INVESTIGATION OF INFLUENCE OF MILLING PARAMETERS ON SURFACE ROUGHNESS AND FLATNESS

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ABSTRACT

This paper deals with the effect of three selective parameters viz. cutting speed, feed and depth of cut on the surface roughness of Aluminium 1050 during milling operation. The main objective of this work is to investigate the influence of the above mentioned parameters on the surface roughness and flatness to obtain the optimum surface texture using Response Surface Methodology and to recommend the best parameters that contribute to obtain the optimum surface roughness value. The values of said three parameters taken for the study are: cutting speed range - 500 to 1500 rpm, feed range - 50 to 70 mm/rev and depth of cut range - 0.5 to 1.5mm, and given as input to the Mini Tab software. As a result 15 number of design of experiments with various combinations of the three parameters under consideration have been generated. Experiments have been conducted in the run order on CNC Milling Machine by using manual coding method, and the surface roughness has been tested using TR-200 surface roughness tester, and the flatness has been tested by using Coordinate Measuring Machine (CMM).The obtained surface roughness and flatness values are analyzed through graphs generated by using Response Surface Methodology (RSM) of Minitab Software. In addition an empirical relation between cutting parameters, surface roughness and Flatness is also derived.

KEYWORDS: *End Milling Process, Cutting parameters, Response Surface Methodology, Surface roughness, flatness.*

I. INTRODUCTION

Surface roughness is an important measure of product quality, since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behaviour, corrosion resistance, etc. and functional attributes like friction, wear, light reflection, heat transmission and electrical conductivity, etc. There have been many research developments in modelling surface roughness and optimization of the controlling parameters to obtain a surface finish of desired level, since only the proper selection of cutting parameters can produce a better surface finish. In the manufacturing industries, various machining processes are adopted for removing the material from the work piece for a better product. Out of these, end milling process is one of the most vital and common metal cutting operations used for machining parts because of its ability to remove materials faster with a reasonably good surface quality. In recent times, Computer Numerically Controlled (CNC) machine tools have been implemented to utilize full automation in milling, since they provide greater improvements in productivity, increase the quality of the machined parts and require less operator input.

While using the Coordinate Measuring Machine (CMM), the inspection of dimensional errors is relatively easy and reliable, whereas the *form errors* are more difficult to measure and quantify. Of the several types of form tolerances, the flatness tolerance finds a large instance of usage by designers and hence is taken up for study in this paper.The step-by-step procedure has been presented in the work flow diagram as shown in figure 1.

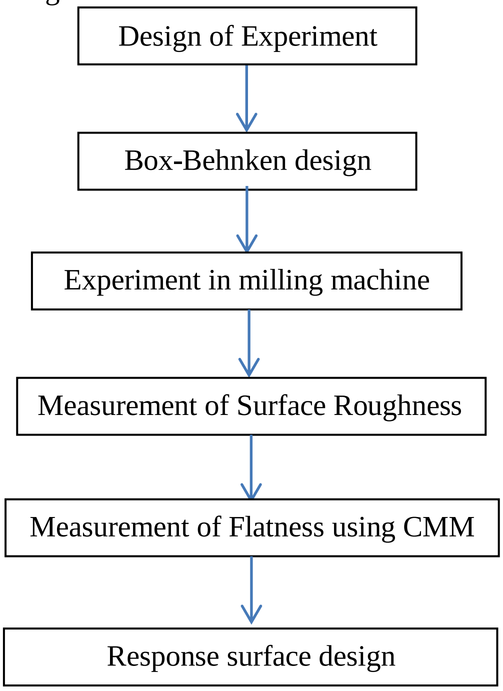

Figure 1. Work Flow Diagram

This paper has been organized as mentioned below. Introduction to the present work has been presented in section (1), and a brief review of literature on surface roughness modelling in milling is presented in section (2). In section (3), the methodology used for mathematical modelling, formulation of empirical relation has been presented. The experimental procedure had been presented in brief in section (4). The results obtained are presented and discussed in section (5) and the conclusions with scope of future work are presented in sections (6) and (7) respectively.

