

Influence of Cutting Parameters on Surface Roughness in Face Milling Operation

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ABSTRACT: Face Milling is presently the most efficient and creative manufacturing method for roughing and finishing large surfaces of metallic parts. The current study presents an approach to the determination of the optimal cutting parameters to create high metal removal rate in the face milling of high carbon alloy steel. The metal removal rate seriously varies with the change of machining parameter. This requires proper selection of the process parameter. The machining parameters taken for the study are cutting speed (rpm), feed rate (mm/tooth), depth of cut (mm) and coolant condition. Out of these four parameters the coolant used is a categorical parameter rest has numeric value. In present study the fractional factorial de-sign technique is used to optimize the process parameter in face milling of high carbon alloy steel EN-31 with tungsten coated face mill inserts. Two levels of 24-1 fractional factorial designs of eight runs were selected for conducting the experiments. The mathematical models were developed from the data generated. The significance of coefficients and adequacy of developed models were tested by 't'-test and 'F' -test respectively. Out of four variables, depths of cut contribute the highest effect on MRR, followed by feed, interaction effect of feed and depth of cut. From the analysis it is clear feed con-tribute the highest effect on surface roughness. The established equations clearly show that surface roughness increased with increasing the feed and depth of cut but decreased with increasing the cutting speed under wet condition.

KEYWORDS: Optimization, EN-31, Machining parameter, Face Milling, Fractional factorial design technique.

I. INTRODUCTION

Milling is the process for removing excess material from a work piece with a rotating cutting tool. Milling process is used for producing flat, contoured or helical surface, for cutting threads and toothed gears and for making helical grooves [2]. A face mill consists of a cutter body (with the appropriate-ate machine taper) that is designed to hold multiple disposable carbide or ceramic tips or inserts, often golden in colour [6]. The tips are not designed to be re-sharpened and are selected from a range of types that may be determined by various criteria, some of which may be: tip shape, cutting action required, and material being cut. When the tips are blunt, they may be removed, rotated (indexed) and replaced to present a fresh, sharp face to the work piece. This increases the life of the tip and thus its economical cutting life [3]. In machining process, most of the mechanical energy used to remove material becomes heat. This heat generates high temperature in the cutting region. The higher the cutting speed, the faster the heat generation and higher temperature resulted. The new challenge in ma-chining is to use high cutting speed in order to increase the productivity with high surface finish. This is the main reason for rapid tool wear and surface roughness [1]. Another Conventional method used to reduce this surface roughness is by using cutting fluid. This cutting fluid acts as lubricant and coolant as well during the machining process. Usage of cutting fluid can increase the cutting speed up to 30% without affecting the surface roughness and tool life [1]. However the usage of cutting fluid has negative effect to the economy, environment and health [1]. Total elimination of cutting fluid seems to be not promising due the unsatisfactory tool life and poor surface finish [5]. This rapid tool wears not only gives higher surface roughness value, but also higher micro hardness and major microstructure alteration [6]. So it is better to optimize the variable parameters (coolant flow rate, cutting speed, feed rate and depth of cut) for tool life to increase the productivity at good surface finish. For optimization factorial design technique is used. In full factorial design the number of trials increases with increase in

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number or levels of the factors. Increased number of that is mainly due to higher order interactions which in most cases do not affect the response significantly [7]. The number of trials in a factorial experiment is considerably greater than the coefficients of a linear model to be determined. In other words a factorial experiment has a great surplus number of trials as a result increased cost of experimentation and wastage of time [8]. Obviously, it is desirable to reduce the number of trials and cost of running experiment. Often a large proportion of experimental effort is wasted in evaluating unimportant interactions and in determining the experimental error with unnecessary degree of precision [9]. Hence fractional factorial design enables the size of an experiment to be reduced to a fraction that of full factorial experiment, which still provide all the important information.

II. METHODOLOGY

Work piece

EN -31 is a high carbon alloy steel having 16mm thick plate was used in this research work. The chemical composition of the material was determined with the spectrometer and tabulated in Table 1 also Composition of work piece has been shown in Table 2. The work piece used for present study in the rectangular form with the dimensions as 97 X 75 X 16 mm³

Table 1: Composition (Wt. %) of EN-31

C	Si	Mn	Cr	S	P
0.95	0.25	0.46	1.36	0.04	0.035

Cutting Tool Material

The milling cutter used for machining having 4 cutting inserts made from tungsten carbide (coated).

