Implementation of Response Surface Methodology for Analysis of Milling Process using Multi Point Cutting Tool for Surface Finish

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Abstract

This paper investigates the effect of cutting speed, feed rate and depth of cut on the surface roughness of components of mild steel material. The response surface methodology (RSM) was employed in the experiment. The investigated milling parameters were cutting speed (105, 225RPM) and depth of cut (0.75 and 1.5 mm) and no. of cuts (1 and 2). The results showed that the speed and no. of cut were the primary factors controlling surface roughness. The responses of various factors were plotted using a three-dimensional surface graph. The optimum condition required for minimum surface roughness includes cutting speed of 225RPM and no. of cut 2. Depth of cut has no significant effect on surface roughness of the components. With this optimum condition, a surface roughness of 1.32µm was obtained.

Keywords: *High-speed milling, Surface roughness, Response surface method, etc.*

I. INTRODUCTION

Surface roughness is generally known to be highly affected by cutting speed, followed by no. of cuts and depth of cut. The geometrical shape of the insert is another factor considered in studies on surface roughness. Surface roughness is used to assess the performance of cutting tools under various conditions. This study aims to determine the cutting conditions that will result in the lowest value of surface roughness.

Surface roughness is one of the most important requirements in machining process, as it is considered an index of product quality. It measures the finer irregularities of the surface texture. Achieving the desired surface quality is critical for the functional behaviour of a part. Surface roughness influences the performance of mechanical parts and their production costs because it affects factors, such as friction, ease of holding lubricant, electrical and thermal conductivity, geometric tolerances and more. The ability of a manufacturing operation to produce a desired surface roughness depends on various parameters. The factors that influence surface roughness are machining parameters, tool and work piece material properties and cutting conditions. For example, in milling operation the surface roughness depends on cutting speed, depth of cut, lubrication of the cutting tool, machine vibrations, tool wear and on the mechanical and other properties of the material being machined. Even small changes in any of the mentioned factors may have a significant effect on the produced surface [1].Therefore, it is important for the researchers to model and quantify the relationship between roughness and the parameters affecting its value. The determination of this relationship remains an open field of research, mainly because of the advances in machining and materials technology and the available modelling techniques. In machinability studies investigations, statistical design of experiments is used quite extensively. Statistical design of experiments refers to the process of planning the experiments so that the appropriate data can be analysed by statistical methods, resulting in valid and objective conclusions [2]. Design methods such as factorial designs, response surface methodology (RSM) and taguchi methods are now widely use in place of one factor at a time experimental approach which is time consuming and exorbitant in cost.

II. EXPERIMENTAL WORK

In this study, milling experiments are planned using 2 level full factorial experimental designs. Machining tests are conducted by considering three cutting parameters: milling speed (v), depth of cut (d), and no. of cuts (n). Total 2^3=8 milling experiments are carried out. Low-high level of milling parameters in cutting space of two level full factorial experimental designs is shown in Table 2. Ranges of cutting parameters are selected based on shop floor. All the experiments were carried out on All Geared Milling Machine model by BHAMBAR Machine Tools (India). This milling machine has speed range 40 RPM to 1020 RPM total 15 variable speeds we could get on that machine. Surface finish of the work piece material was measured by Mitutoyo SJ-201P Surface finish tester. The surface roughness was measured at three equally spaced locations on the milled surface of the work pieces to obtain the statistically significant data for the test. In the present work, the work piece material was mild steel. This material has good wear and corrosion resistance. The high and low values of parameters used for this test are given in Table 1.

Table 1: Input Parameters and their Levels.

Sr.No.	Parameters	Level 2	Level 1
1	Milling speed (v), RPM	225	105
2	Depth of cut (d), mm	1.5	0.75
3	No. of cuts	2	1

Table 2

Responses							
Input Variables			Coded Variables			Output	
N	DOC	No. of cuts	A	B	C	Difference in Diameter	Surface finish
2	2	2	1	1	1	2.5	2.68
2	2	1	1	1	-1	0.98	1.48
2	1	2	1	-1	1	1.50	4.18
2	1	1	1	-1	-1	0.70	1.32
1	2	2	-1	1	1	2.96	4.88
1	2	1	-1	1	-1	1.28	1.43
1	1	2	-1	-1	1	1.86	3.06
1	1	1	-1	-1	-1	0.90	1.74

In Table 2, the values of input variables are showed and these values have converted into coded variables using following formulae.

