

# Design of Experiment Approach to Identify Optimal Parameters for Minimal Surface Roughness of Titanium Alloy on Aerospace Fasteners

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**ABSTRACT:** It is important to understand the factors which affect a particular characteristic; it would be worthwhile doing an experimental method using industrial engineering techniques. There are plenty of techniques available to conduct the experiments but this study can be best carried out by technique called DOE.

In a manufacturing industry where factors such as machining parameters speed, feed, depth of cut plays an important role on the quality characteristics such as surface roughness and surface finish. Thus by using DOE approach the changes in this quality characteristics can be studied effectively.

Design of experiments provides a scientific pathway to identify and analyze the crucial factors which affects the response variables (Surface roughness). To conduct the experiment, few factors were chosen which includes Speed, feed and depth of cut with two levels and the experiment was carried out using DOE principle, such as Randomization and Replication. Various types of response variables such as Average surface roughness, face average for surface roughness, surface roughness range and standard deviation for surface roughness for titanium steel were obtained to analyze the significant effects. The choice of these response variables were based on understanding the effects on mean as well as variability of surface roughness.

**KEYWORDS:** Surface Roughness, Speed, feed, depth of cut, 2-level design ( $2^k$  design), Design Of Experiments, ANOVA

## I. INTRODUCTION

Titanium alloy has been widely used in the aerospace due to its various properties such as ( low weight, high strength, non-corrosive etc..) however it is important to understand when subjected to various machining factors like physical properties can change, properties such as surface finish is affected. In order to understand the effects of these parameters on the surface finish, surface roughness is used as the measure for analysis.

The aim of the paper is to reduce the defects and defectives in the production line and minimizing surface roughness using Industrial engineering tools and techniques. To conduct the experiment, using surface roughness as response variable,  $2^3$  is used with following details which are shown in the table.2.

Machining was carried out using CNC machine and material used was Titanium Alloy (Ti-6Al-4V). To machine, Titanium alloy were used with 8mm diameter and 10 mm length as shown in the figure.

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Fig 1. Work piece

The chemical composition of Titanium alloy Ti-6Al-4V is summarized shown in the table 1. All the work from initial preparation of work piece to final machining experiment was done at ABC Company.

Table 1. Chemical composition of Ti-6Al-4V, % wt

Element	Al	V	Fe	O	C	N	Y	H	Ni
Wt(%)	6.1	4	0.16	0.11	0.02	0.01	0.001	0.001	Bal

## II. LITERATURE REVIEW

There have been various literatures on and carried in analysing the effects of various machining factors on material such as titanium.

Mohammed T. Hayajneh et al., carried out a set of experimental design to understand the surface quality for End-Milling Process. Their objective was to know the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a multiple regression model.

Navneet Khanna, J P Davim studied the effect of control factors i.e. cutting speed, feed rate and cutting tool temperature using taguchi technique. The output of their study was to suggesting Aerospace industry to use titanium alloys which has superior strength

Goutam Devaraya Revankara et al. carried out their study on Titanium alloy (Ti-6Al-4V) and Polycrystalline Diamond Tool using different factors such as speed feed and depth of cut. The aim of their study was to know the effect of these parameters on surface roughness and hardness. The study tells, the smaller the roughness, better hardness is achieved.

## III. EXPERIMENTAL DESIGN

A 2<sup>3</sup> design was considered with factors and levels as shown in Table 2. The response variables considered are shown in Table 3.

Table 2. Process control parameters and their level

Parameters	Units	Level 1	Level 2
Speed	Rpm	2300	3700
Feed	mm/rev	04	06
Depth of cut	mm	0.2	0.3

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### 3.1 Experimental procedure

The turning, Outer diameter(OD) and part off operations were carried out in CNC machine at ABC Company. The CNC machine is equipped with AC variable speed spindle motor up to 4000 rpm and regular industrial power was used for present experimental work. The cutting tool used was Carbide tool and inserts.



Fig 2. Photo of CNC machine

### 3.2 Response values

The response values were taken using **Surface Roughness Tester** in Advance Material science lab at MSRIT, Bangalore. Surface Roughness can be measured in  $\mu\text{m}$  and the cut off length is 0.25mm and 2.5mm. If we place the specimen below the tester, it automatically calculates the surface roughness of it. To check the repeatability, the readings were collected for many trials. The figure3 shows the surface testing machine.



Fig 3. Surface roughness testing machine

The response variables are tested as follows

- Average surface roughness
- Face Average for surface roughness
- Surface roughness Range
- Standard deviation for surface roughness

After collecting the responses, the data was input in run order sheet and using Minitab software, then accordingly data was analysed using Minitab software package. Table 4 shows the run orders and response values. The experiment was run for 32 runs ( $2^3 * 4$  Replicates) based on randomization for which the details have been provided in Table 4.

