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Analysis and Prediction of Milling Process on Vertical Milling Centre (VMC) by using Response Surface Methodology (RSM)

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Abstract

The main aim of this paper is to analyze and experimentally investigate the face milling parameters for purpose of maximizing material removal rate and minimizing surface roughness. Face milling parameters were analyzed to determine their significance on mild steel by design of experiments (DOE) with employing response surface method designs to have response (Material removal rate and surface roughness). The effects of following three parameters: spindle speed, depth of cut, feed will investigate upon following two performance measures: material removal rate and surface roughness on material of mild steel. The experimental results were analyzed using ANOVA and significance of effects of all the tested parameters upon performance measures was determined. Empirical models for tensile strength and distortion, in terms of significant parameters, were developed and numerical optimization was performed according to the desirability for the maximization of tensile strength and minimization of distortion.

Keywords: Face Milling, Material Removal Rate, Surface Roughness, Response Surface Method, ANOVA.

I. INTRODUCTION

Milling is one of the important machining operations. In this operation the work piece is fed against a rotating cylindrical tool. The rotating tool consists of multiple cutting edges (multipoint cutting tool).The major design and industry constraints are higher material removal rate and cost competitive. The various process parameters of milling which can optimize by orthogonal array are Spindle speed, Feed rate, Depth of cut, Material, Coolant, Insert, and Offset.

II. LITERATURE REVIEW

– **M.R. SOLEYMANI YAZDI and A. KHORRAM [1]**

They have focused on the selection of optimal machining parameters (i.e., spindle speed, depth of cut and feed rate) for face milling operations which was investigated by them in order to minimize the surface roughness and to maximize the material removal rate. The effects of selected parameters on process variables (i.e., surface roughness and material removal rate) were investigated by them using Response Surface Methodology (RSM) and artificial neural network methods.

– **V K LAKSHMI AND DR K VENKATASUBBAIAH [2]**

They have done an investigation on surface finish and material removal rate during the high speed end milling of En24 alloy steel in order to develop an appropriate roughness prediction model and optimize the cutting parameters using RSM.

– **S. KALIDASS, P. PALANISAMY AND V. MUTHUKUMARAN [3]**

They have used two innovative models, regression and artificial neural network (ANN), for predicting and As certain tool wear in a CNC machining center for machining AISI 304 steel using a solid carbide end mill cutter Based on the DOE technique.

– **NITIN AGARWAL [4]**

He has focused on to develop a technique to predict the surface roughness of a part to be machined and to avoid “trial and error” approaches to set-up machining condition in order to achieve the desired surface roughness.

– **R. BURAPA AND W. BOONCHOUYTAN [5]**

They have used factorial designs for their experimental study of investigating the surface roughness in aluminum 7075-T6 face milling process by CNC milling machine and the result showed that the factors effecting the surface roughness were the feed ratio and the speed while the depth did not affect the surface roughness.

III. EXPERIMENTAL PLAN AND PROCEDURE

A. Milling Machine

Vertical milling center is used to carry out the experimentation as shown in figure1

