# Experimental Investigation on the Influence of Machining Parameters using Response Surface Methodology (RSM)

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***Abstract***

*The present work is to study the influence of turning process parameters on the multiple responses. For the present study medium carbon steel EN8 is considered as the work piece and the process parameters of speed, feed and depth of cut are taken as the controllable parameters at three different levels. Response surface methodology (RSM) along with Analysis of variance (ANOVA) is employed to find the influence of parameters on the various performance characteristics such as surface roughness ($R_a$), mean cutting force ($F_m$) and specific cutting forces ($K_s$). The results concluded that the feed is the most influencing factor for both surface roughness and specific cutting force where as depth of cut is for mean cutting force.*

**Keywords** - *Surface roughness ($R_a$), Mean cutting force ($F_m$), Specific cutting force ($K_s$), RSM and ANOVA.*

## I. INTRODUCTION

In manufacturing industries, turning is the most commonly used metal removal processes because of its ability to remove unwanted material at faster rate and with a reasonable surface quality. In turning operation, it is a vital task to select the process parameters in order to achieve the desired performance characteristics. In general material removal rate, surface roughness, cutting forces, tool wear etc can be considered as the quality characteristics in turning. Surface roughness is one of the essential quality characteristics in manufacturing industries as it influences the functioning of the machined parts as well as production cost. In actual practice, there are many factors which affect the surface roughness like cutting conditions, tool variables and work piece variables etc. cutting conditions include speed, feed and depth of cut where as tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle etc. work piece variables include material hardness and other mechanical properties. Generally, the selection of cutting parameters is based on experience or by hand book usage. But better results can be achieved by modeling the output characteristics and optimization of cutting parameters. There are several mathematical models based on statistical regression techniques have been constructed to establish the relationship between the performances and the cutting parameters.

Response surface method (RSM) adopts both mathematical and statistical techniques which are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables. RSM attempts to analyze the influence of the independent variables on a specific dependent variable. The purpose of developing the mathematical models relating the machining responses and their factors is to facilitate the optimization of the machining process. The steps involved on RSM technique are as follows;

1. Designing a set of experiments foe adequate and reliable measurement of the true mean response of interest.
2. Determination of the mathematical model with best fit.
3. Finding the optimum set of experimental factors to produce maximum or minimum of the response.
4. Representing the direct or interactive effects of process variables on the responses.

The mathematical model commonly used for the machining response Y is represented as, $Y = \Psi(d, N, f) + \epsilon$; Where, d, N, f are depth of cut, spindle speed and feed rate respectively and $\epsilon$ is the error which is normally distributed about the observed machining response. The second order polynomial model (Quadratic model) can be expressed as:

$$Y_u = b_0 + \sum_{i=1}^{n} b_i x_{iu} + \sum_{i<j}^{n} b_{ij} x_{iu} x_{ju} + \sum_{i=1}^{n} b_{ii} x_{iu}^2$$

## II. EXPERIMENTATION DETAILS

In the present work, En8 medium carbon steel work pieces in the form of cylindrical shape are taken for the experiments. The chemical composition and mechanical properties of EN8 steel are given in the tables 1 and 2. The control parameters used for the experiment and their levels are given in the table 3. The machining was conducted on turret lathe as per the selected L27 Orthogonal array given in the table 4.

**Table 1. Chemical Composition of EN8 Steel**

| C | Mn | S | P | Si |
|---|---|---|---|---|
| 0.35-0.45 % | 0.6-1 % | 0.06 % | 0.06 % | 0.05-0.35 % |

**Table 2. Mechanical Properties of EN8 Steel**

| Max Stress | Yield Stress | Elongation | Hardness | Impact load |
|---|---|---|---|---|
| 700-850 $N/mm^2$ | 465 $N/mm^2$ | 16 % | 201-255 BHN | 28 J/min |

**Table 3. Process Parameters with Their Levels**

| Parameter | Level-1 | Level-2 | Level-3 |
|---|---|---|---|
| Speed, v (Rpm) | 360 | 560 | 760 |
| Feed, f (mm/Rev) | 0.1 | 0.2 | 0.3 |
| Depth of cut, d (mm) | 0.5 | 1 | 1.5 |