II. REVIEW OF LITERATURE

Surface roughness and dimensional accuracy have been important factors in predicting the machining performances of any machining operation. Kline et al.[1] investigated the effect of vibration, deflection and chatter of the tool-work system on roughness in end milling. Alauddin et al.[2] developed a mathematical model of surface roughness for end milling of Aluminium material considering only the centre line average (CLA) roughness parameter (Ra) in terms of cutting speed, feed rate and depth of cut using response surface method (RSM). Fuht and Wu [3] studied using RSM the influence of tool geometries (nose radius and flank width) and cutting parameters (cutting speed, feed rate, depth of cut) on surface roughness in end milling of Aluminium material. Kadirgama et al**.** [4], presented optimum surface roughness by using milling mould aluminium alloys (AA6061-T6) with Response Ant Colony Optimization (RACO). Weon-Seok and Raman [5], done a experiment the efficiency of sampling strategy relevant to the CMM probe path, two experimental objectives were considered. The first objective sought to evaluate the model of the sampling strategy for minimising the sample size. The second objective was to investigate alternative optimisation models for minimizing the CMM probe path.

III. METHODOLOGY

In this work, mathematical models have been developed using experimental results with the help of response surface methodology. The purpose of developing mathematical models relating the machining responses and their factors is to facilitate the optimization of the machining process. The mathematical model has been used as an objective function and the optimization was carried out with the help of Response surface methodology.

3.1. Mathematical formulation

Response Surface methodology (RSM) is a combination of mathematical and statistical techniques useful for modelling and analyzing the problems in which several independent variables influence a dependent variable or response. The mathematical models commonly used are represented by.

$$Y = \phi (N, f, d) + \varepsilon \qquad \text{............(1)}$$

Where, Y is the machining response, φ is the response function and N, f and d are milling variables and ε is the error which is normally distributed about the observed response Y with zero mean. The relationship between surface roughness and other independent variables can be represented as follows.

$$R_a = C\, N^a f^b d^c \qquad \text{............ (2)}$$

Where, C is a constant and a, b and c are exponents. To facilitate the determination of constants and exponents, the mathematical model will have to be linearized by performing a logarithmic transformation as follows.

$$\ln R_a = \ln C + a\ln N + b\ln f + c\ln d \qquad \text{............(3)}$$

The constants and exponents C, a, b and c can be determined by the method of least squares. The first order linear model, developed from the above functional relationship using least squares method, can be represented as follows.

$$Y_1 = Y - \varepsilon = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 \qquad \text{............(4)}$$

where Y_1 is the estimated response based on the first-order equation, Y is the measured surface roughness on a logarithmic scale, $x_0 = 1$, x_1, x_2 and x_3 are logarithmic transformations of cutting speed, feed rate and depth of cut respectively, ε is the experimental error and b values are the estimates of corresponding parameters.

The general second order polynomial response is as given below:

$$Y_2 = Y - \varepsilon = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 \qquad \text{............(5)}$$

Where, Y_2 is the estimated response based on the second order equation. The parameters b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33} are to be estimated by the method of least squares.

3.2. Surface Finish in End milling operations

The basic geometry of the end milling process is shown in Figure 2. And the factors influencing surface finish in end milling process is as shown in figure 3.

Where,

- v = cutting speed (peripheral) of the cutter (m/min)
- D = diameter of the cutter (mm)
- N_s = rotational speed of the cutter (rev/min)
- f_z = feed per tooth (mm/tooth)
- f_m = feed per minute (mm/min) or table speed (= f_z x z x N_s)
- z = number of teeth in the cutter
- a_a = axial depth of cut (mm)
- a_r = radial depth (width) of cut (mm).

