iJRASET
International Journal For Research in
Applied Science and Engineering Technology

# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 6 **Issue:** IV **Month of publication:** April 2018

**DOI:** http://doi.org/10.22214/ijraset.2018.4078

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue IV, April 2018- Available at www.ijraset.com

# Experimental Study of Induced Vibration & Work Surface Roughness in the Turning of Mild Steel in Belt Operated Lathe using Factorial Design of Experiments

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***Abstract: This study investigates experimentally the relationship between induced vibration and surface roughness, with the machining parameters in turning of mild or low carbon steel in a Belt operated lathe, using factorial design of experiments. The levels of process cutting parameters in the study are limited to the following data; Depth of cut (1.0, 1.5 mm), cutting speed (300, 400 rpm), Work piece overhang (25, 35 mm), Tool overhang (20, 25 mm). The data are generated by lathe turning of mild steel samples at different levels of lower and higher. The study have quantitatively examined relationship between the machining parameters and the Responses of the experiments. In case of both the Responses (Vibration and Surface roughness), Spindles speed factor seems to have a higher impact. Work piece overhang's effect, even though negligible, becomes important due to its interaction with other parameters. The data obtained can be found relevant in optimizing the machining operations on Belt operated lathes.***

***Keywords: induced vibration, work surface roughness, quality of the product.***

## I. INTRODUCTION

The problem of stability in the machining processes is an important task. In the turning operation, vibration is a frequent problem, which affects the result of the machining, and, in particular, the surface finish. Tool life is also influenced by vibration. Severe acoustic noise in the working environment frequently occurs as a result of dynamic motion between the cutting tool and the work piece. In all cutting operations like turning, boring and milling, vibrations are induced due to the deformation of the work-piece. This implies several disadvantages, economical as well as environmental. Today, one of the standard procedures to avoid vibration during machining is by careful planning of the cutting parameters. The methods are usually based on experience, and trial and error to obtain suitable cutting data for each cutting operation involved in machining a product. Machining vibration exists throughout the cutting process. However, at least two types of vibrations, forced vibration and self-excited vibration, were identified as machining vibrations. Forced vibration is a result of certain periodical forces that exist within the machine. The source of these forces can be bad gear drives, unbalanced machine-tool components, misalignment of motors and pumps, etc. Self-excited vibration or self induced vibration, which is also known as chatter, is caused by the interaction of the chip removal process and the structure of the machine tool, which results in disturbances in the cutting zone. A large number of theoretical and experimental studies on surface roughness of machined products have been reviewed where cutting conditions (such as cutting speed, feed rate, depth of cut, tool geometry, and the material properties of both the tool and work piece) significantly influence surface finish of the machined parts. In machining operation, the quality of surface finish is an important requirement for many turned work pieces.

The purpose of this paper is to investigate experimentally the effects of induced tool vibration on the resulting surface roughness (response) in lathe turning operation of mild steel as a function of depth of cut, cutting speed and tool Over hang (input factors), using response surface Methodology (RSM).

## II. MATERIALS AND METHOD

### *A. Materials and Equipment*

Materials and equipment used in the experimental procedure of this investigation are, the work piece material type Mild or Low carbon steel round bar of 25Ø x 50 mm with the following specifications: (UTS = 540MPa, BHN = 120HB and Chemical composition of 0.55% - 0.95% C, 0.6% 1.65% Mn) [Fig 1a]; Lathe machine with carbide (F30 Type) cutting tool of the dimension

(86x25x25mm) type (HSS)[Fig 1b]; A Vibration Meter VM6360 series type measurement devise [Fig 1c]; and A Surface Roughness Tester, TR110 type, 100 series instrument [Fig 1d].


(a) Mild Steel Work pieces

(b) Lathe Machine


(c) Vibro Meter VM6360 series


(d) Surface Roughness Tester 100 series

Fig 1: Material and equipment used

### *B. Induced Machining Vibration*

Self-excited vibration or self- induced vibration, which is also known as chatter, is the basis under consideration which is caused by the interaction of the chip removal process and the structure of the machine tool, that results in disturbances in the cutting zone. Chatter always indicates defects on the machined surface; vibration especially self-excited vibration is associated with the machined surface roughness. A Vibration Meter measurement device (Fig 1c) was used for measuring the vibration acceleration of a point on the cutting tool. The data includes acceleration of the indicated point on the tool for each sample.