A=N-1.5/0.5, B=DOC-1.5/0.5, C=NOC-1.5/0.5

After completion of the milling operation on each of the 8 components, the change in diameter and surface roughness of each component has been measured. The output values are specified in Table 2.

Image.No.1- Mitutoyo SJ-201P Surface Finish Tester

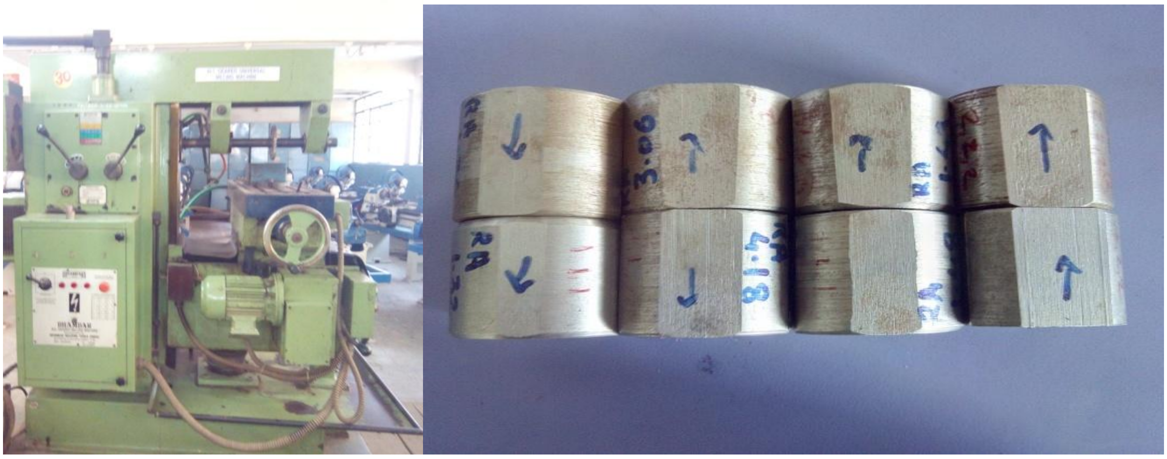


Image No.2- Photo of Actual Milling Carried out at DKTE Workshop and Finished Milled Components

The next step was to find out fitting model for response surface method. It had been found out theoretically by the following procedure.

1] Created a matrix of coded variables.

$$X = \begin{bmatrix} 1. & 1. & 1. & 1. \\ 1. & 1. & 1. & -1. \\ 1. & 1. & -1. & 1. \\ 1. & 1. & -1. & -1. \\ 1. & -1. & 1. & 1. \\ 1. & -1. & 1. & -1. \\ 1. & -1. & -1. & 1. \\ 1. & -1. & -1. & -1. \end{bmatrix}$$

2] Found out inverse of X matrix

$$X' = \begin{bmatrix} 1. & 1. & 1. & 1. & 1. & 1. & 1. & 1. \\ 1. & 1. & 1. & 1. & -1. & -1. & -1. & -1. \\ 1. & 1. & -1. & -1. & 1. & 1. & -1. & -1. \\ 1. & -1. & 1. & -1. & 1. & -1. & 1. & -1. \end{bmatrix}$$

3] Next created a column matrices for output values surface roughness (SF) and change in diameter(Dia)

$$SF = \begin{bmatrix} 2.68 \\ 1.48 \\ 4.18 \\ 1.32 \\ 4.88 \\ 1.43 \\ 3.06 \\ 1.74 \end{bmatrix}$$

$$Dia = \begin{bmatrix} 2.5 \\ 0.98 \\ 1.5 \\ 0.7 \\ 2.96 \\ 1.28 \\ 1.86 \\ 0.9 \end{bmatrix}$$