**Table 4. L27 Orthogonal Array**

| S.No. | Speed, Rpm | Feed, mm/rev | Doc, mm |
|---|---|---|---|
| 1 | 360 | 0.1 | 0.5 |
| 2 | 360 | 0.1 | 1 |
| 3 | 360 | 0.1 | 1.5 |
| 4 | 360 | 0.2 | 0.5 |
| 5 | 360 | 0.2 | 1 |
| 6 | 360 | 0.2 | 1.5 |
| 7 | 360 | 0.3 | 0.5 |
| 8 | 360 | 0.3 | 1 |
| 9 | 360 | 0.3 | 1.5 |
| 10 | 560 | 0.1 | 0.5 |
| 11 | 560 | 0.1 | 1 |
| 12 | 560 | 0.1 | 1.5 |
| 13 | 560 | 0.2 | 0.5 |
| 14 | 560 | 0.2 | 1 |
| 15 | 560 | 0.2 | 1.5 |
| 16 | 560 | 0.3 | 0.5 |
| 17 | 560 | 0.3 | 1 |
| 18 | 560 | 0.3 | 1.5 |
| 19 | 760 | 0.1 | 0.5 |
| 20 | 760 | 0.1 | 1 |
| 21 | 760 | 0.1 | 1.5 |
| 22 | 760 | 0.2 | 0.5 |
| 23 | 760 | 0.2 | 1 |
| 24 | 760 | 0.2 | 1.5 |
| 25 | 760 | 0.3 | 0.5 |
| 26 | 760 | 0.3 | 1 |
| 27 | 760 | 0.3 | 1.5 |

## III. EXPERIMENTAL RESULTS & DISCUSSIONS

The output characteristics of surface roughness, mean force and the specific cutting forces are measured and given in the table 5. The three responses are analyzed by using the taguchi's smaller-the-better characteristic.

Smaller-the-better: $S/N = -10 \log (Y_{ij}^2)$

Where S/N is signal-to-noise ratio and $Y_{ij}$ is response.

**Table 5. Experimental Results**

| S.No. | Surface Roughness ($R_a$), µm | Mean cutting Force ($F_m$) | Specific Cutting force ($K_s$) |
|---|---|---|---|
| 1 | 5.00 | 12 | 240 |
| 2 | 5.75 | 19 | 190 |
| 3 | 4.70 | 21 | 140 |
| 4 | 6.10 | 12 | 120 |
| 5 | 6.20 | 19 | 95 |
| 6 | 7.25 | 22 | 73.33 |
| 7 | 9.45 | 16 | 106.66 |
| 8 | 9.00 | 34 | 113.33 |
| 9 | 5.50 | 46 | 102.22 |
| 10 | 5.40 | 8 | 160 |
| 11 | 5.30 | 15 | 150 |
| 12 | 3.80 | 21 | 140 |
| 13 | 5.25 | 9 | 90 |
| 14 | 4.35 | 24 | 120 |
| 15 | 6.85 | 21 | 70 |
| 16 | 9.25 | 18 | 120 |
| 17 | 7.05 | 34 | 113.33 |
| 18 | 4.45 | 36 | 80 |
| 19 | 2.55 | 27 | 540 |
| 20 | 3.75 | 32 | 320 |
| 21 | 7.35 | 43 | 286.66 |
| 22 | 5.20 | 10 | 100 |
| 23 | 3.95 | 16 | 80 |
| 24 | 6.80 | 38 | 126.66 |
| 25 | 7.95 | 53 | 353.33 |
| 26 | 6.85 | 20 | 66.66 |
| 27 | 3.45 | 51 | 113.33 |

### *A. RSM results*

For the analysis of results, response surface methodology (RSM) and ANOVA are employed. The multiple regression equations for the individual responses are generated using MINITAB-17 software.

$R_a$ = 3.44 - 0.0093 s +40.9 f + 1.54 d + 0.000005 s*s + 14.7 f*f + 0.42 d*d – 0.0163 s*f + 0.00417 s*d – 26.92 f*d

$F_m$ = 58.1 – 0.136 s – 265 f – 1.4 d + 0.000165 s*s + 911 f*f + 8.4 d*d – 0.092 s*f – 0.0058 s*d + 13.3 f*d

$K_s$ = 741 – 0.889 s – 3373 f – 167 d + 0.001501 s *s + 8809 f*f + 103 d*d – 1.52 s*f – 0.263 s*d + 148 f*d

The analysis of variance is employed at 95% of confidence level to find the influence of the process parameters and their interactions affects on the individual performance characteristics. The ANOVA results of surface roughness, mean force and secific cutting forces are given in the tables 6, 7 and 8. From the results of table 6 ($R_a$), it is observed that feed interaction with depth of cut (f*d) and feed has the highest influence on the surface roughness.