### *C. Work Surface Roughness*

An inside surface Roughness tester, TR110 type instrument (Fig 1d) was used for the measurement of surface roughness. Three different positions for each sample at 120º with each other and the average of the three reading are considered as surface texture of the turned surface.

### *D. Response Surface Method*

A Fourth-order composite factorial design was chosen, so that different interactions between independent variables could be effectively investigated. The independent variables in the study are depth of cut, cutting speed, work piece overhang and the tool overhang. The dependent variables are the resulting first cut surface finish and the acceleration in feed directions. The levels of the constant parameters are given in Table 1.These levels were selected in order to cover the normal range of lathe cutting operations for an alloy steel. In order to minimize the effect of tool wear, which could affect the surface roughness quality, the tool was changed after 4 cuts. The newly installed tool was run for a few machining times to eliminate rapid tool wear.

Table1: Levels of parameters are shown below-

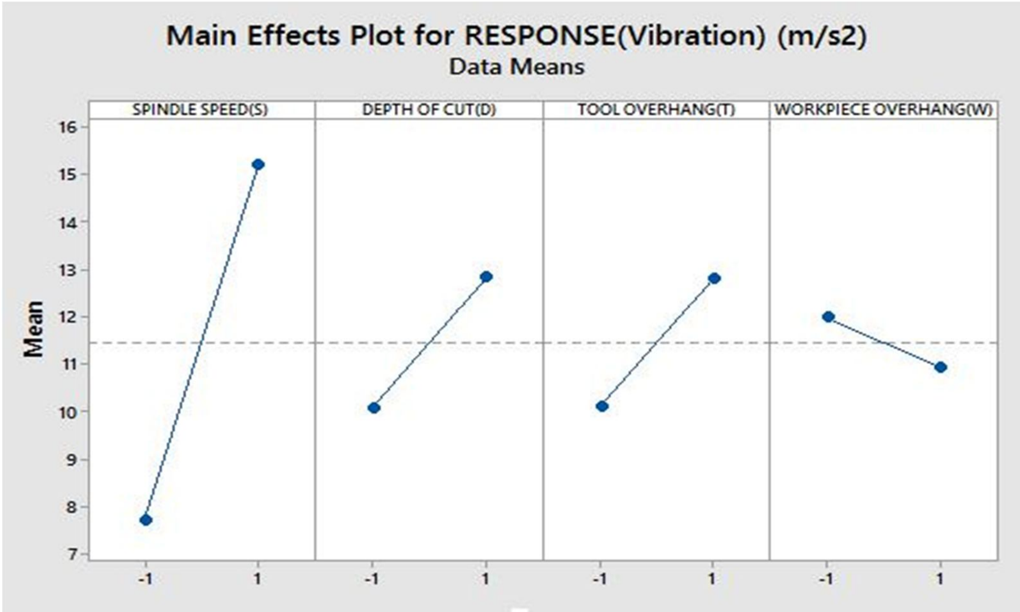
| Factors | Level | Value |
|---|---|---|
| Depth of cut | Lower(-1) | 1.00mm |
| | Higher(+1) | 1.50mm |
| Spindle Speed | Lower(-1) | 300rpm |
| | Higher(+1) | 400rpm |
| Work piece overhang | Lower(-1) | 25mm |
| | Higher(+1) | 35mm |
| Tool overhang | Lower(-1) | 20mm |
| | Higher(+1) | 25mm |

## III. RESULTS AND DISCUSSION

The induced vibration acceleration and surface quality data obtained using Response Surface Methodology of the forth Order Composite Factorial Design are given in Table 2. The design of experiment took into consideration 16 experimental runs consisting of two levels (lower, higher) of the following independent variables: Depth of cut (1.0,1.5mm),cutting speed (300,400 rpm), tool overhanging (20,25mm) and Work piece overhanging (25,35mm) (Table 1) while feed rate
(7mm/min) is kept constant. The observation for fourth order composite factorial design are given in below table:

Table 2 : Fourth order composite factorial design.

| Standard order | Actual order | Spindle Speed | Depth of cut | Tool overhang | Work piece overhang | Vibration Acceleration($m/s^2$) | Surface Roughness (Ra value in mm) |
|---|---|---|---|---|---|---|---|
| 1 | 6 | -1 | -1 | -1 | -1 | 4.489 | 1.404 |
| 2 | 5 | 1 | -1 | -1 | -1 | 12.494 | 0.562 |
| 3 | 2 | -1 | 1 | -1 | -1 | 6.635 | 1.287 |
| 4 | 8 | 1 | 1 | -1 | -1 | 17.983 | 0.234 |
| 5 | 15 | -1 | -1 | 1 | -1 | 13.264 | 0.515 |
| 6 | 13 | 1 | -1 | 1 | -1 | 17.42 | 0.301 |
| 7 | 1 | -1 | 1 | 1 | -1 | 9.083 | 0.649 |
| 8 | 7 | 1 | 1 | 1 | -1 | 14.323 | 0.312 |
| 9 | 3 | -1 | -1 | -1 | 1 | 3.269 | 1.755 |
| 10 | 4 | 1 | -1 | -1 | 1 | 7.949 | 0.809 |
| 11 | 9 | -1 | 1 | -1 | 1 | 9.373 | 0.639 |
| 12 | 11 | 1 | 1 | -1 | 1 | 18.638 | 0.218 |
| 13 | 14 | -1 | -1 | 1 | 1 | 7.869 | 0.842 |
| 14 | 16 | 1 | -1 | 1 | 1 | 13.824 | 0.466 |
| 15 | 10 | -1 | 1 | 1 | 1 | 7.683 | 0.899 |
| 16 | 12 | 1 | 1 | 1 | 1 | 18.768 | 0.208 |




Analysis of the data from table 2 gave rise to the prediction equations for induced vibration and surface roughness given, respectively, as:

For Vibration Measurement:

Y = 11.4415+(3.7334*S)+1.3693*D)+(1.3378*T)-(0.5199*W)+(0.8839*S*D)-(0.4289*S*T)-(1.6842*D*T)+(0.1398*S*W)+(1.3246*D*W)-(0.2234*T*W)
(0.1071*S*D*T)+(0.3305*S*D*W)+(0.8158*S*T*W)+(0.1799*D*T*W)+(0.1753*S*D*T*W)