4] Last step was to find out equation of fitted model using following formulae

A. For Surface Finish

The equation for RSM is,

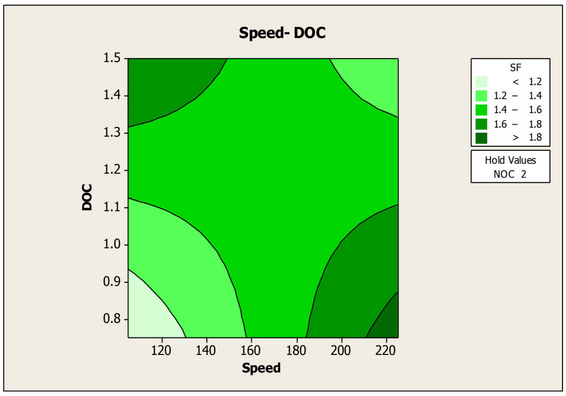
Z=((X'*X)^-1)*X'*SF

$$Z = \begin{bmatrix} 2.59625 \\ -0.18125 \\ 0.02125 \\ 1.10375 \end{bmatrix}$$

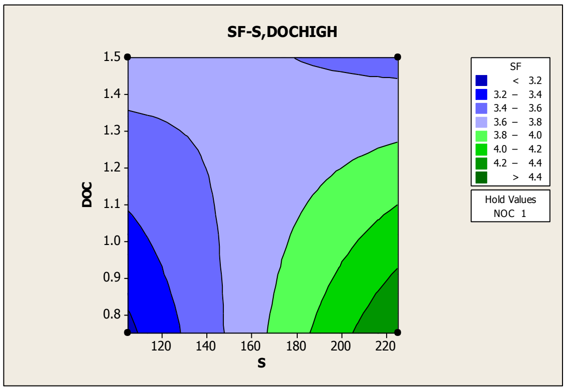
By using Z matrix fitted equation for surface finish was achieved and it was as bellow

SF= 2.59265 - 0.18125A + 0.02125B + 1.10375C

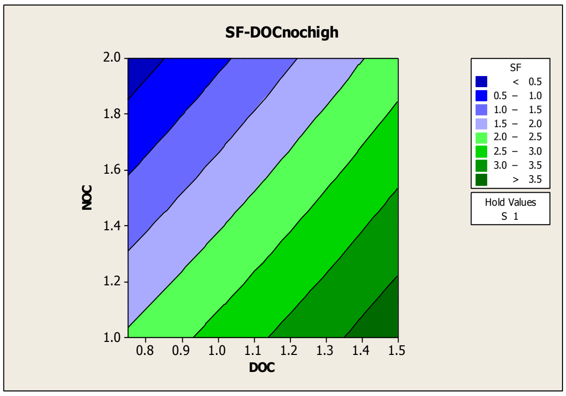
RSM Tool from Minitab software has been used for analysis and got the following graphs of contour plots and surface plots, showing the effect of DOC, NOC, and Speed on surface finish.



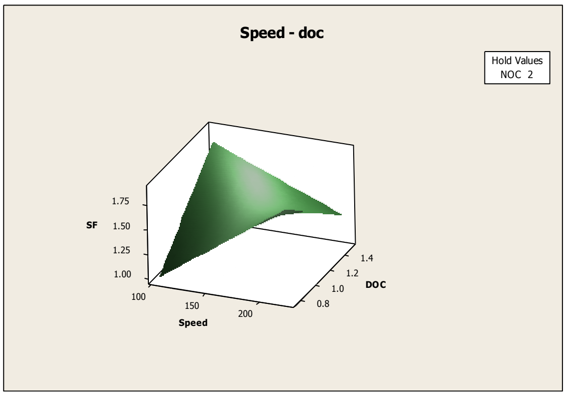
Graph No.1. Contour Plot for Speed Vs DOC