Table 2 Composition

Serial No.	Content	Weight %
1	WC	87
2	Co	13

Table 3 Geometry of Cutting Tool

Serial No.	Content	mm
1	Cutter Dia.	50
2	Nose Radius	0.6

Cutting Fluid

Water immiscible cutting fluid was used during this experiment. However, this coolant is miscible with solvent or mineral oil. Desired coolant flow rate was achieved by regulating the supplied air pressure and the opening of nozzle.

Design of Experiment

All the machining was carried out on 3 -axis CNC milling machine. Type of machining done in this experiment is Face milling. Design of experiment was multilevel factorial design which is summarized below in table 4.

Table 4 Parameter type

Name	Units	Type	Min.	Max.
Speed	rev/min	Numeric	200	600
Feed	mm/tooth	Numeric	0.05	0.15
Depth of cut	mm	Numeric	0.6	3
Coolant	ml/hr	Categorical	on	off

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The design matrix developed to conduct the eight trials runs of 2^{4-1} or 2^3 fractional factorial design as given in Table 5

Table 5: Design matrix

S. no.	S	F	D	C
1	1	1	1	1
2	2	1	1	2
3	1	2	1	2
4	2	2	1	1
5	1	1	2	2
6	2	1	2	1
7	1	2	2	1
8	2	2	2	2

The models of the type $Y = f(S, F, D, C)$ could be developed to facilitate the prediction of a response within the specified dimensional tolerance for a particular set of direct process parameters. Assuming a linear relationship in the first instance and taking into account all the possible two factor interaction and confounded interactions, it could be written as

$$Y = b_0 + b_1S + b_2F + b_3D + b_4C + b_{12}SF + b_{13}SD + b_{14}SC + b_{23}FD + b_{24}FC + b_{34}DC \quad [\text{Eqn. 1}]$$

The regression coefficients of the selected model were calculated using Equation 3.2. This is based on the method of least squares.

$$b_j = \frac{\sum_{i=1}^N (X_{ji} Y_i)}{N}, \quad j = 0, 1, \dots, k \quad [\text{Eqn. 2}]$$

Where,

X_{ji} = Value of a factor or interaction in coded form Y_i = Average value of response parameter

N = No. of observation

K = Number of coefficients of the model

Table 6 Coefficients of model

S. no.	Coefficient	Due to
1	b_0	Combined effect of all parameter
2	b_1	Cutting speed
3	b_2	Feed rate
4	b_3	Depth of cut
5	b_4	Coolant effect
6	b_{12}	Interaction of S and F
7	b_{13}	Interaction of S and D
8	b_{14}	Interaction of S and C
9	b_{23}	Interaction of F and D
10	b_{24}	Interaction of F and C
12	b_{34}	Interaction of D and C

Checking The Adequacy Of The Developed Model

The adequacy of the model was determined by the analysis of variance technique. The regression coefficients were determined by the method of least square, from which the 'F'-ratio for the polynomial was found. The variance of the response and the adequacies were calculated. The 'F'- ratio of the model were compared with the corresponding 'F'-ratio from the standard table and it was found that the model is adequate within 95% level of confidence, thus justifying the use of assumed polynomials. After calculating the coefficients of model, it must be tested for its fitness. Thus

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adequacy of the model was tested using analysis of variance technique. For this variance of optimization parameter (S^2y) was determined. It can be calculated with Equation 3 as follows

$$S^2 y = 2 \frac{\sum_{i=1}^N (\Delta M^2)}{N} \quad \text{Equation-3}$$

Where,

$$\Delta Y^2 = (Y_{iq} - Y_m)^2$$

Y_m = Arithmetical mean of repetitions Y_{iq} = Value of response in a repetition trial N = Number of observations

i = No. of trials

q = No. of repetition

Further, the variance of adequacy, also called as residual variance was determined by using following Equation 4

$$S^2 ad = \frac{\sum_{i=1}^N (\Delta M^2)}{3} \quad \text{Equation -4}$$

Where,

$S^2 ad$ = variance of adequacy y_m = observed response

y_p = estimated / predicated value of response $f = N - (K + 1)$ (Degree of freedom)

\sum = residual sum of square

K = number of independently controllable variables.