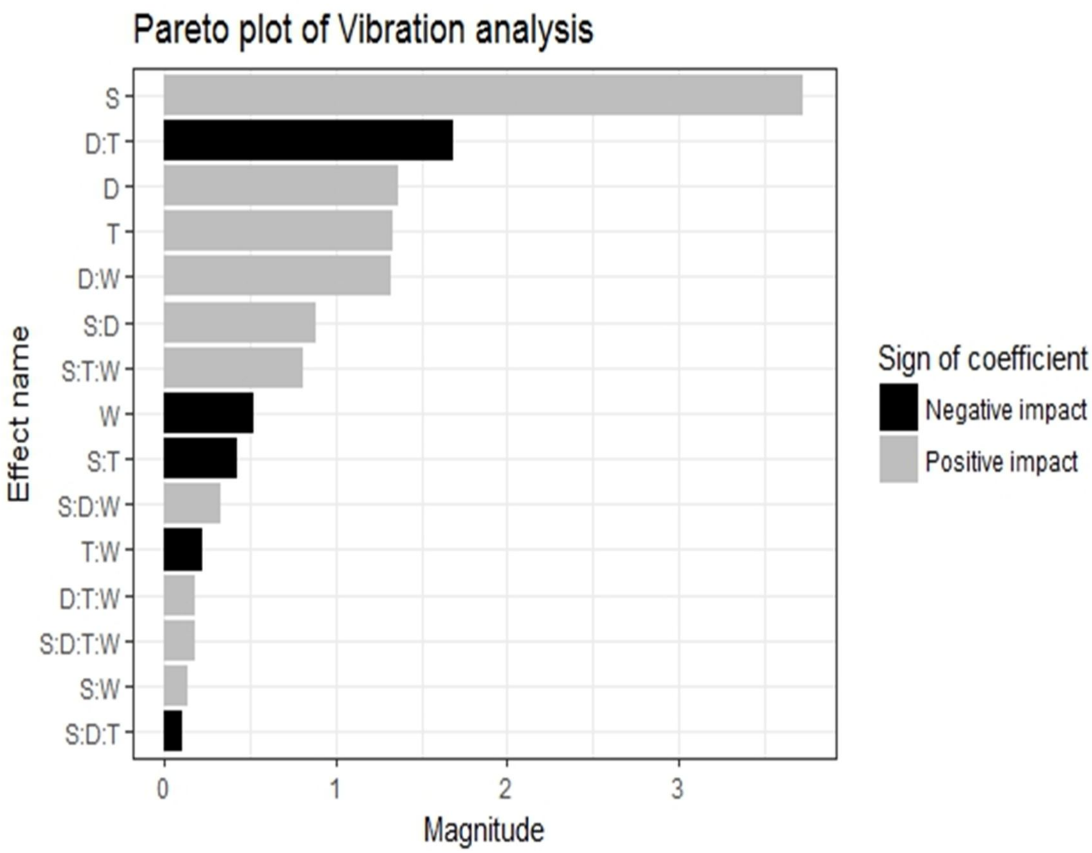



Fig 2: Plots for vibration data

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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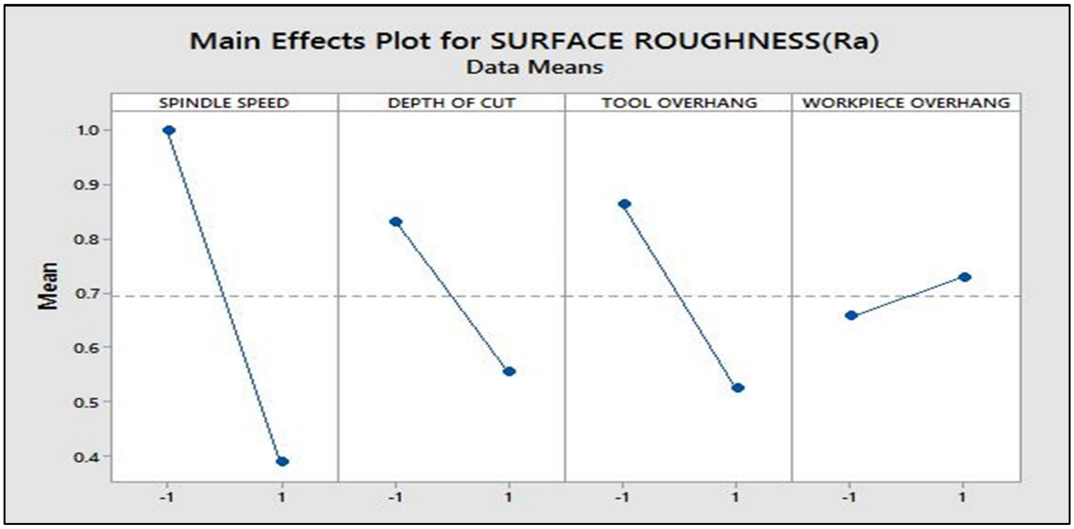
*A. This plot shows that*

1) The factor that influences Vibration output the most is Spindle speed(S), and is having a positive impact on the Vibration output. From the Pareto plot the magnitude of effect that Spindle speed has on the response is found to be around 3.73 units. It simply means that when Spindle speed changes from the lower level (-1) to upper level (+1), the average change in the Response (Vibration) will be 3.73m/s$^2$.
2) The most influencing interaction is the interaction between Depth of cut (D) and Tool overhang (T), and is having a negative impact on the Response. From the Pareto plot it is clear that the magnitude of effect that the interaction is having on the response is around -1.68m/s$^2$. It means that, when factors D and T are changed simultaneously in one direction, between the Higher and lower levels of respective factors, the response (Vibration output) will be inversely affected by an Average of 1.68 units.
3) The least influencing individual factor is Work piece overhang (W), and is having a negative impact. The magnitude of effect is around -0.52m/s$^2$.
4) The least influencing interaction is the interaction between Spindle speed (S), Depth of cut (D) and Tool overhang (T), and this interaction is having a negative impact on the response.




