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“Optimization of machining parameters for minimum surface roughness in end milling„

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ABSTRACT

This paper focuses on determining optimized parameters for minimum surface roughness in CNC end milling. Design of experiments based on response surface methodology with three independent factors (cutting speed, feed rate and depth of cut) and one category factor (nose radius), five level central composite rotatable designs has been used to develop relationships for predicting surface roughness. Model adequacy tests were conducted using ANOVA table and the effects of various parameters were investigated and presented in the form of contour plots and 3D surface graphs. Numerical optimization was carried out considering all the input parameters within range so as to minimize the surface roughness.

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INTRODUCTION

Machining parameters such as speed feed, depth of cut and nose radius play a vital role in machining the given work piece to the required shape. These have a major effect on the quantity of production, cost of production and production rate; hence their judicious selection assumes significance. In manufacturing industries, manufacturers focus on both the quality and productivity. To increase the productivity, computer numerically control (CNC) machine tools have been implemented during the past decades. Surface roughness is one of the most important parameters to determine the quality of product. The mechanism behind the formation of surface roughness is very dynamic, complicated, and process dependent. Several factors influence the surface roughness obtained in a CNC milling operation. These can be categorized as controllable factors (spindle speed, feed rate, depth of cut and nose radius) and uncontrollable factors (tool geometry and material properties of both tool and work piece).

As the milling process is the most productive process, the study is expected to be quite beneficial. Here, end milling has been selected for the study to determine the impact of process parameters on the surface quality of the product.

1.1 Milling

Milling is the most common form of machining, a material removal process, which can create a variety of features on a part by cutting away the unwanted material. By feeding the work piece into the rotating cutter, material is cut away from the work piece in the form of chips to create the desired shape.

1.2 End milling

An end mill makes either peripheral or slot cuts, determined by the step-over distance, across the work piece in order to machine a specified feature, such as a profile, slot, pocket, or even a complex surface contour. The depth of the feature may be machined in a single pass or may be reached by machining at a smaller axial depth of cut and making multiple passes.

1.3 Factors affecting surface roughness:

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

A) The machining variables which include
a) Cutting speed
b) Feed, and
c) Depth of cut.
B) The tool geometry
Some geometric factors which affect achieved surface finish include:
a) Nose radius
b) Rake angle
c) Side cutting edge angle, and
d) Cutting edge.

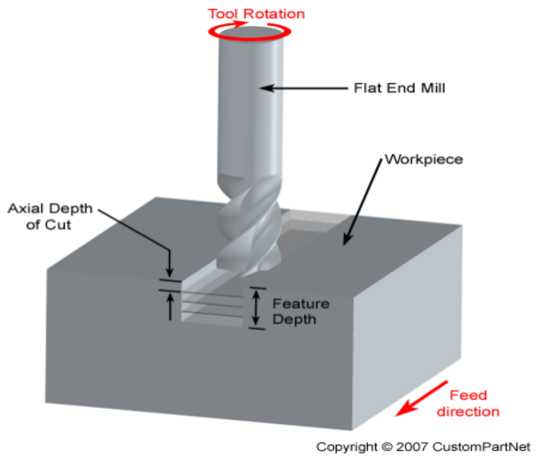

Figure 1: End milling

2. Literature review

Many researchers investigated and formulated the effect of cutting variables for the optimization of the surface roughness. Published work of different authors in the referred area is mentioned here.

Iqbal et al. studied the effect of minimum quantity of lubrication (MQL) for optimal surface finish by response surface methodology in milling of AISI D2 using coat carbide inserts [1]. Kadirgama et al. developed an approach for optimization of surface roughness in end milling of Aluminium alloys (AA6061-T6) using coated carbide inserts [2]. Gopalswamy et al. experimentally investigated grey rational theory and ANOVA for optimal cutting parameters in end milling of annealed tool steel (55 HRc). The cutting speed, feed, depth of cut and depth of cut are the independent parameters [3]. Zhang et al. investigated the optimal surface topography and roughness using Taguchi-design of experiment in finish hard milling of AISI H13 by coated carbide inserts [4]. Rai et al. developed a surface roughness prediction model based of artificial neural network for machining of AISI H11 hardened steel using coated carbide cutters [5]. Yazdi and Khorram developed an approach for the selection of optimal machining parameters for face milling of Aluminum 6061-T6 using coated carbide inserts. The effect of cutting speed, feed and depth of cut is investigated in order to minimize the surface roughness and to maximize the material removal rate using RSM and artificial neural networks [6].