The ratio of variance of adequacy to the variance of optimization parameter gives Fisher ratio:-

$$\text{'F' ratio} = S^2 ad / S^2 y \quad \text{Eqn. 5}$$

The F-value obtained and denoted as (F_m) was compared with the table value as (F_t). It was found that the model was adequate at 95% level of significance thus justifying the use of the assumed polynomial

Checking The Significance Of Coefficients Of Model

The statistical significance of the coefficients can be tested by applying 't' test. The level of significance of a particular parameter can be assessed by the magnitude of the 't' value associated with it. Higher the value of 't', the more significant it becomes. 't' value for the given coefficients of the models were calculated using Equation 3.7 as follows.

$$t = |b_j| / S_{b_j}$$

where,

$|b_j|$ = absolute value of coefficients S_{b_j} = standard deviation of coefficients

$$S_{b_j} = S^2 y / N \quad \text{Eqn. 6}$$

Calculated 't' value were compared with the t-table value and statistically insignificant terms of the models were dropped. The value of 't' from the standard table for eight degree of freedom and 95% confidence level is 2.306. Coefficients having calculated 't' value less than or equal to 't' value from the standard table for eight degree of freedom and 95% confidence level, are the members of reference distribution i.e. due to the and hence, they cannot be significant.

Final Modal

The final model could be obtained by dropping statistically in-significant terms from the developed models. Only significant decision variables are to be considered in the final model.

Observation

According to design matrix, experiment has been done and three set of MRR and surface roughness has been recorded as shown in table 7.

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Table 7 Observational Table for surface roughness

Trial no.	Speed (rev/min)	Feed (mm/tooth)	D.O.C (mm)	Coolant	(Set-1)R ₁ (Microns)	(Set-2)R ₂ (Microns)	(Set-3)R ₃ (Microns)
1	600	0.15	3	On	1.24	1.28	1.23
2	200	0.15	3	Off	1.83	1.92	1.87
3	600	0.05	3	Off	1.3	1.27	1.34
4	200	0.05	3	On	1.24	1.22	1.27
5	600	0.15	0.6	Off	1.23	1.22	1.2
6	200	0.15	0.6	On	1.25	1.42	1.31
7	600	0.05	0.6	On	0.71	0.77	0.75
8	200	0.05	0.6	Off	1.14	1.17	1.19

Development of Mathematical Model

Coefficients of models were calculated using Equation 2 and presented in Table 8

Table 8: Coefficients of surface roughness

Coefficient	Due to	b _t
b ₀	Combined effect of all parameters (main effect)	1.263
b ₁	Speed	-0.135
b ₂	Feed	0.160
b ₃	Depth of cut	0.149
b ₄	Coolant	-0.121
b ₁₂	Interaction of Speed and Feed	-0.045
b ₁₃	Interaction of Speed and Depth of cut	-0.004
b ₁₄	Interaction of Speed and Coolant	-0.0056
b ₂₃	Interaction of Feed and Depth of cut	-0.0056
b ₂₄	Interaction of Feed and Coolant	-0.0046
b ₃₄	Interaction of Depth of cut and Coolant	-0.0456

Inserting the values of coefficients in the Equation 1, the model for surface roughness can be obtained as:

$$R_a = 1.263 - 0.135S + 0.160F + 0.149D - 0.121C - 0.045SF - 0.004SD - 0.0056SC - 0.0056FD - 0.0046FC - 0.0456DC$$

[Eqn. 7]

Variance of optimization (S²y) for surface roughness is obtained by putting the values of surface roughness from two set of reading in Equations 3. Table 11 shows the variance of optimization for surface roughness.

t'-Values for the coefficient of metal removal rate

Using the Equation 3.7, 't' – values were calculated . These values were compared with the 't' –values taken from standard table. The value of 't' from standard table at (8, 0.05) is 2.306, hence statistically in significant terms i.e. having values less than 2.306 were dropped.

$$R_a = 1.26 - 0.13A + 0.16B + 0.14C - 0.12D - 0.04AB - 0.04CD$$

Variance Of Adequacy (S² ad) For Surface Roughness

Variance of adequacy value for surface roughness obtained by inserting the estimated and observed values of surface roughness in Equation 4 are as shown in Table 10.