In this main effects plot, it appears that the spindle speed is associated with the highest mean strength. On the other hand, as the depth of cut increases surface finish decreases from lower level to higher level. Similarly, as the tool overhang increases surface finish also increases from lower level to higher level. Whereas, the last factor which is work piece overhang will not affect much to the surface finish.

For Surface Roughness

Ra=0.69375-(0.30500*S)-(0.13800*D)-(0.16975*T)+(0.03575*W)-(0.0775*S*D)+(0.10275*S*T)+(0.13100*D*T)+(0.00075*S*W)-(0.10050*D*W)+(0.04400*T*W)-(0.04700*S*D*T)+(0.03400*S*D*W)-(0.06525*S*T*W)+(0.05725*D*T*W)-(0.05800*S*D*T*W)

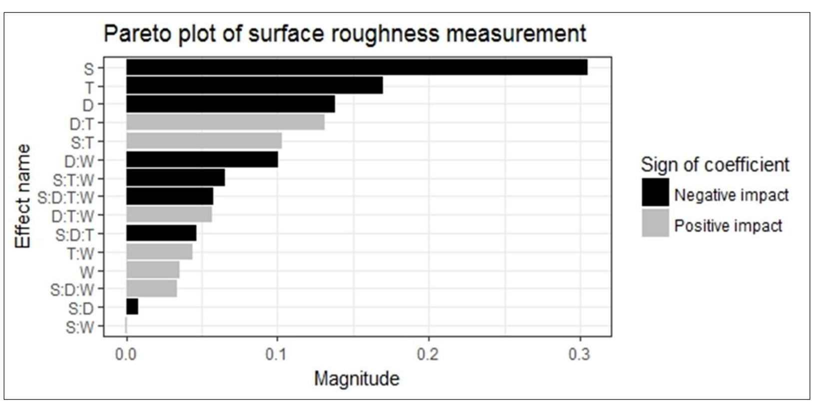



Fig 3: Plots for Surface Finish

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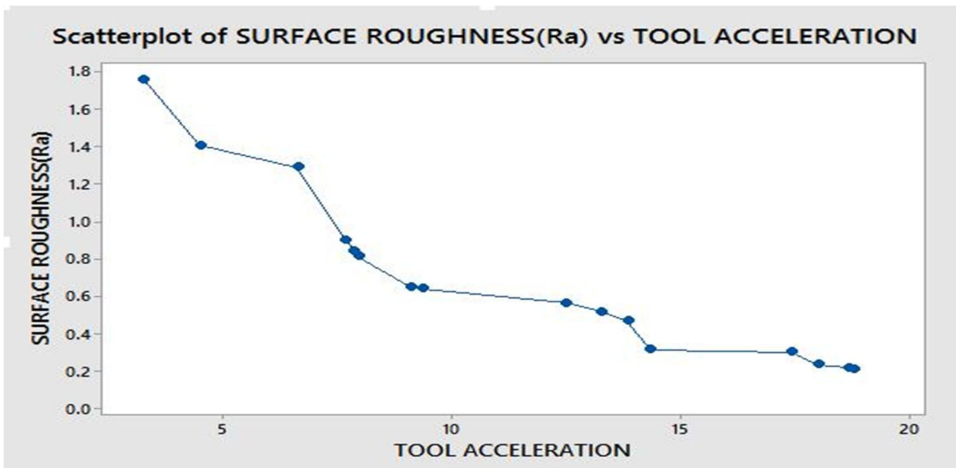
*B. This plot shows that*