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Table 3. Response variables

Std Order	Run Order	Speed	Feed	Depth of cut	Std Order	Run Order	Speed	Feed	Depth of cut
5	1	3700	O4	0.2	31	17	3700	O6	0.2
19	2	2300	O6	0.2	17	18	2300	O4	0.2
1	3	2300	O4	0.2	29	19	3700	O4	0.2
26	4	2300	O4	0.3	30	20	3700	O4	0.3
15	5	3700	O6	0.2	4	21	2300	O6	0.3
9	6	2300	O4	0.2	14	22	3700	O4	0.3
21	7	3700	O4	0.2	27	23	2300	O6	0.2
2	8	2300	O4	0.3	13	24	3700	O4	0.2
8	9	3700	O6	0.3	11	25	2300	O6	0.2
32	10	3700	O6	0.3	20	26	2300	O6	0.3
18	11	2300	O4	0.3	10	27	2300	O4	0.3
6	12	3700	O4	0.3	23	28	3700	O6	0.2
24	13	3700	O6	0.3	16	29	3700	O6	0.3
3	14	2300	O6	0.2	7	30	3700	O6	0.2
25	15	2300	O4	0.2	28	31	2300	O6	0.3
12	16	2300	O6	0.3	22	32	3700	O4	0.3

Table 4. Run orders

StdOrder	RunOrder	Speed	Feed	Depth of cut	ResponseAverage	Range	Std Dev	Face Avg
5	1	3700	O4	0.2	0.313	0.02	0.0088515	0.215
19	2	2300	O6	0.2	0.178	0.11	0.045629	0.46
1	3	2300	O4	0.2	0.31	0.06	0.0244949	0.56
26	4	2300	O4	0.3	0.39	0.33	0.1332291	0.42
15	5	3700	O6	0.2	0.227	0.12	0.0511859	0.295
9	6	2300	O4	0.2	0.33	0.03	0.0130384	0.515
21	7	3700	O4	0.2	0.44	0.07	0.0268746	0.815
2	8	2300	O4	0.3	0.39	0.33	0.1332291	0.505
8	9	3700	O6	0.3	0.36	0.08	0.0296648	0.865
32	10	3700	O6	0.3	0.301	0.27	0.1025612	0.28
18	11	2300	O4	0.3	1.98	0.68	0.2598461	0.34
6	12	3700	O4	0.3	0.292	0.08	0.0303315	0.415
24	13	3700	O6	0.3	0.334	0.05	0.0194936	0.41
3	14	2300	O6	0.2	0.358	0.1	0.0363318	0.52
25	15	2300	O4	0.2	0.326	0.06	0.0279285	0.22
12	16	2300	O6	0.3	0.266	0.05	0.0194936	0.36
31	17	3700	O6	0.2	0.32	0.04	0.0158114	0.245
17	18	2300	O4	0.2	0.334	0.11	0.0450555	0.24
29	19	3700	O4	0.2	0.36	0.12	0.0570088	0.8
30	20	3700	O4	0.3	0.258	0.08	0.0303315	0.51
4	21	2300	O6	0.3	1.702	0.3	0.1125611	0.265
14	22	3700	O4	0.3	0.378	0.08	0.0327109	0.275
27	23	2300	O6	0.2	0.334	0.13	0.049295	0.58

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13	24	3700	O4	0.2	0.32	0.13	0.0484768	0.175
11	25	2300	O6	0.2	1.258	0.7	0.274718	0.6
20	26	2300	O6	0.3	0.348	0.1	0.0376829	0.385
10	27	2300	O4	0.3	0.365	0.06	0.0260768	0.18
23	28	3700	O6	0.2	0.415	0.12	0.049295	0.19
16	29	3700	O6	0.3	0.33	0.35	0.1325468	0.28
7	30	3700	O6	0.2	0.29	0.18	0.0746324	0.505
28	31	2300	O6	0.3	0.384	0.12	0.0501996	0.44
22	32	3700	O4	0.3	0.408	0.1	0.0438178	0.48

## IV. RESULTS

### 4.1 Main effects plot of average surface roughness for titanium alloy



Fig 4. Main effects plot of average surface roughness for titanium alloy

It is seen from the main effects plot of Average surface roughness of titanium alloy that, there is a change from 0.30 to 0.60, when speed is changed from 2300 rpm to 3700 rpm this shows that speed plays an significant role in Surface roughness average value. Likewise the changes are minimal and insignificant for feed and depth of cut.