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Table 9 Variance of adequacy (S^2_{ad}) for metal removal rate

Surface roughness (Microns)				S^2_{ad}
Estimated values	Observed values	ΔR	ΔR^2	
1.224	1.23	0.006	3.306E-05	
1.922	1.87	-0.052	2.678E-03	
1.329	1.34	0.011	1.156E-04	
1.174	1.27	0.096	9.168E-03	
1.169	1.2	0.031	9.456E-04	
1.379	1.31	-0.069	4.796E-03	
0.787	0.75	-0.037	1.351E-03	
1.119	1.19	0.071	5.006E-03	0.008

Table 10: Analysis of Variance for surface roughness

Degree of freedom		Variance of Adequacy	Variance of response	'F'-ratio model (F_m)	'F'-ratio table (F_t)	Adequacy of model
f	N				At 3,8,0.05	Whether $F_m < F_t$
3	8	0.008	0.0027	2.887	4.12	Yes

III. RESULT AND DISCUSSION

The proposed models for the prediction of surface roughness after dropping the statistically insignificant terms, in coded form as given below:-

$$R_a = 1.26 - 0.13A + 0.16B + 0.14C - 0.12D - 0.04AB - 0.04CD$$

The hypothesis adopted for identifying the parameters, which were mainly and predominantly responsible for the interaction effect in a confounded pattern was to first drop those interactions that were due to parameter having insignificant effects and if there were still two or more interactions left in the confounded pattern then the interaction due to parameter which the most predominant effect was selected. The mathematical models furnished above can be used to predict the surface roughness by substituting the values of respective factors in coded form.

Influence of Cutting Speed on Surface Roughness

The relationship between the cutting speed and surface roughness for a given model of surface roughness has been shown in Fig.3. It could be concluded from this figure that with increase in cutting speed from 200 rpm to 600 rpm, there is decrease in surface roughness from 1.39 micron to 1.2 micron. As cutting speed increases the temperature also increases, which soften the material to enhance the cutting performance leading to reduced surface roughness.

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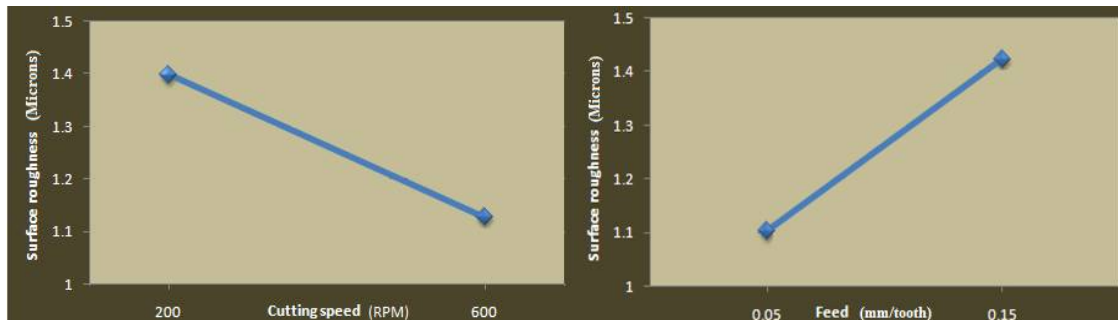


Fig.3: Plot between cutting speed & surface roughness Fig.4: Plot between feed & surface roughness

Influence Of Feed on Surface Roughness

The relationship between the feed and surface roughness for the given model of surface roughness has been shown in Fig. 4. It could be concluded from this figure that with increase in feed from 0.05 mm/tooth to 0.15 mm/tooth, there is increase in surface roughness from 1.10 microns to 1.42 microns. Because higher feed rate tool traverses the work piece too speedily resulting in deteriorated surface quality and also high feed increase the chatter, which leads to higher surface roughness. The cutting forces increase with the increase in the rate of feed, resulting in increased heat generation. Higher feed rate increases vibrations which is responsible for rough surface.