1) The factor that influences Surface roughness the most is Spindle speed(S), and is having a negative impact on the response. From the Pareto plot the magnitude of effect that Spindle speed has on the response is found to be around -0.305µm. It simply means that when Spindle speed changes from the lower level (-1) to upper level (+1), the average inverse change in the Response (surface roughness) will be -0.305µm.
2) Most influencing interaction is Depth of cut (D) and Tool overhang (T), and it is having a positive impact. The magnitude of impact is 0.131 µm.
3) The least influencing individual factor is Work piece overhang (W), and is having a positive impact. The magnitude of effect is around 0.03572µm.
4) The least influencing interaction is the interaction between Spindle speed (S) and Work piece overhang (W), and this interaction is having a positive impact on the response. The magnitude of effect on the response (surface roughness) is around 0.00075 µm.



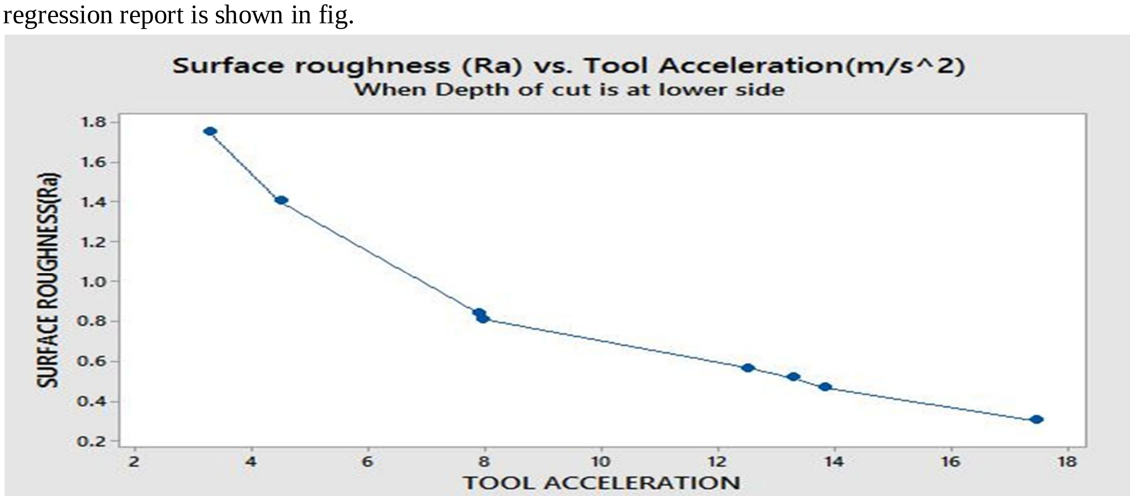

Graph: Scatter plots for Surface Roughness VS Tool Acceleration.

From the Scatter plot obtained we can understand that the relation between the surface roughness and vibration is inversely proportion in the given data range, but in actual condition in a broad data range the relation is quite non-linear and there may be a point where further increase in vibration may keep the surface roughness constant or increasing like a quadratic curve.2.381 - 0.2374X + 0.006631 $X^2$

Where, X=Tool Acceleration

Y= Surface Roughness

The detailed regression report is shown in fig.




Graph: Scatter plots for Surface Roughness VS Tool Acceleration When Depth of cut is on the lower side.