**Table 6. ANOVA of $R_a$**

| Source | DF | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|
| Model | 9 | 55.1433 | 6.1270 | 3.59 | 0.011 |
| Linear | 3 | 29.6463 | 9.8821 | 5.80 | 0.006 |
| s | 1 | 6.8450 | 6.8450 | 4.01 | 0.061 |
| f | 1 | 20.8013 | 20.8013 | 12.20 | 0.003 |
| d | 1 | 2.0000 | 2.0000 | 1.17 | 0.294 |
| Square | 3 | 0.4110 | 0.1370 | 0.08 | 0.970 |
| s*s | 1 | 0.2141 | 0.2141 | 0.13 | 0.727 |
| f*f | 1 | 0.1300 | 0.1300 | 0.08 | 0.786 |
| d*d | 1 | 0.0669 | 0.0669 | 0.04 | 0.845 |
| 2-way interactions | 3 | 25.0860 | 8.3620 | 4.90 | 0.012 |
| s*f | 1 | 1.2675 | 1.2675 | 0.74 | 0.401 |
| s*d | 1 | 2.0833 | 2.0833 | 1.22 | 0.284 |
| f*d | 1 | 21.7352 | 21.7352 | 12.75 | 0.002 |
| Error | 17 | 28.9830 | 1.7049 | | |
| Total | 26 | 84.1263 | | | |

From the ANOVA results of mean force, it is observed that depth of cut has highest influence and followed by feed and speed; very limited interaction effects were observed. Similarly, the interaction effect of feed*feed and feed are the highest influencing factors for specific cutting force.

***Table 7. ANOVA of $F_m$***

| Source | DF | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|
| Model | 9 | 2946.64 | 327.404 | 4.10 | 0.006 |
| Linear | 3 | 2109.83 | 703.278 | 8.81 | 0.001 |
| s | 1 | 440.06 | 440.056 | 5.51 | 0.031 |
| f | 1 | 672.22 | 672.222 | 8.42 | 0.010 |
| d | 1 | 997.56 | 997.556 | 12.5 | 0.003 |
| Square | 3 | 787.06 | 262.352 | 3.29 | 0.046 |
| s*s | 1 | 262.24 | 262.241 | 3.28 | 0.088 |
| f*f | 1 | 498.07 | 498.074 | 6.24 | 0.023 |
| d*d | 1 | 26.74 | 26.741 | 0.33 | 0.570 |
| 2-way interactions | 3 | 49.75 | 16.583 | 0.21 | 0.890 |
| s*f | 1 | 40.33 | 40.333 | 0.51 | 0.487 |
| s*d | 1 | 4.08 | 4.083 | 0.05 | 0.824 |
| f*d | 1 | 5.33 | 5.333 | 0.07 | 0.799 |
| Error | 17 | 1357.21 | 79.836 | | |
| Total | 26 | 4303.85 | | | |

**Table 8. ANOVA of $K_s$**

| Source | DF | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|
| Model | 9 | 210744 | 23415.9 | 4.48 | 0.004 |
| Linear | 3 | 118462 | 39487.3 | 7.55 | 0.002 |
| s | 1 | 36100 | 36099.8 | 6.90 | 0.018 |
| f | 1 | 55311 | 55311.4 | 10.58 | 0.005 |
| d | 1 | 27051 | 27050.6 | 5.17 | 0.036 |
| Square | 3 | 72189 | 24062.9 | 4.60 | 0.016 |
| s*s | 1 | 21621 | 21620.8 | 4.13 | 0.058 |
| f*f | 1 | 46554 | 46554.4 | 8.90 | 0.008 |
| d*d | 1 | 4014 | 4013.6 | 0.77 | 0.393 |
| 2-way interactions | 3 | 20093 | 6697.6 | 1.28 | 0.313 |
| s*f | 1 | 11136 | 11135.6 | 2.13 | 0.163 |
| s*d | 1 | 8299 | 8298.7 | 1.59 | 0.225 |
| f*d | 1 | 659 | 658.6 | 0.13 | 0.727 |
| Error | 17 | 88910 | 5230.0 | | |
| Total | 26 | 299654 | | | |

Figures 1, 2 and 3 shows the residual plots for surface roughness, mean force and specific cutting force respecively. From the figures, it is found that the models prepared for the responses are best fit as the residuals are falling on the straight line in normal probability plot and they are not representing any regular patterens in versus fits and order plots.