3. Design of experiments

Design of Experiment is a powerful approach to improve product design or improve process performance where it can be used to reduce cycle time required to develop new product or processes. Design experiment is a test or series of test where changes are made in the input variable (parameter) of a process for observing and identifying corresponding changes in the output response. The main objectives of DOE are –

1) Determination of factors that have an influential effect on the response.
2) Determination of the appropriate settings of the influential factors for optimization of the response.
3) Determination of the appropriate settings of the influential factors for minimization of the responses variability.

There are several statistical techniques available in design of experiments for the optimization i.e factorial designs, Taguchi method, Response Surface Methodology etc. Response surface Methodology has been selected in the present work.

3.1 Response surface methodology (RSM)

This method is used to determine the optimum contribution of factors that yield a desired response and describes the response near the optimum. RSM consists of a group of empherical techniques devoted to the evaluation of relations existing between a cluster of controlled experimental factors and measured responses, according to one or more selected criteria. If the model contains coefficients for main effects, coefficients for quadratic effects and coefficients for two factor interactions, a full factorial design with all the factors at three levels would provide estimation of all the required regression parameters.

3.2 Central composite rotatable design (CCRD)

A central composite rotatable design is an experimental design useful in RSM for building a second order (quadratic) model for the response variable without the need to use a complete three level factorial experiment. The total number of treatments combinations is reduced significantly by employing these designs.

3.3 Analysis of variance (ANOVA)

ANOVA is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. Analysis of variance (ANOVA) consists of simultaneous hypothesis tests to determine if any of the effects are significant. Several calculations will be made for each main factor and interaction term.

3.4 End milling machine

Table 1: Technical specification of HMT VMC400 Machining Centre

Model no.	VMC400
X-axis	1020 mm
Y-axis	510mm

Z-axis	510mm
Table size (L*W)	1200*500 mm
Spindle speed (max.)	8000 R.P.M
Spindle motor	18.5 Kw

3.5 Work piece specification

The machining experiments were performed on EN-31 alloy steel. All the pieces used in experimentation were 20 mm in thickness and 40 mm in diameter. Chemical composition of EN 31 steel was obtained by spectral analysis and summarized in Table.

Table 2: Chemical composition of EN-31 carbon steel, % weight

Element	C	Mn	Si	P	S	Cr	Ni
Percentage	0.181	0.67	0.23	0.021	0.013	0.81	1.1

4. Experimental Study

Number of experiments required, mainly depends on the approach adopted for design of experiment. Thus, it is important to have a well designed experiment so that number of experiments required can be minimized. In this study, the design suggested by RSM has been implemented to analyze the effect of four independent variables for milling i.e. cutting speed, feed, depth of cut and nose radius on surface roughness. Out of four parameters speed, feed and depth of cut are numeric parameters and nose radius is categoric parameter.

Table 3: Factors and levels of independent variables according to input provided

Factors	Symbol	Type	Lower limit	Upper limit
Speed (m/min)	A	Numeric	50	200
Feed (mm/tooth)	B	Numeric	0.05	0.15
Depth of cut (mm)	C	Numeric	0.10	0.60
Nose radius (mm)	D	Categiric	0.5	0.8

Table 4: Factors and levels of independent variables according to response surface methodology

Factors	**Symbol**	**Type**	**Lower limit**		**Levels**		**Upper limit**
Speed (m/min)	A	Numeric	50	80.40	125	169.60	200
Feed (mm/tooth)	B	Numeric	0.05	0.07	0.10	0.13	0.15
Depth of cut (mm)	C	Numeric	0.10	0.20	0.35	0.50	0.60
Nose radius (mm)	D	Categoric	0.5	-	-	-	0.8