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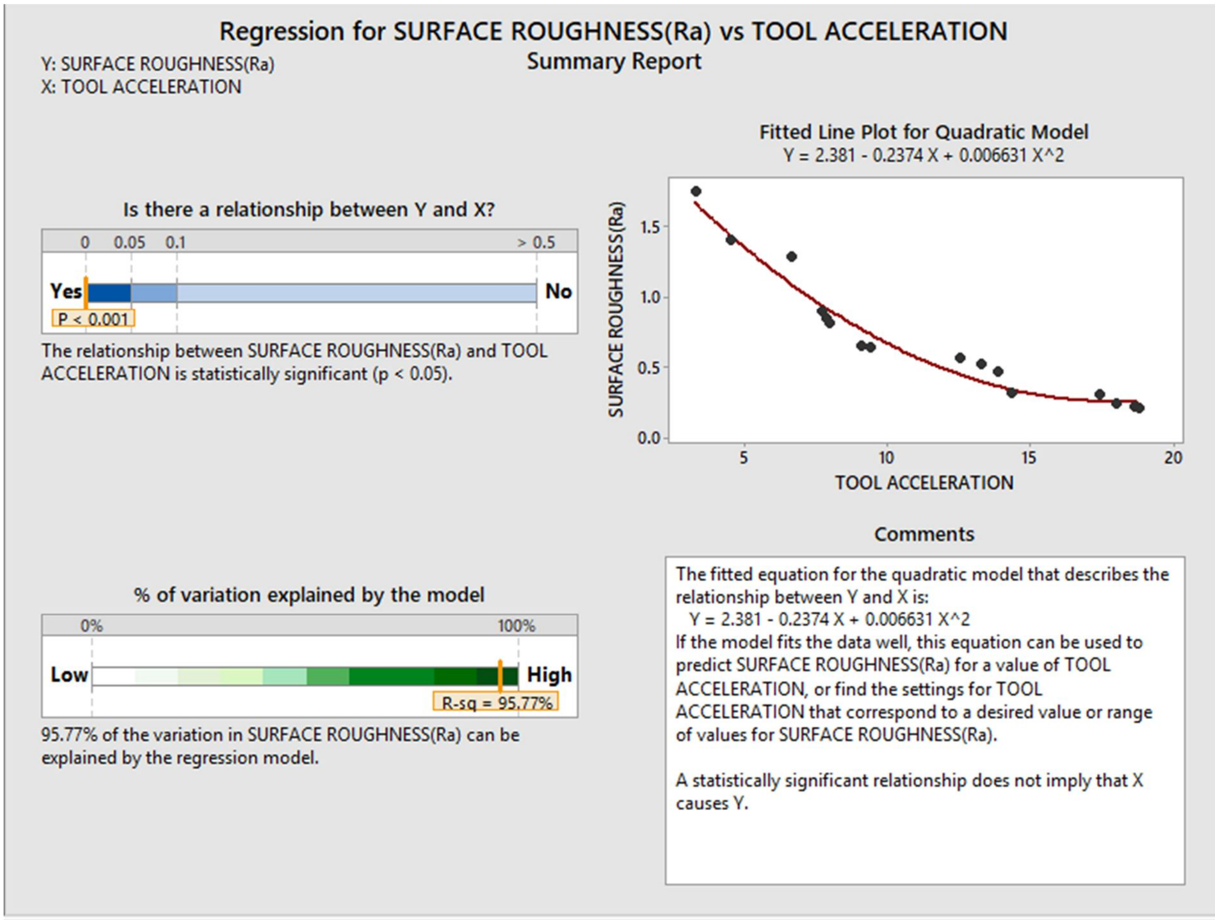
The graph depicts the relationship between surface roughness and tool acceleration when the depth of cut is constant. The graph can be found to be more of a smooth curve. This means that if depth of cut is constant the variation in relationship between surface roughness and tool acceleration will be minimum. Reason being the vibrations were recorded along the z-axis/along the machining direction, so the vibration of the tool along the machining surface would have resulted in a more uniformly machined area proportional to the magnitude of tool displacement. This would have resulted in reduction of Ra number.




Graph: Regression summary report for Surface Roughness VS Tool Acceleration.

## IV. CONCLUSION

In this paper we considered induced vibrations and surface roughness of a tool-work piece system in a turning process induced by random disturbances, and their effect on a product surface. The surface roughness of machined parts is predicted by using the response surface methodology. From the study, it is shown that, induced vibration has a significant effect on surface roughness of work piece. Also from the above experiment results, it can be concluded that, the factors that affect Vibration and Surface Roughness the most is Spindle Speed. Other factors even though having a diminishing impact, cannot be ignored because of the significant interactions they produce. There are good scope for future research in the work done till date. The data obtained can be effectively used to optimize the system, by applying Response Surface Methodology. Further experiments can be performed either using factorial design or fractional factorial design, to validate the results obtained.