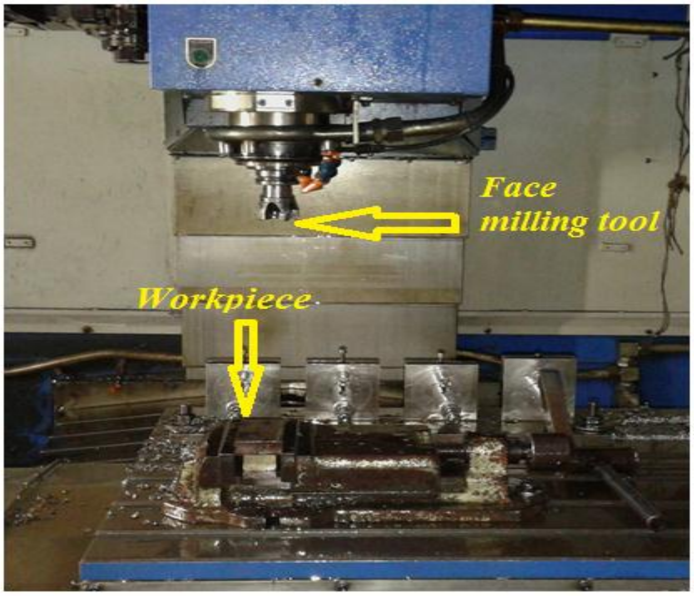

Fig. 1: Experimental Set Up

B. Selection of Material

Mild steel of grade EN 37 is mostly used in company for making different part of textile machine, which is difficult to machine. Mild steel is used as work piece in the present study. It is general purpose steel used for General purpose steel bars for machining, suitable for lightly stressed components including studs, bolts, gears and shafts. Above material is widely used in manufacturing industry because of their different characteristics. The sample rectangular plate of size 980mm x 530mm x 20mm is used for machining. The material is shown in Figure 2.

Fig. 2: Mild Steel of Grade EN37

C. Process Parameters

In present study, there are three parameters: feed, Speed, Depth of cut are taken as input process factors. Each process parameter has three levels of values as mentioned in Table.1

Table - 1

Level	*Process parameters*		
	Feed(rpm)	*Speed(mm/min)*	*Depth of cut(mm)*
-1.682	*181.821*	*314.776*	*0.79773*
-1	*250*	*400*	*0.9*

0	350	525	1.05
+1	450	650	1.2
+1.682	518.179	735.224	1.30227

D. Response parameter
In present study, there are two response parameters: material removal rate and Surface roughness. Material removal rate is measured by using below equation.

$$MRR = \frac{W_1 - W_2}{T} \; gm/sec.$$

Where,

W_1=Weight before machining

W_2=Weight after machining

T =Machining time

As per above equation for measuring the MRR, we have to subtract weight before machining from weight after machining. Surface roughness measurement is carried out by using Surface roughness tester as shown in figure 3.

Fig. 3: Surface Roughness Tester

E. Experimental deign using Response surface method
The objective of Design of experiment is to determine the variables in a process that are the critical parameters and their target values. On the basis of selected parameters, experimental design is carried out. In RSM, the equation and ANOVA are the important elements to analyze the result. Therefore from this information, one can easily determine the degree of significant of each factor. The desirability criterion available in the software for RSM will easily help user to determine the optimum condition. Taguchi method requires less run to find the optimum condition than RSM. Therefore it is recommended to use Taguchi method if the experimental run is time consuming and costly. If user wants to use RSM, the steepest accent concept must be visualized to ensure the optimum condition is accurately determined, which requires more data. So, RSM is selected. Table 2 shows complete design matrix with coded variables as well as actual value of this variables.

Table - 2

Std Order	Run Order	Pt Type	Blocks	Speed (rpm)	Depth of cut (mm)	Feed (mm/min)	MRR (gm/sec)	Ra (μm)
1	1	1	1	400	0.9	250	1.3372	1.702
2	2	1	1	650	0.9	250	1.3393	1.727
3	3	1	1	400	1.2	250	1.9239	1.452

4	*4*	*1*	*1*	*650*	*1.2*	*250*	*1.8282*	*2.957*
5	*5*	*1*	*1*	*400*	*0.9*	*450*	*2.6276*	*2.932*
6	*6*	*1*	*1*	*650*	*0.9*	*450*	*2.7161*	*1.264*
7	*7*	*1*	*1*	*400*	*1.2*	*450*	*3.4047*	*1.26*
8	*8*	*1*	*1*	*650*	*1.2*	*450*	*3.5714*	*1.383*
9	*9*	*-1*	*1*	*314.775892*	*1.05*	*350*	*2.4955*	*1.775*
10	*10*	*-1*	*1*	*735.224108*	*1.05*	*350*	*2.4806*	*1.838*
11	*11*	*-1*	*1*	*525*	*0.797731075*	*350*	*1.7438*	*1.988*
12	*12*	*-1*	*1*	*525*	*1.302268925*	*350*	*2.9464*	*1.716*
13	*13*	*-1*	*1*	*525*	*1.05*	*181.8207169*	*1.126*	*2.146*
14	*14*	*-1*	*1*	*525*	*1.05*	*518.1792831*	*3.518*	*1.679*
15	*15*	*0*	*1*	*525*	*1.05*	*350*	*2.4107*	*1.769*
16	*16*	*0*	*1*	*525*	*1.05*	*350*	*2.4107*	*1.766*
17	*17*	*0*	*1*	*525*	*1.05*	*350*	*2.4644*	*1.89*
18	*18*	*0*	*1*	*525*	*1.05*	*350*	*2.5595*	*1.865*
19	*19*	*0*	*1*	*525*	*1.05*	*350*	*2.4289*	*1.778*
20	*20*	*0*	*1*	*525*	*1.05*	*350*	*2.5433*	*1.821*