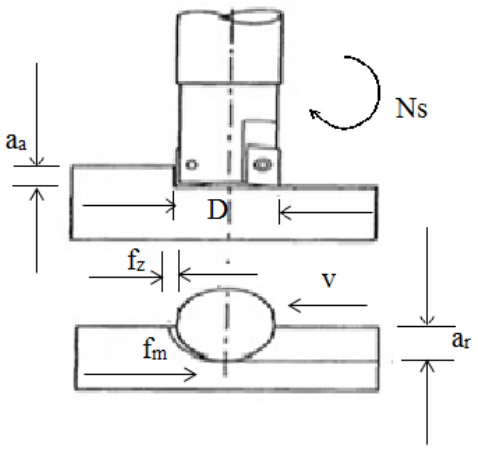

Figure 2.End Milling Process

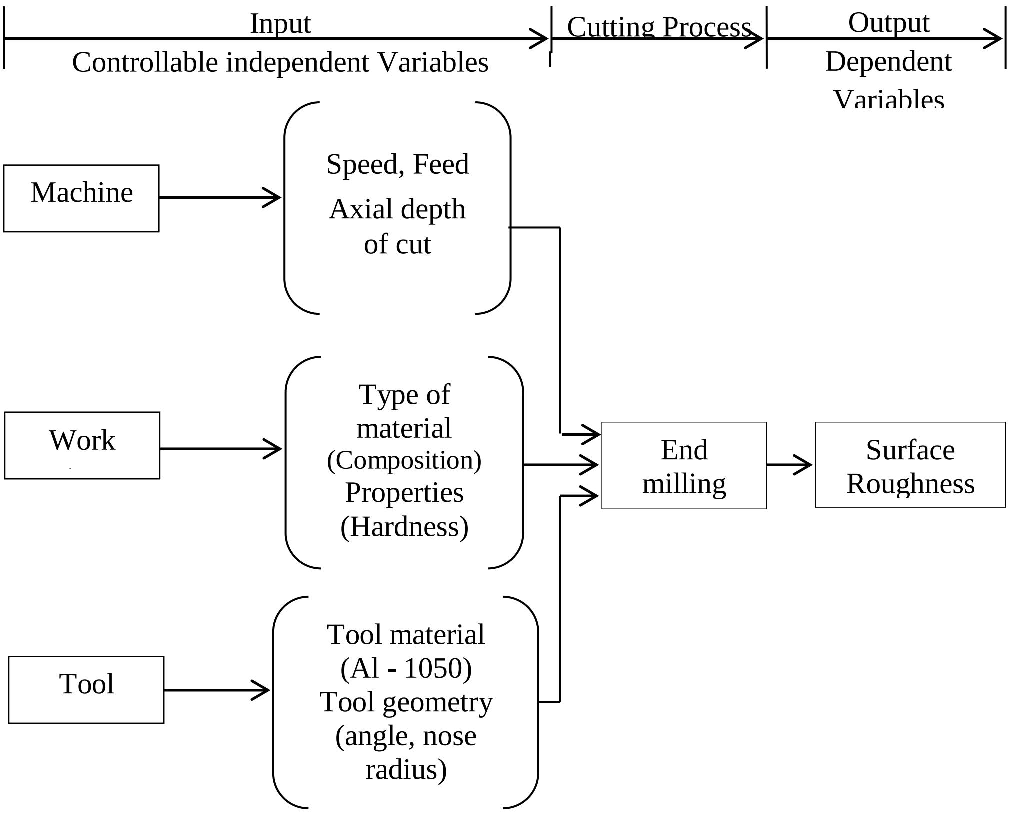

Figure 3. Factors influencing surface finish in End milling processes

IV. EXPERIMENTAL PROCEDURE

4.1. Design of experiment

The design of experiments technique is an important tool, which permits us to carry out the modelling and analysis of the influence of process variables on the response variable. The response variable is an unknown function of the process variables, which are known as design factors. There are a large number of parameters that can be considered for machining of a particular material in end milling. In the present study most widely used machining parameters such as cutting speed, feed rate and depth of cut are considered as design factors. The range of values of each factor was set at three different levels as shown in Table 1. A full factorial design is used to design factors so that all the interactions between the response variable and process variables can be investigated. For three factors number of experiments is 15. Combination of different parameters are shown in Table 2.

Table 1. Process variables used in the experimentation

S. No	Parameter	Unit	Level-1	Level-2	Level-3
1	Cutting Speed	rpm	500	1000	1500
2	Feed rate	mm/rev	50	60	70
3	Depth of cut	mm	0.5	1.0	1.5

Table 2. Combination of Process Parameters

Std Order	Run Order	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	1	500	50	1.0
7	2	500	60	1.5
8	3	1500	60	1.5
6	4	1500	60	0.5
15	5	1000	60	1.0
9	6	1000	50	0.5
11	7	1000	50	1.5
10	8	1000	70	0.5
4	9	1500	70	1.0
5	10	500	60	0.5
14	11	1000	60	1.0
12	12	1000	70	1.5
2	13	1500	50	1.0
3	14	500	70	1.0
13	15	1000	60	1.0

4.2. Work piece material

Aluminium 1050 specimens of 100 × 50 mm and 19 mm thickness were used in the present study. The workpiece material is mounted onto the machine table to provide maximum rigidity. The workpiece material is parallel to the machine table and perpendicular to the machine's spindle head. The experiment was performed by using 12 mm End milling cutter in milling and measurement of flatness in CMM. The chemical composition of specimens is presented in Table 3.