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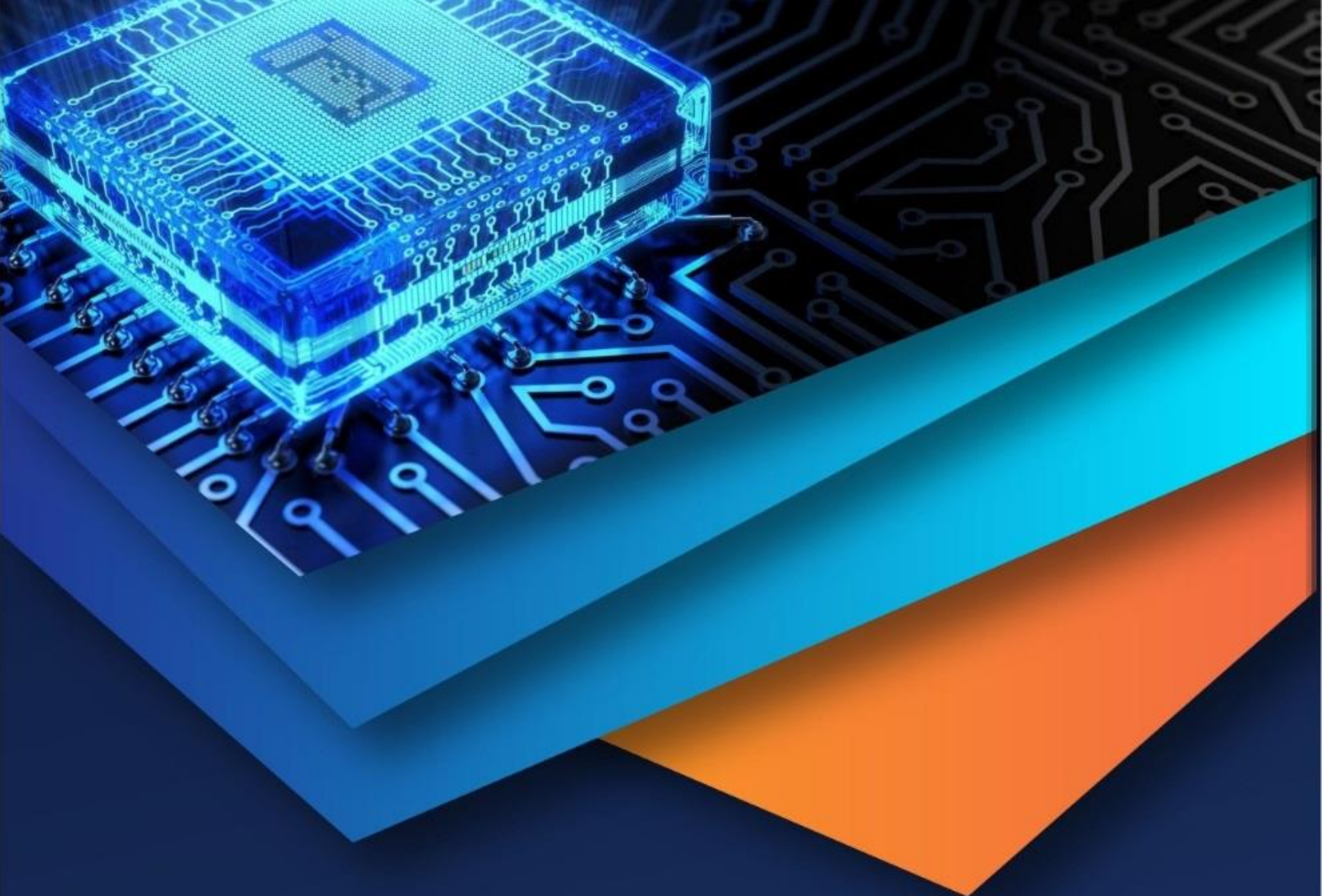


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