IV. RESULTS AND DISCUSSION

ANOVA is carried out to analysis the effect of factors on response with the aid of trial version of MINITAB16 Software.

A. *Analysis of variance for Material removal rate*

Table - 3
Estimated Regression Coefficients For MRR

Term	*Coef*	*SECoef*	*T*	*P*
Constant	*2.47076*	*0.02432*	*101.594*	*0.000*
Speed	*0.01000*	*0.01614*	*0.620*	*0.549*
Depth of cut	*0.34638*	*0.01614*	*21.467*	*0.000*
Feed	*0.72594*	*0.01614*	*44.990*	*0.000*
*Speed*Speed*	*-0.00115*	*0.01571*	*-0.073*	*0.943*
*Depth of cut*Depth of cut*	*-0.05169*	*0.01571*	*-3.291*	*0.008*
*Feed*Feed*	*-0.05985*	*0.01571*	*-3.811*	*0.003*
*Speed*Depth of cut*	*-0.00245*	*0.02108*	*-0.116*	*0.910*
*Speed*Feed*	*0.04360*	*0.02108*	*2.068*	*0.065*
*Depth of cut*Feed*	*0.06960*	*0.02108*	*3.301*	*0.008*

S = 0.0596297	PRESS = 0.139689	
R-Sq=99.61%	R-Sq(pred) = 98.45%	R-Sq(adj) = 99.25

Table - 4
Analysis of Variance For MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Cont.%
Regression	9	8.97421	8.97421	0.99713	280.43	0.000	99.605
Linear	3	8.83694	8.83694	2.94565	828.43	0.000	98.081
Speed	1	0.00137	0.00137	0.00137	0.38	0.549	00.015
Depth of cut	1	1.63858	1.63858	1.63858	460.83	0.000	18.186
Feed	1	7.19700	7.19700	7.19700	2024.07	0.000	79.880
Square	3	0.08325	0.08325	0.02775	7.80	0.006	00.924
Speed*Speed	1	0.00117	0.00002	0.00002	0.01	0.943	00.013
Depth of cut*Depth of cut	1	0.03046	0.03850	0.03850	10.83	0.008	00.338
Feed*Feed	1	0.05163	0.05163	0.05163	14.52	0.003	00.573
Interaction	3	0.05401	0.05401	0.01800	5.06	0.022	00.599
Speed*Depth of cut	1	0.00005	0.00005	0.00005	0.01	0.910	00.000
Speed*Feed	1	0.01521	0.01521	0.01521	4.28	0.065	00.169
Depth of cut*Feed	1	0.03875	0.03875	0.03875	10.90	0.008	00.460
Residual Error	10	0.03556	0.03556	0.00356			00.395
Lack-of-Fit	5	0.01342	0.01342	0.00268	0.61	0.702	00.149
Pure Error	5	0.02214	0.02214	0.00443			00.246
Total	19	9.00976					100.00

For the insulation data, the analysis of variance table shows the following:

1) *Regression*
These tests whether the terms in the model have any effect on the response. The regression model is significant (p = 0.000). That is, at least one of the terms in the regression equation has an impact on the mean response. Regression is further broken into the different orders of terms in the model linear, square, and interaction.