Table 5: Constraints for optimization of cutting conditions

Condition	**Goal**	**Lower Limit**	**Upper Limit**
Speed (A)	Is in range	80.40	169.60
Feed (B)	Is in range	0.07	0.13
Depth of cut (C)	Is in range	0.2	0.5
Nose radius (D)	Is in range	0.5	0.8

Table 6: Complete design layout

Run	A:speed m/mm	B:Feed mm/tooth	C: Depth of cut mm	D: Nose Radius Mm	R_a: Surface Roughness µm
1	200	0.10	0.35	0.8	0.638
2	80.40	0.07	0.50	0.8	1.308
3	125	0.10	0.35	0.5	1.902
4	80.40	0.13	0.20	0.5	2.369
5	200	0.10	0.35	0.5	0.801
6	125	0.10	0.35	0.5	1.936
7	80.40	0.07	0.50	0.5	1.969
8	125	0.10	0.60	0.5	1.87
9	125	0.10	0.35	0.8	1.348
10	169.60	0.07	0.50	0.5	1.01
11	125	0.10	0.35	0.8	1.42
12	125	0.05	0.35	0.8	0.94
13	125	0.15	0.35	0.8	1.691
14	50	0.10	0.35	0.8	1.682
15	169.60	0.13	0.20	0.5	1.271
16	169.60	0.07	0.20	0.5	0.989
17	125	0.15	0.35	0.5	2.1
18	125	0.10	0.35	0.5	1.804
19	125	0.10	0.60	0.8	1.246
20	80.40	0.13	0.20	0.8	1.73
21	125	0.10	0.10	0.5	1.688
22	125	0.10	0.35	0.8	1.196
23	125	0.10	0.35	0.5	1.74
24	125	0.10	0.35	0.8	1.373
25	80.40	0.13	0.50	0.8	1.758
26	169.60	0.07	0.20	0.8	0.807
27	169.60	0.07	0.50	0.8	0.795
28	125	0.10	0.35	0.5	1.823
29	125	0.10	0.35	0.8	1.413
30	125	0.05	0.35	0.5	1.225
31	50	0.10	0.35	0.5	2.38
32	80.40	0.07	0.20	0.5	1.675
33	125	0.10	0.35	0.8	1.266
34	125	0.10	0.35	0.5	1.901
35	169.60	0.13	0.50	0.8	1.072
36	169.60	0.13	0.20	0.8	1.12
37	169.60	0.13	0.50	0.5	1.384
38	120	0.10	0.10	0.8	1.237
39	80.40	0.07	0.20	0.8	1.263
40	80.40	0.13	0.50	0.5	2.391

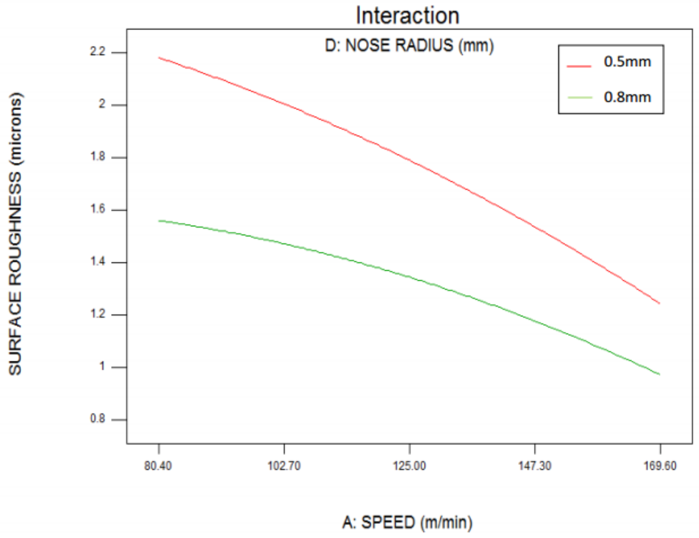

Fig.2: Interaction plot between nose radius and speed at feed 0.10 mm/tooth and depth of cut 0.35 mm for Ra