Influence Of Depth of cut on Surface Roughness

The relationship between the depth of cut and surface roughness for a given model of surface roughness has been shown in Fig. 5. It could be concluded from this figure that with increase in depth of cut from 0.6 mm to 3mm, there is increase in surface roughness from 1.11 microns to 1.41 microns. The number of teeth engaged in the cut is directly proportional to the depth of cut; cutting friction is also increased because of more teeth cut grooves in to the work material this leads to increase in overall cutting forces. As the depth of cut increases the cutting forces also increase resulting in increased vibrations and chattering as a result increased surface roughness.

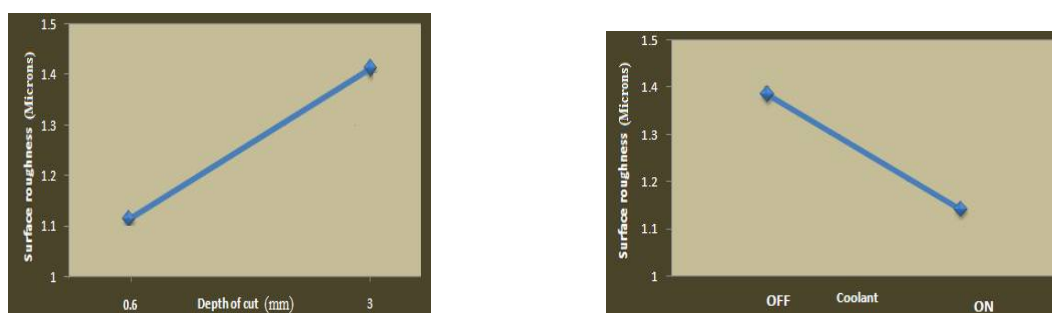


Fig.5: Plot between depth of cut & surface roughness Fig.6: Plot between coolant levels & surface Roughness

Influence Of Coolant on Surface Roughness

The relationship between the level of coolant and surface roughness for a given model of surface roughness has been shown in Fig. 6. It is clear from the plot that the value of surface roughness is less when coolant is on as compare to the condition of coolant off. From figure it is clear surface roughness decrease from 1.38 micron to 1.14 micron when coolant is on. Because coolant decreases the friction between tool and work piece during cutting thus improve the surface finish. The reduced temperature due to the application of coolant appears to have a negative effect on the formation of built up edge, as the formation of built up edge is less this will leads to reduce of surface roughness. The good surface finish was obtained by using coolant. The coolant used acted as a lubricant reducing the friction that resulted a good surface finish.

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Interactive effect of cutting speed and feed on surface roughness

The influence of cutting speed and feed on the surface roughness is shown in Fig.6. The plot clearly explains that at constant speed, the surface roughness increases as the feed rate increases because higher feed rate tool traverses the work piece too speedily resulting in deteriorated surface quality and also high feed increase the chatter, which leads to higher surface roughness. Also, at constant feed rate, the surface roughness decreases as the cutting speed increases resulting in better surface quality. It is further observed that rate of increase in surface roughness is higher at low cutting speed. The response surface due to interaction of cutting speed and feed on surface roughness has been shown in Fig. 7



Fig.7: Interaction plot between cutting speed & feed for surface roughness



Fig.8 interaction plot between surface roughness and coolant

Interactive effect of depth of cut and coolant on surface roughness

Interactive effect of depth of cut and coolant on the surface roughness is shown in Fig.8. The plot clearly explains that at constant depth of cut, the surface roughness is higher when the coolant is off as compared to when coolant is on. It is due to the fact that coolant decrease the friction between tool and work piece during cutting thus improve the surface finish. It is further observed that surface roughness is higher at higher value of depth of cut. It is clear from the figure that roughness obtained without the use of coolant is higher than using the coolant. The response surface due to interaction of cutting speed and feed and interaction of coolant and depth of cut on surface roughness has been shown in Fig 9 and fig. 10 respectively.