Table 3. Chemical Composition of AA1050

Si	Cu	Mg	Zn	Mn	Ti	V	Fe	Al
0.25	0.05	0.03	0.05	0.03	0.03	0.05	0.4	99.50

4.3. Equipment and cutting tools used

The work piece material is mounted on to the machine table to provide maximum rigidity. The workpiece material is parallel to the machine table and perpendicular to the machine's spindle head. The experiment was performed by using 12 mm End milling cutter in milling and measurement of flatness in CMM. The machine used for the milling tests is a LV 45 A40 CNC vertical milling centre with 15 KVA driver motor as shown in Figure 4. For generating the milled surfaces, CNC part programs for tool paths were created with specific commands. The experimentation was carried out with end mill cutters (12 mm diameter) of HSS and coated carbide manufactured by Mirinda and Sandvik respectively. Machining was conducted as recommended by Box-Behnken design in Table 2. The surface roughness (response) was measured by using a portable surface roughness tester (TR 200) as shown in Figure 5. An average of three measurements was used as a response value. Flatness obtained on the surfaces during the 15 experiments were measured using Coordinate measuring machine (CALYPSO G2) as shown in Figure 6. The measured surface roughness and flatness values are presented in Table 4. Using these responses optimized response surfaces are generated for further discussion.

Figure 4. Experimental Work onCNC Vertical Milling Machine

Figure 5. Measurement of Surface Roughness Using Surface Roughness Tester (TR 200)

Table 4. Combination of Process Parameters and Responses

Std Order	Run Order	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Surface Roughness (µm)	Flatness (µm)
1	1	500	50	1.0	1.207	0.0610
7	2	500	60	1.5	4.326	0.0624
8	3	1500	60	1.5	4.024	0.0698
6	4	1500	60	0.5	1.022	0.0577
15	5	1000	60	1.0	3.489	0.0573
9	6	1000	50	0.5	1.327	0.0537
11	7	1000	50	1.5	2.236	0.0598
10	8	1000	70	0.5	2.368	0.0596
4	9	1500	70	1.0	4.128	0.0644
5	10	500	60	0.5	1.353	0.0617
14	11	1000	60	1.0	3.257	0.0527
12	12	1000	70	1.5	4.024	0.0546
2	13	1500	50	1.0	0.634	0.0491
3	14	500	70	1.0	4.498	0.0518
13	15	1000	60	1.0	3.368	0.0561

Figure 6. Measurement of Flatness Using Coordinate Measuring Machine

V. RESULTS AND DISCUSSION

5.1. Surface Roughness

The influences of cutting speed, feed rate and depth of cut have been assessed by conducting experiments. The variation of experimental R_a values for varying Feed rate and Depth of cut is shown in Figure 7. At constant cutting speed of 1000 rpm, increases in Feed rate causes non uniform variation in roughness values. For lower depth of cut the roughness values increases from 1.327 to 2.368, but in-between maximum roughness is achieved. For higher depth of cut (1.5 mm) increase in roughness value is very near to linear pattern. At lower feed rates (50 mm/rev) when the depth of cut is increased, near linear is increases in roughness values is obtain. With high feed rate (70 mm/rev) higher variation is observed in the roughness value. Higher depth of cut and higher feed rate leaves at very rough surface.