2) *Interaction effects*
The p-value of 0.910 for the speed*depth of cut interaction is not less than 0.05. Therefore, there is a non-significant interaction effect. The p-value of 0.008 for the depth of cut*feed interaction is less than 0.05. Therefore, there is a significant interaction effect. That is, the effect of depth of cut on MRR depends on the feed.

3) *Squared effects*
Squared terms are used to evaluate whether or not there is curvature in the response surface. The p-value of 0.006 for the squared effects is less than 0.05. Therefore, there is significant evidence of a quadratic effect. The individual p-values for speed*speed, depth of cut*depth of cut and feed*feed are 0.943, 0.008 and 0.003 respectively, indicating that the relationships between depth of cut and MRR and feed and MRR follows a curved line.

4) *Linear effects*
The p-value of speed, feed and depth of cut are 0.549, 0.000 and 0.000. Among these three factors feed and depth of cut are significant.

5) *Residual Error*
The residual error measures amount of variation in the response left unexplained by the model. If repeated response values are observed at certain settings of the predictors, the unexplained variation can be divided into two parts (Lack-of-Fit and Pure Error).

6) *Lack-of-Fit*
The variation due to model inadequacy (lack-of-fit). The p-value of 0.702 is not less than 0.05. Therefore, there is no evidence that the model does not adequately explain the variation in the responses. If there is a significant lack-of-fit, that may have excluded important terms from the model or the regression may not explain well the presence of several large residuals.

B. Analysis of variance for Surface Roughness

Table - 5
Estimated Regression Coefficients For Ra

Term	Coef	SECoef	T	P
Constant	1.83540	0.01317	139.317	0.000
Speed	0.00666	0.01594	0.418	0.683
Depth of cut	-0.07545	0.01594	-4.733	0.000
Feed	-0.13066	0.01594	-8.195	0.000
Speed*Depth of cut	0.40888	0.02083	19.629	0.000
Speed*Feed	-0.38438	0.02083	-18.453	0.000
Depth of cut*Feed	-0.31662	0.02083	-15.200	0.000

S = 0.0589173	PRESS = 0.149882	
R-Sq = 98.77%	R-Sq(pred) = 95.92%	R-Sq(adj) = 98.21%

Table - 6
Analysis of Variance For Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Cont.%
Regression	6	3.63290	3.63290	0.60548	174.43	0.000	98.773
Linear	3	0.31150	0.31150	0.10383	29.91	0.000	08.469
Speed	1	0.00061	0.00061	0.00061	0.17	0.683	00.016
Depth of cut	1	0.07775	0.07775	0.07775	22.40	0.000	02.114
Feed	1	0.23315	0.23315	0.23315	67.17	0.000	06.339
Interaction	3	3.32139	3.32139	1.10713	318.94	0.000	90.303
Speed*Depth of cut	1	1.33743	1.33743	1.33743	385.29	0.000	36.363
Speed*Feed	1	1.18195	1.18195	1.18195	340.50	0.000	32.135
Depth of cut*Feed	1	0.80201	0.80201	0.80201	231.04	0.000	21.805
Residual Error	13	0.04513	0.04513	0.00347			01.227
Lack-of-Fit	8	0.03108	0.03108	0.00388	1.38	0.375	00.845
Pure Error	5	0.01405	0.01405	0.00281			00.382
Total	19	3.67802					100.00

For the insulation data, the analysis of variance table shows the following:

1) *Regression*
These tests whether the terms in the model have any effect on the response. The regression model is significant (p = 0.000). That is, at least one of the terms in the regression equation has an impact on the mean response. Regression is further broken into the different orders of terms in the model linear, square, and interaction.

2) *Interaction effects*
The p-values of the speed*depth of cut, speed*feed, and feed*depth of cut interaction are 0.000 which is less than 0.05. Therefore, there is a significant interaction effect.