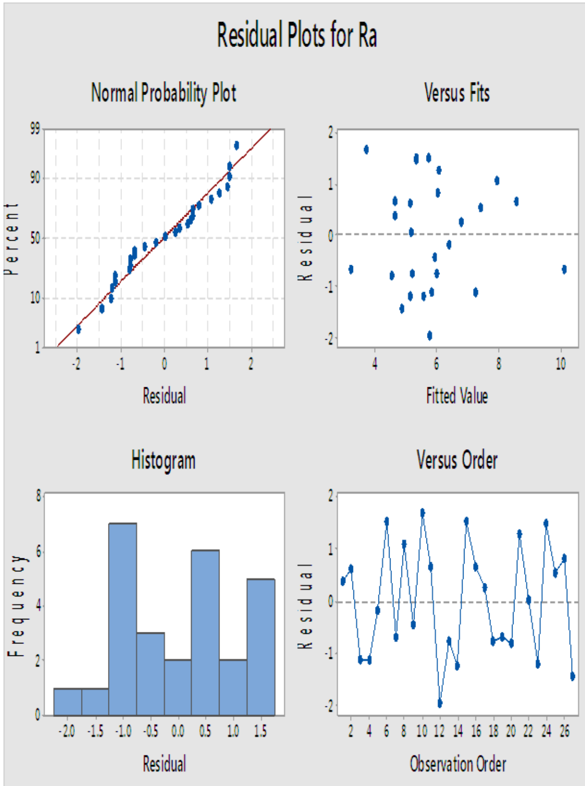


**Figure 1. Residual Plots for Ra**

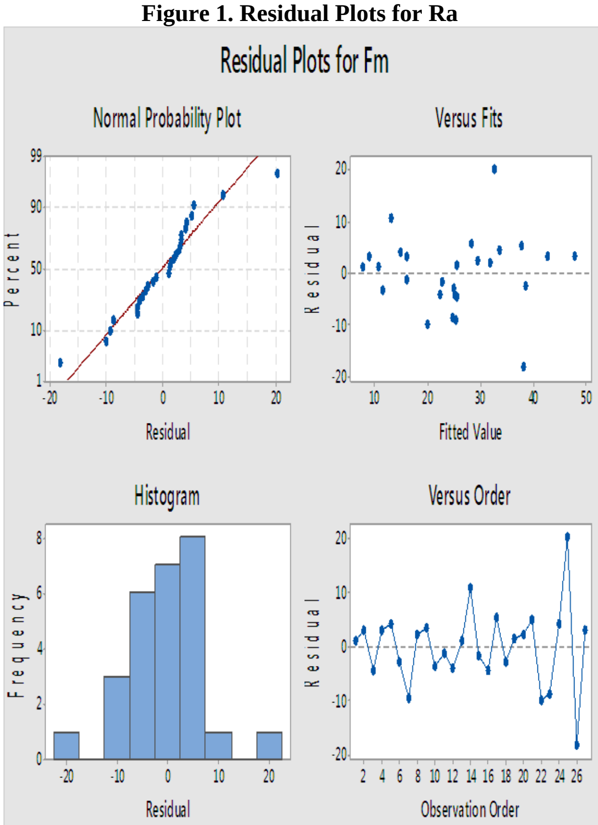


**Figure 2. Residual Plots for Fm**

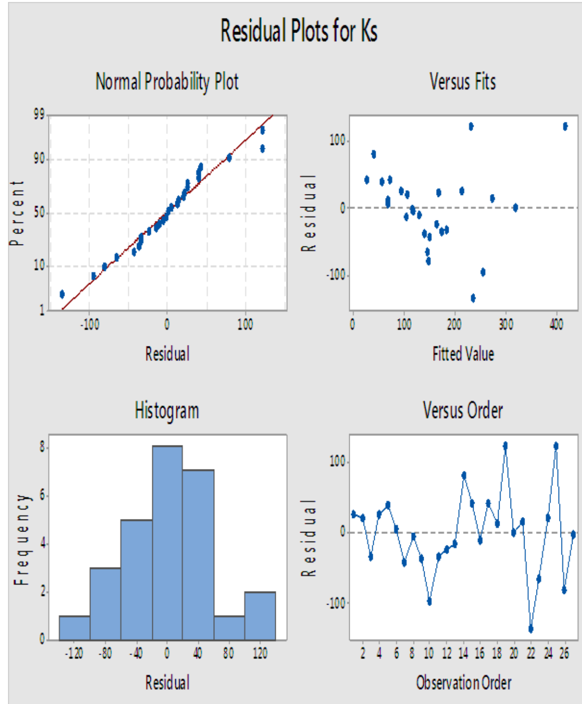


**Figure 3. Residual Plots for Ks**

## IV. CONCLUSIONS

From the experimental and response surface methodology the following conclusions can be drawn:

1. Feed is the most influencing factor for the surface roughness and specific cutting force.
2. Depth of cut is the most influencing factor for the mean cutting force.
3. The interaction effect of feed*depth of cut is observed and it has high contribution on surface roughness.
4. For the mean cutting force there is very less interactions effects are observed among the process parameters.
5. The interaction effect of feed*feed is observed and it has high contribution on specific cutting force.
6. The regression models prepared for the responses are best fit as they following the normality as well as the constant variance assumptions of ANOVA.
7. The regression models can be used effectively for the best prediction of the performance characteristics.

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