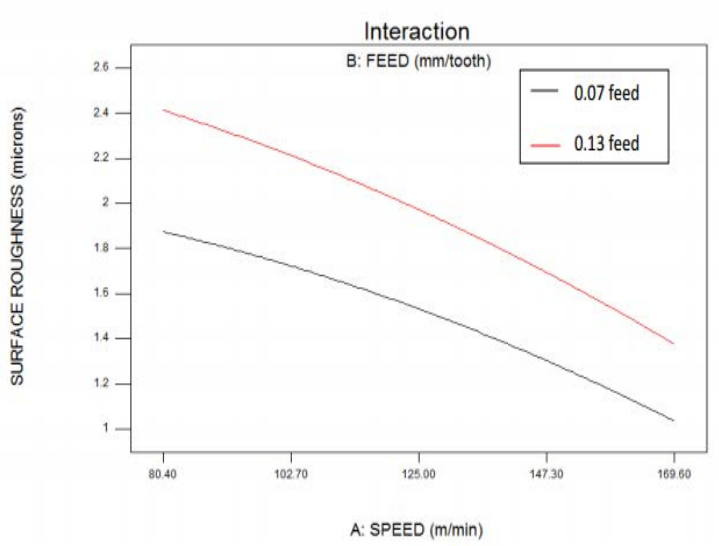

Fig.3: Interaction plot between cutting speed & feed at constant depth of cut 0.35 mm & nose radius 0.5 mm for Ra.

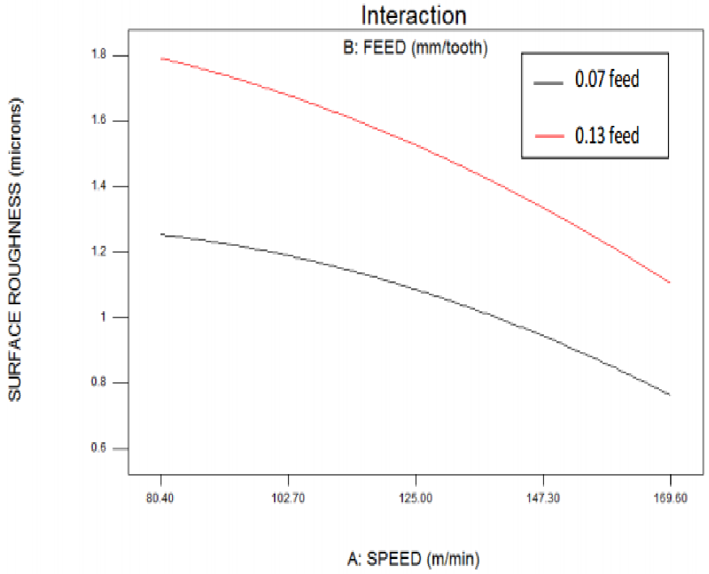

Fig.4: Interaction plot between cutting speed & feed at constant depth of cut 0.35 mm & nose radius 0.8 mm for Ra.

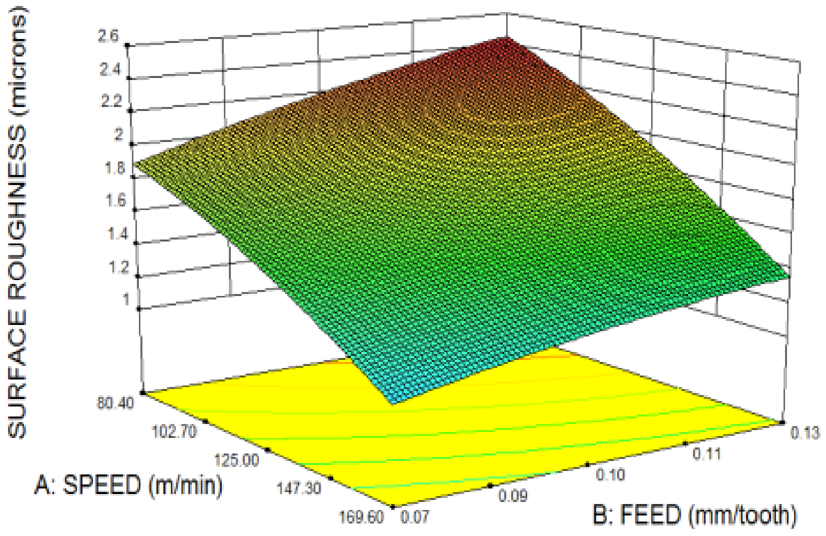

Fig.5: 3D surface graph for surface roughness at depth of cut 0.35mm and nose radius 0.5mm.