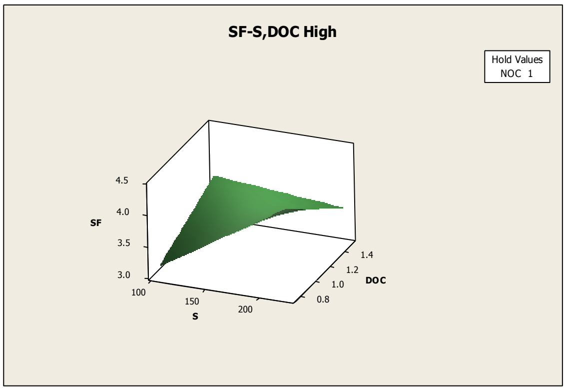
Graph No. 2.Contour Plots for SF Vs Speed, DOC



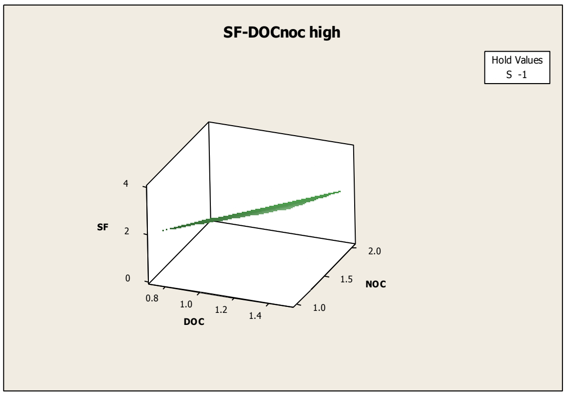
Graph No.3. Contour Plots for SF Vs DOC, NOC



Graph No.4. Surface Plots for SF Vs Speed, DOC



Graph No.5. Surface Plots for SF Vs Speed, DOC



Graph No.6. Surface Plots for SF Vs DOC, NOC

B. For Diameter,

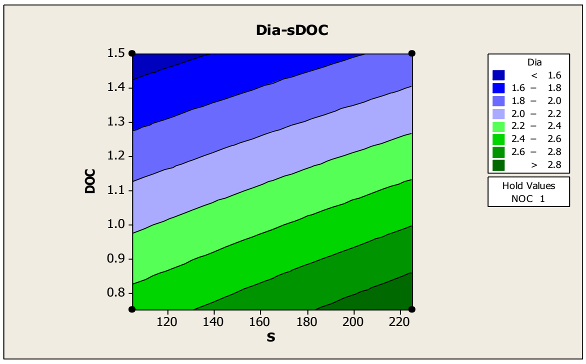
The equation for RSM is,

FD= ((X'*X)^-1)*X'*Dia

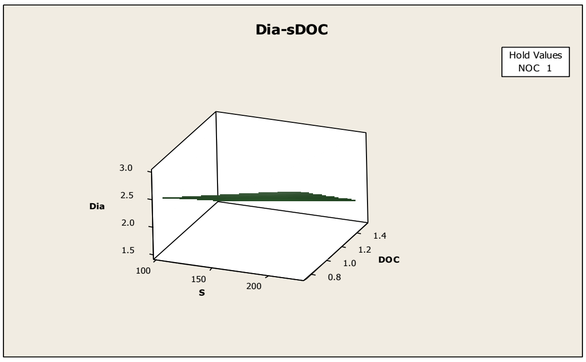
$$FD = \begin{bmatrix} 1.585 \\ -0.165 \\ 0.345 \\ 0.62 \end{bmatrix}$$

By using above matrix the equation for change in diameter was found out as bellow,

