters on the response. In summary, the following conclusions can be drawn:

1. The analysis of variance inferred that the spindle speed cutting parameter has significant effect on the surface roughness (*Ra*).
2. The better surface quality of milling process is obtained for the minimum value of surface roughness (Ra = 1.481 µm).
3. The surface roughness decreases with increase the spindle speed and increases with increasing feed rate and depth of cut.

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