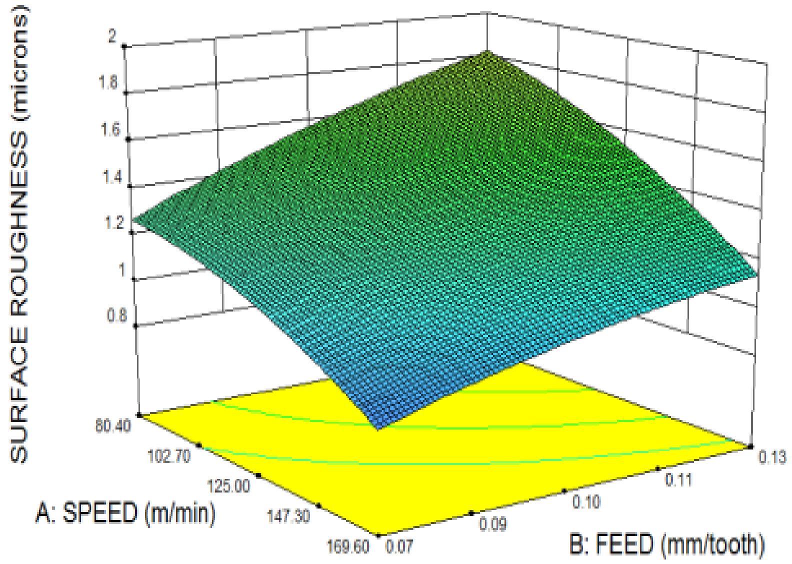

Fig.6: 3D surface graph for surface roughness at depth of cut 0.35mm and nose radius0.8mm

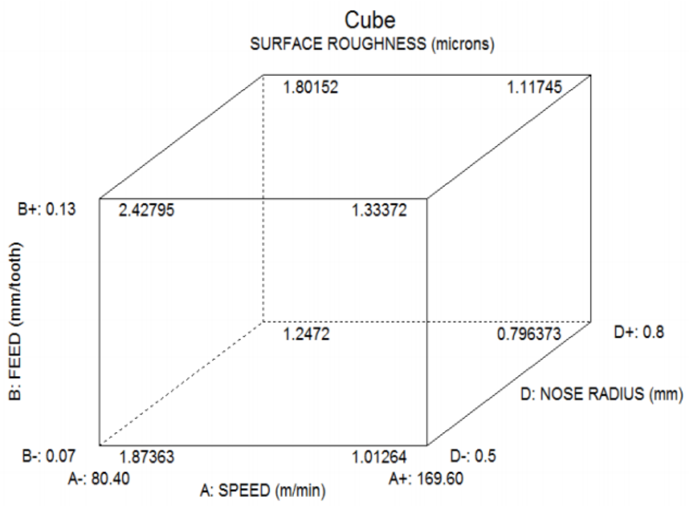

Fig.7: Cube plot for surface roughness at depth of cut 0.35mm

6. Conclusions

The important conclusions drawn from the present work are summarized as follows:

1. Out of four variables considered cutting speed seems to be the most significant and influential machining parameter followed by feed rate. The nose radius has the least effect on the surface roughness.
2. The depth of cut has insignificant influence on the surface roughness.
3. The mathematical models developed clearly show that surface roughness increases with increasing the feed but decreases with increasing the cutting speed and nose radius.
4. The results of ANOVA and the confirmation runs verify that the developed mathematical model for surface roughness show excellent fit and provide predicted values of surface roughness that are close to the experimental values, with a 95 per cent confidence level.
5. The percentage error between the predicted and experimental values of the response factor during the confirmation experiments are within 5 per cent.
6. The model can be used for direct evaluation of Ra under various combinations of machining parameters during end milling of EN 31 steel.

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