3) *Squared effects*
The p-value of squared effect is not less than 0.05 so there is no significant squared effect on surface roughness. So we do not include the squared effect in Analysis of surface roughness.

4) *Linear effects*
The p-value of speed 0.683 which is not less than 0.05 so there is no significant effect of speed on surface roughness. The p-value for depth of cut and feed are 0.000 which is less than 0.05 so the feed and depth of cut are the significant factor for the surface roughness.

5) *Residual Error*

The residual error measures amount of variation in the response left unexplained by the model. If repeated response values are observed at certain settings of the predictors, the unexplained variation can be divided into two parts (Lack-of-Fit and Pure Error).

6) *Lack-of-Fit*

The variation due to model inadequacy (lack-of-fit). The p-value of 0.375 is not less than 0.05. Therefore, there is no evidence that the model does not adequately explain the variation in the responses. If there is a significant lack-of-fit, that may have excluded important terms from the model or the regression may not explain well the presence of several large residuals.

V. REGRESSION ANALYSIS

The simple analysis starts with a main effects plot. A main effects plot is a plot of the means of the response variable for each level of a factor. It gives a general idea of which main effects may be important. The Figure 4 and 5 show the locations of the main effects for MRR and Ra.

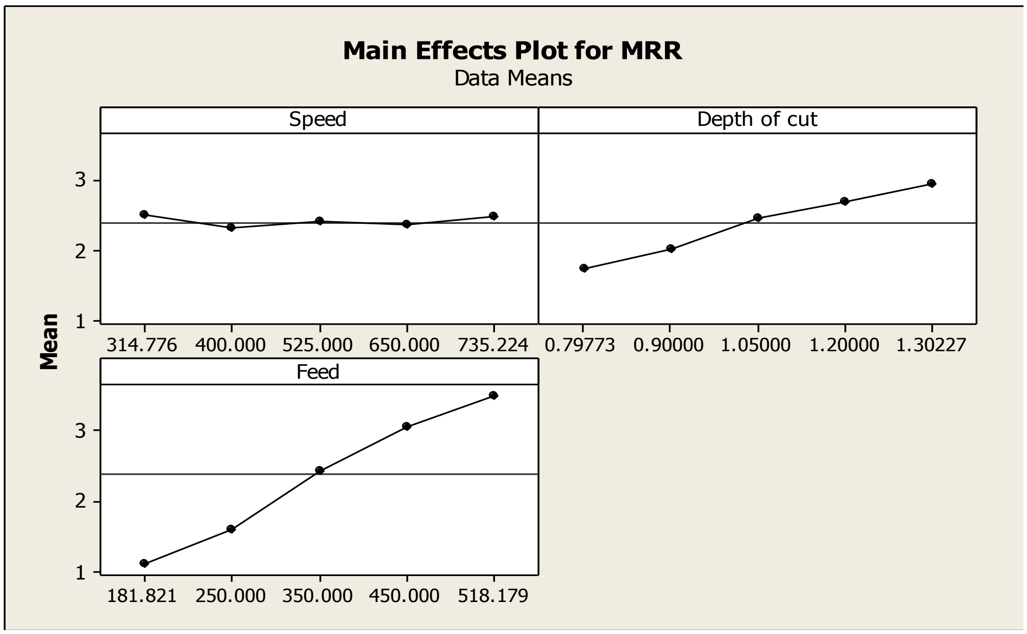

Fig. 4: Main Effects Plot For MRR

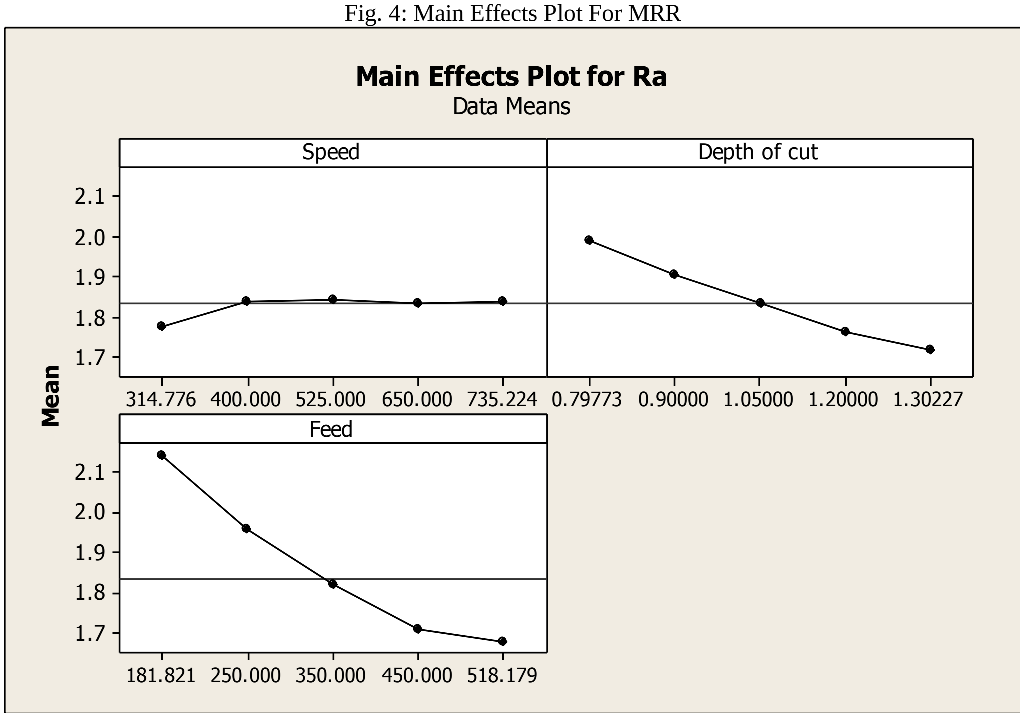

Fig. 5: Main Effects Plot For Ra

Analysis indicates that the factors depth of cut and feed increase when they move from the low level to the high level of material removal rate (MRR) and they decrease when they move from the low level to the high level of surface roughness (Ra). Speed is seems independent to both response variable MRR. Each level of the factors affects the response differently. The optimize parameter table is as shown in Table 7.