### 4.2 Main effects plot for face average of surface roughness for titanium alloy

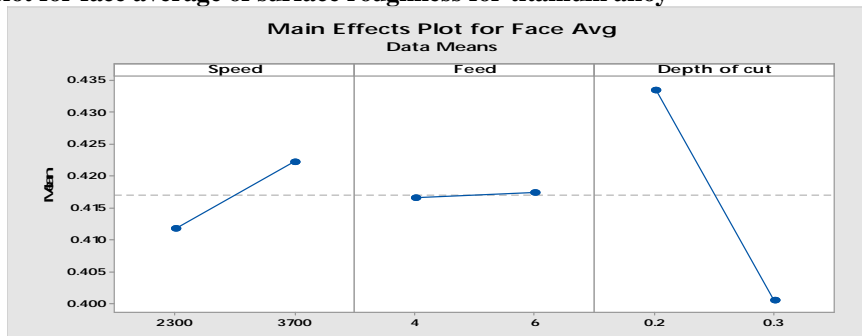


Fig 5. Main effects plot for face average of surface roughness for titanium alloy

It is seen from the main effects plot of Face average of Surface roughness for titanium alloy, that there is minimal change in depth of cut as it varies from 0.4 to 0.435. When depth of cut is changed from 0.2mm to 0.3mm. This shows that depth of cut plays a insignificant role in face average for surface roughness. Likewise the changes are insignificant for feed and speed.

**4.3 Main effects plot of surface roughness range for titanium alloy**

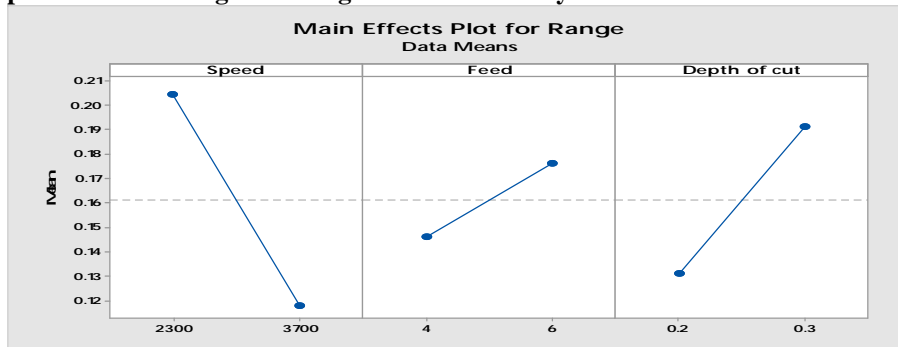


Fig 6. Main effects plot of surface roughness range for titanium alloy

It is seen from the main effects plot of Surface roughness range for titanium alloy that, there is a minimal change from 0.12 to 0.20, when speed is changed from 2300 rpm to 3700 rpm this shows that speed plays an insignificant role in Surface roughness for range. Likewise the changes are insignificant for feed and depth of cut.

**4.4 Main effects plot of standard deviation for surface roughness for titanium alloy**

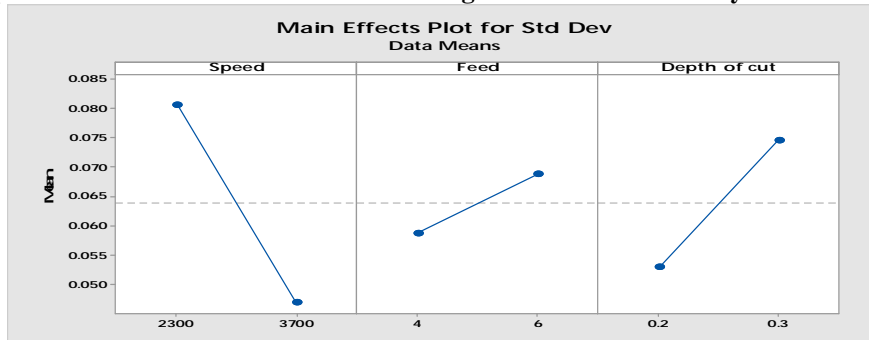


Fig 7. Main effects plot of standard deviation for surface roughness of titanium alloy

It is seen from the main effects plot of Standard deviation for Surface roughness of titanium alloy that there is minimal change from 0.05 to .08, when speed is changed from 2300 rpm to 3700 rpm. This shows that speed plays an insignificant role in Standard deviation for surface roughness. Likewise the changes are insignificant for feed and depth of cut.