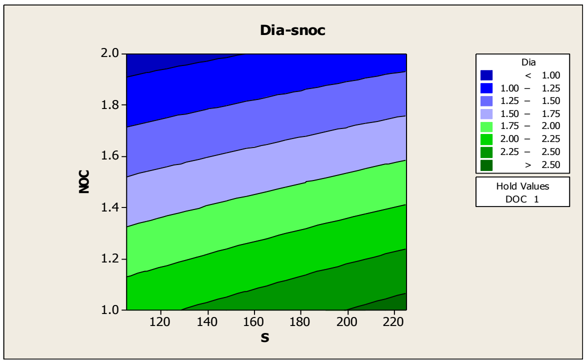
FD= 1.585 – 0.165A + 0.345B + 0.62C



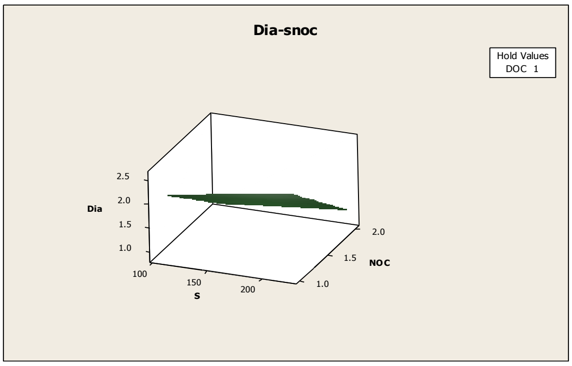
Graph No.7. Contour plot for Dia. Vs Speed, DOC



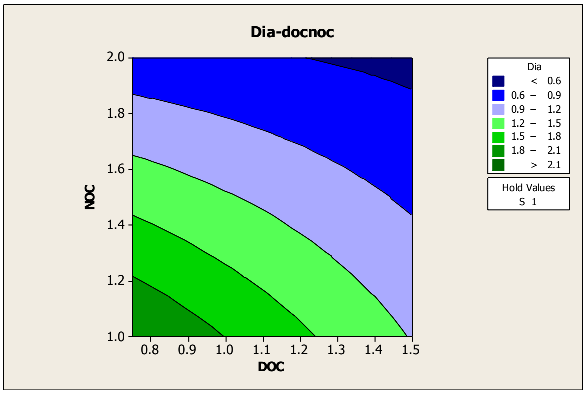
Graph No. 10.Surface plot for Dia. Vs Speed, DOC



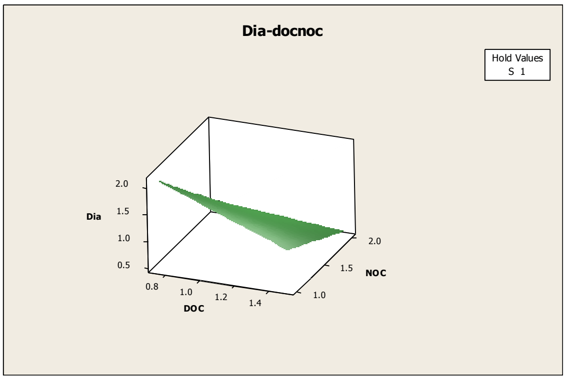
Graph No. 8.Contour plot for Dia. Vs Speed, NOC



Graph No.11. Surface Plot for Dia. Vs Speed, NOC



Graph No.9. Contour plot for Dia. Vs DOC, NOC



Graph No.12. Surface plot for Dia. Vs DOC, NOC

Regression analysis using taguchi method was performed and results achieved are as follows,

Taguchi Analysis: SF versus S, DOC, NOC

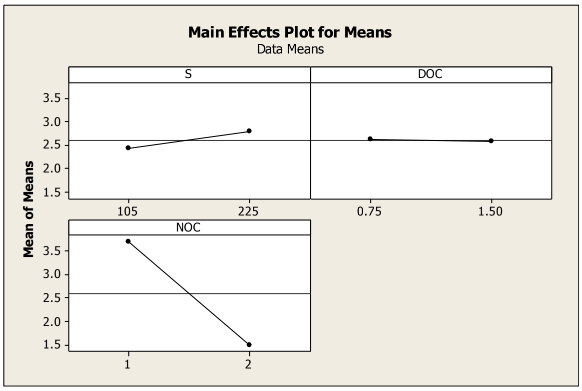
Response Table for Signal to Noise Ratios
Smaller is better

Level	S	DOC	NOC
1	-6.701	-7.211	-11.117
2	-7.850	-7.340	-3.434
Delta	1.149	0.129	7.684
Rank	2	3	1