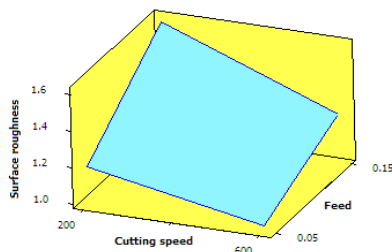


Fig.8: Response surface due to an interaction of cutting speed and feed

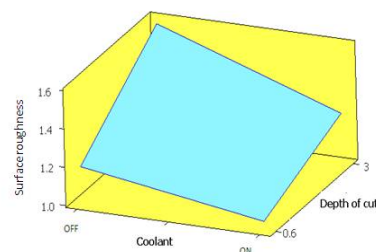


Fig.10: RS due to an interaction of coolant condition and D.O.C

IV. CONCLUSION

Out of four variables, feed contribute the highest effect on surface roughness, followed by depth of cut, cutting speed and coolant. The established equations clearly show that surface roughness increased with increasing the feed and depth of cut but decreased with increasing the cutting speed under wet condition.

Surface roughness decrease with increase cutting speed. The surface roughness was minimum (1.12 mic.) at 600 rpm and maximum (1.39 mic.) at 200 rpm.

Surface roughness increase with increase feed. The surface roughness was maximum (1.42 mic.) at feed 0.15 mm/tooth and minimum (1.10 mic.) at feed 0.05 mm/tooth.

Surface roughness increase with increase depth of cut. The surface roughness was maximum (1.41 mic.) at depth of cut 3 mm. and minimum (1.11 mic.) at depth of cut 0.6 mm.

Surface roughness decrease under wet condition and increase under dry condition.

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REFERENCES

- [1] Kapil Kumar Chauhan & Dinesh Kumar Chauhan (2013) "Optimization of Machining Parameters of Titanium Alloy for Tool Life" in "Journal of Engineering, Computers & Applied Sciences (JEC&AS)" Volume 2, No.6, June 2013 (ISSN No: 2319-5606).
- [2] Baek, Dae Kyun & kim, Hee sool.(2001).Optimization of feedrate in a face mill-ing operation using a surface roughness model, *International Journal of Machine Tools & Manufac-ture*, Vol.41, pp.451-462.
- [3] Benardos, P.G. & Vosniakos, G.C.(2002). Predic-tion of surface roughness in CNC face milling using neural networks and Taguchi's design of experi-ments, *Robotics and Computer Integrated Manufac-turing*, Vol.18, pp.343-354.
- [4] Dweiri, F. & Al-Jarrah, M.(2003).Fuzzy surface roughness modeling of CNC down milling of Alomic-79, *Journal of Materials Processing Tech-nology*, Vol.133, pp.266-275.
- [5] Lo, ship-peng. (2003). An adaptive-network based fuzzy inference system for prediction of workpiece surface roughness in end milling, *Journal of Mate-rials Processing Technology*, Vol.142, pp.665-675.
- [6] Wang, Ming-Yung & Chang, Hung-yen.(2004).Experimental study of surface roughness in slot end milling AL2014-T6, *International Jour-nal of Machine Tools & Manufacture*, Vol.44, pp.51-57.
- [7] Brezocnik, M. & kovacic, M.(2004).Prediction of surface roughness with genetic programming, *Jour-nal of Materials Processing Technology*, Vol. 157-158, pp. 28-36.
- [8] Oktem, Hasan. & Erzurumlu, Tun-cay.(2005).Prediction of minimum surface rough-ness in end milling mold parts using neural network and genetic algorithm, *Materials and design*, Vol. 27, pp. 735-744.
- [9] Chang, Ching-Kao & Lu, H. S.(2005). Study on the prediction model of surface roughness for side mill-ing operations, *Int J Adv Manuf Technol*, Vol. 29, pp. 867-878
- [10] Zhang, Julie Z. & Chen, Joseph C.(2006).Surface roughness optimization in an end-milling operation using the Taguchi design method, *Journal of Mate-rials Processing Technology*, Vol. 184, pp. 233-239.