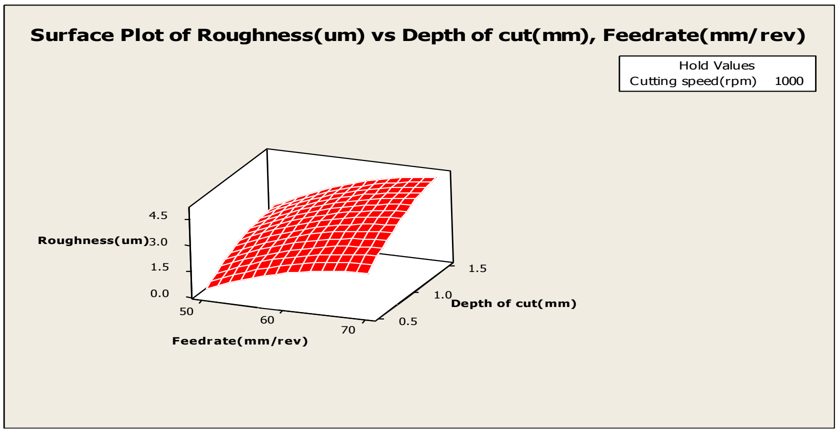

Figure 7. Surface Roughness vs Depth of Cut, Feed Rate

In Figure 8. the relation between Cutting speed, Feed rate and Surface roughness is illustrated. It is observed that high Feed rate induces high R_a value, whether Cutting speed is low or high. Where as minimum R_a value is observed with the constant Cutting speed 1500 rpm and feed rate 50 mm/rev. But influence of feed rate is seen as high significant factors.

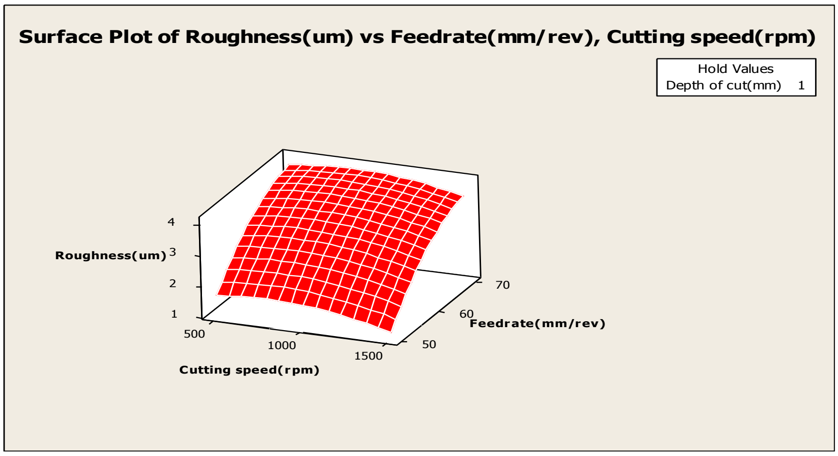

Figure 8.Surface Roughness vs Feed Rate, Cutting Speed

In Figure 9, the relation between Cutting speed, Depth of cut and Surface roughness is illustrated. It is observed high depth of cut causes high R_a value, whether Cutting speed is low or high. Where as minimum R_a value is observed with the constant cutting speed 1500 rpm and depth of cut 0.5mm. In both the cases (Figure 8 & 9) effect of cutting speed is seen as in significant factors. Linear relationship between Feed rate vs roughness and Depth of cut vs roughness is observed.

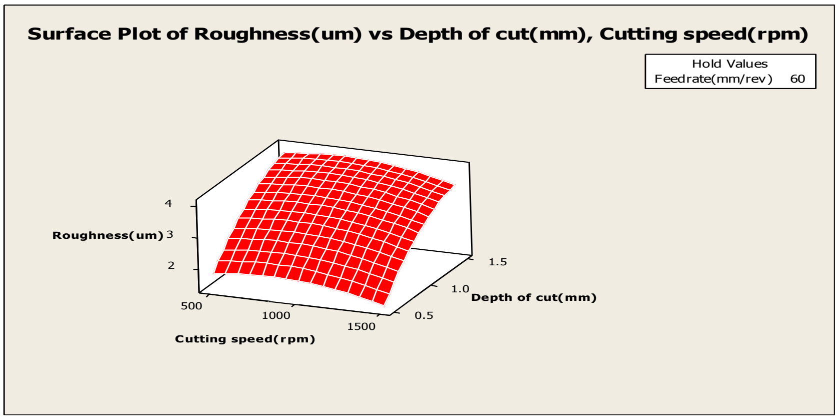

Figure 9. Surface Roughness vs Depth of Cut, Cutting Speed

5.2. Flatness

In Figure 10. At constant Cutting speed of 1000 rpm, increases in Feed rate increases the Flatness value to 0.0596 µm. With the same Feed rate when Depth of cut is increased the Flatness value reaches 0.0546 µm. At lower depth of cut, flatness increase from lower value, where as at higher depth of cut, flatness decreases from higher value. When feed rate is increased. Comparing Figures (7 & 10) it is observed at low depth of cut, roughness and flatness act in different ways. At high depth of cut and feed rate, roughness values is maximum, where as flatness value is minimum.