Table – 7
Optimize Parameter Table

Output	*Goal*	*Optimum combination*			*Lower*	*Target*	*Upper*	*Predicted response*	*Desirability*
		Speed (rpm)	*Depth of cut (mm)*	*Feed (mm/min)*					
MRR (gm/sec)	*Max.*	*314.776*	*1.3023*	*518.1793*	*1.126*	*3.5714*	*3.5714*	*4.01911*	*1.00*
Ra(μm)	*Min.*	*314.776*	*1.3023*	*518.1793*	*1.26*	*1.26*	*2.957*	*0.51271*	*1.00*

VI. CONCLUSION

In the present study, an attempt has been made to investigate the effect of process parameters (cutting speed, feed rate and depth of cut) on the performance characteristics (material removal rate and surface roughness) in face milling of Mild Steel.

From the results found in this study, the following conclusions were drawn:

(1) The experimental analysis show that feed is most significant factor for response variable MRR. It contributes effect about 79.88%.
(2) From above analysis it is observed that interaction effect of independent variable from regression is most significant for Ra. It contributes about 90.30%. In this effect the interaction effect of speed and depth of cut, speed and feed, depth of cut and feed contributes 36.36%, 32.13%, 21.81% of significant level.
(3) From the main effect plot for both responses MRR and Ra, it is conclude that depth of cut and feed both are significant factor for both the responses. This plot gives the statement that speed is not a significant factor for both responses.
(4) From the overlaid plot of MRR and Ra, it is conclude that for achieving the maximum MRR at minimum Ra the value of depth of cut and feed should be high as possible and speed should be low as possible.
(5) Simultaneous optimization of the performance characteristics (surface roughness and material removal rate) when face milling of Mild steel was achieved with a cutting speed n = 314.776 rpm, feed rate f_m = 518.179 mm/min and depth of cut doc = 1.3023 mm.

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