Response Table for Means

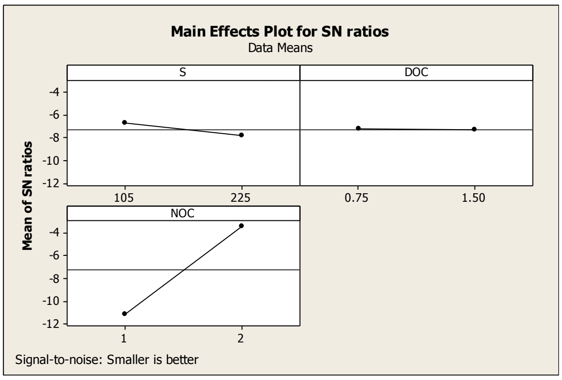
Level	S	DOC	NOC
1	2.415	2.617	3.700
2	2.777	2.575	1.492
Delta	0.362	0.042	2.207
Rank	2	3	1

Main Effects Plot for Means



Graph no.1. Main Effects Plot for Means

Main Effects Plot for SN ratios



Graph no. 2. Main Effects Plot for SN ratios

The above graph no.2 shows, the S-N ratio for this study, it indicates that speed has significant effect on surface finish and it is good when used at high level i.e.225RPM

Depth of cut doesn't have any significant effect on surface finish whereas no. of cuts plays major role t o get good surface finish, its value should be high. i.e.2

Taguchi Design

Taguchi Orthogonal Array Design

L8(2**3)

Factors: 3
Runs: 8

Columns of L8(2**7) Array

1 2 4

Taguchi Analysis: SF versus Speed, DOC, NOC

Response Table for Signal to Noise Ratios
Smaller is better

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Response Surface Regression: SF versus Speed, DOC, NOC

The analysis was done using coded units.

Estimated Regression Coefficients for SF

Term	Coef	SE Coef	T	P
Constant	2.59625	0.4738	5.480	0.115
Speed	0.18125	0.4738	0.383	0.767
DOC	-0.02125	0.4738	-0.045	0.971
NOC	-1.10375	0.4737	-2.330	0.258
Speed*DOC	-0.35625	0.4737	-0.752	0.590
Speed*NOC	-0.08875	0.4737	-0.187	0.882
DOC*NOC	0.05875	0.4737	0.124	0.921

S = 1.33997 PRESS = 114.913
R-Sq = 86.10% R-Sq(pred) = 0.00% R-Sq(adj) = 2.67%

Results for: Worksheet 2

Taguchi Design

Taguchi Orthogonal Array Design

L8(2**3)

Factors: 3
Runs: 8

Columns of L8(2**7) Array

1 2 4

Regression Analysis: SF versus S, DOC, NOC

The regression equation is
SF = 5.47 + 0.00302 S - 0.057 DOC - 2.21 NOC

Predictor	Coef	SE Coef	T	P
Constant	5.473	1.552	3.53	0.024
S	0.003021	0.005019	0.60	0.580
DOC	-0.0567	0.8030	-0.07	0.947
NOC	-2.2075	0.6022	-3.67	0.021

S = 0.851682 R-Sq = 77.5% R-Sq(adj) = 60.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	10.0125	3.3375	4.60	0.087
Residual Error	4	2.9015	0.7254		
Total	7	12.9140			

Source	DF	Seq SS
S	1	0.2628
DOC	1	0.0036
NOC	1	9.7461

III. RESULTS AND DISCUSSIONS

In this paper, application of RSM on the mild steel is carried out for milling operation. The results are as follows:

(1) For the surface roughness, the milling speed is the main influencing factor on the roughness, followed by the no. of cuts.

(2) 3D surface counter plots are useful in determining the optimum condition to obtain particular values of surface roughness.

(3) Response surface optimisation shows that the optimal combination of milling parameters are (Speed=225 RPM, no. of cut= 2) for cutting speed and tool no. of cuts respectively. Depth of cut has no significant effect on the surface roughness of component.

IV. CONCLUSIONS

A series of experiments using RSM were conducted to investigate the factors affecting the surface roughness of mild steel component. The effect of milling speed, depth of cut and no. of cuts was studied. The following conclusions were drawn:
The best surface finish was achieved when milling at 225 RPM, Depth of cut of 0.75 mm and no. of cuts 2.

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