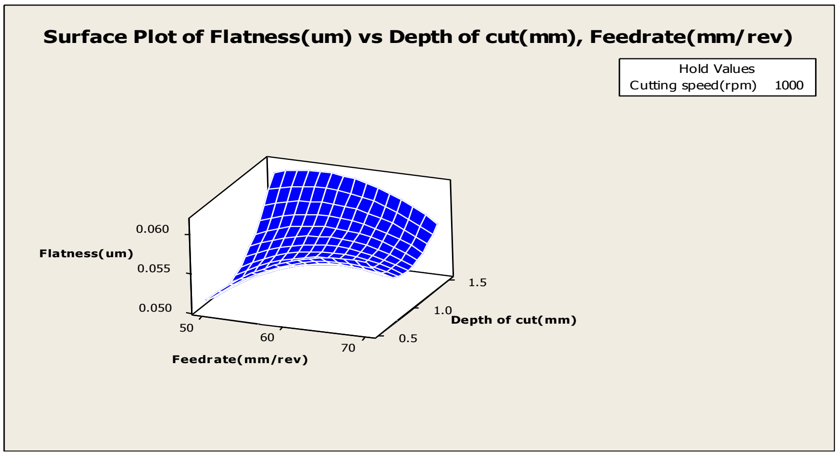

Figure 10. Flatness vs Depth of Cut, Feed Rate

In Figure 11, the relation between Cutting speed, Feed rate and Flatness is illustrated. Higher flatness values are observed with the following combinations low cutting speed and low feed rate, high cutting speed and high feed rate.

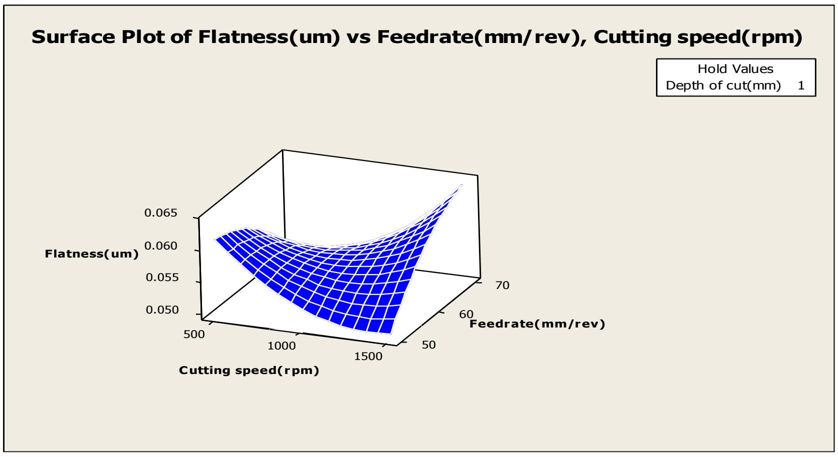

Figure 11. Flatness vs Feed Rate, Cutting Speed

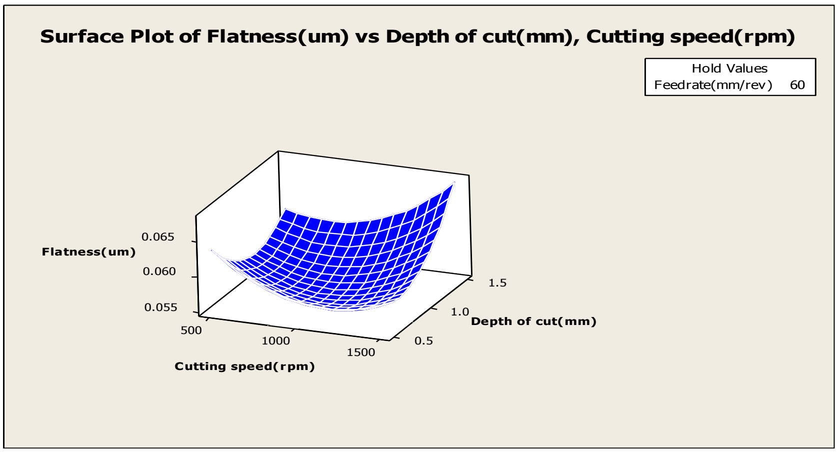

Figure 12. Flatness vs Depth of Cut, Cutting Speed

In Figure 12, the relation between Cutting speed, Depth of cut and Flatness is illustrated. It is observed high Depth of cut causes high Flatness value, whether Cutting speed is low or high. Where as minimum Flatness value is observed with the constant Cutting speed 1500 rpm and Depth of cut

0.5 mm. Also it is observed that flatness value is minimum, when the cutting speed and depth of cut are at mid values (1000 rpm and 1 mm respectively).

The Response surface regression for surface roughness is given by:

$$R_a=-22.5090+0.0012x_1+0.6409x_2+3.1373x_3-0.0000x_1^2-0.0047x_2^2-1.362x_3^2+0.000x_1x_2+0.000x_1x_3+0.0373x_2x_3 \quad \ldots\ldots\ldots\ldots (6)$$

The Response surface regression for Flatness is given by:

$$F=0.041700-0.00013x_1+0.002275x_2-0.006158x_3+0.0000x_1^2-0.000024x_2^2+0.015767x_3^2+0.000001x_1x_2+0.000011x_1x_3-0.000555x_2x_3 \quad \ldots\ldots (7)$$

Where,

x_1= Cutting speed (rpm)
x_2= Feed rate (mm/rev)
x_3= Depth of cut (mm)

5.3. Comparison of Surface Roughness and Flatness

For cutting speed of 1000 rpm at lower depth of cut (0.5 mm) variation in feed rate causes increase in roughness value and flatness, But at higher depth of cut variation in feed rate causes increase in roughness and decrease in flatness. Maximum flatness values are observed, when the roughness value is low and minimum flatness value is observed, when roughness is high as shown in Figures 7 and 10.

For depth of cut 1 mm at lower feed rate 50 mm/rev variation in cutting speed causes increase in roughness value and flatness. But at higher feed rate causes increase in roughness and decrease in flatness, Minimum flatness value is observed, when roughness value is high it is observed in Figures 8 and 11.

When the cutting speed and depth of cut at constant feed rate 60 mm/rev at lower depth of cut 0.5 mm variation in cutting speed causes increase in roughness value and flatness. Where as minimum flatness value is observed with the high cutting speed 1500 rpm and depth of cut 0.5 mm the roughness value reaches 1.022 µm and flatness value is 0.0577 µm. Maximum flatness values are observed, when the roughness value is low it is observed in Figures 9 and 12.

VI. CONCLUSION

Surface milling was done on Aluminium 1050 work piece using CNC machine. Three milling parameters namely cutting speed, feed rate and depth of cut were considered for the study. Using Box-Behnken design for combination of parameters was considered and experiments were conducted. Surface roughness and flatness were measured and using response surface methodology empirical relation for roughness and flatness were obtained. Based on the work the following conclusions are arrived at.

1. The predicted surface roughness from the model is compared to the values measured experimentally.
2. The feed rate is a dominant parameter and the surface roughness increases rapidly with the increase in feed rate and decreases with increase in cutting speed, where as the effect of depth of cut is not regular.
3. This technique can produce accurate relationship between machining parameters and surface roughness.
4. In case of flatness significant changes are caused by depth of cut.
5. Maximum flatness values are observed, when the roughness value is low and minimum flatness value is observed, when roughness is high.

VII. SCOPE OF FUTURE WORK

In this paper, the effect of only three cutting parameters has been considered. Further study is possible in the following cases:

i) Same study can be extended to other machine tools.
ii) Considering more cutting parameters on the same machine tool.
iii) Considering more cutting parameters on the different machine tools.
iv) Considering various work piece materials.

v) Considering various work piece materials.
vi) Considering various combinations of work piece materials and different cutting parameters.
vii) To develop mathematical models for surface roughness and flatness by using design of experiments.

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