**4.5 Interaction plot for average surface roughness for titanium alloy**

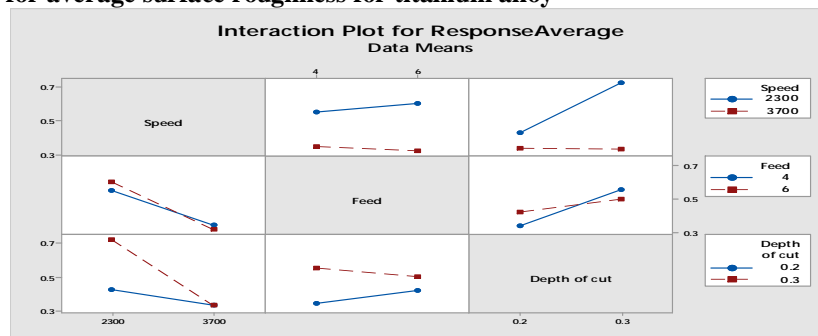


Fig 8. Interaction plot for average surface roughness for titanium alloy

It is seen from the plot that the lines are parallel. Hence there is no lines are intersecting between any of the combinations. This indicates that there is no interaction effect between them.

**4.6 Interaction plot for face Average of surface roughness for titanium alloy**

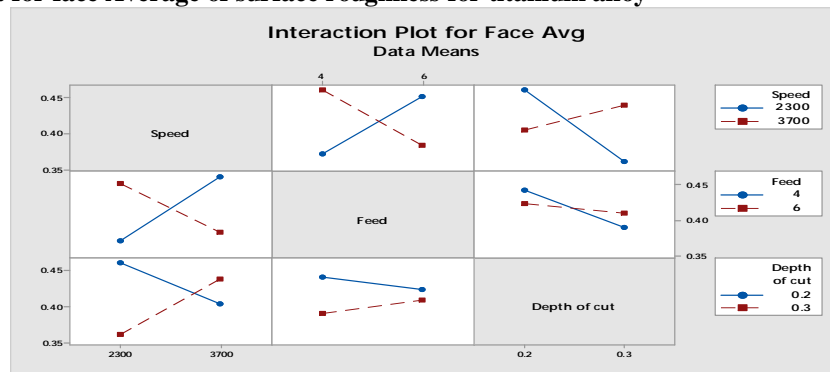


Fig 9. Interaction plot for face average of surface roughness for titanium alloy

It is seen from the plot that the lines are completely intersecting between speed and feed, speed and depth of cut, feed and depth of cut. This indicates an interaction effect between them, however the interaction effect is insignificant between Speed and feed because of low contrast value. But the contrast value between depth and feed, depth cut and speed is little bit more. So the interaction effect between them is significant.

**4.7 Interaction plot for range of surface roughness for titanium alloy**

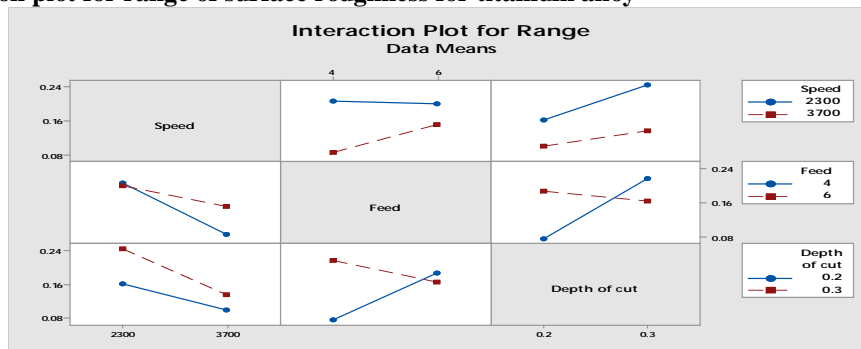


Fig 10. Interaction plot for range of surface roughness for titanium alloy

It is seen from the plot that the lines are completely intersecting between speed and feed, feed and depth of cut. This indicates an interaction effect between them, however the interaction effect is insignificant because of low contrast value.

**4.8 Interaction plot for standard deviation of surface roughness for titanium alloy**

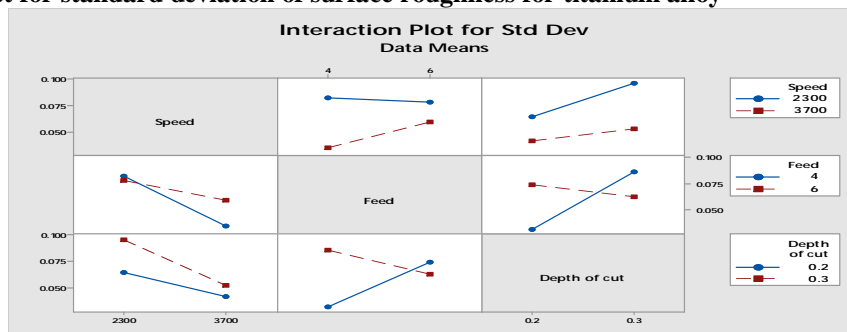


Fig 11. Interaction plot for standard deviation of surface roughness for titanium alloy

It is seen from the plot that the lines are completely intersecting between speed and feed, feed and depth of cut. This indicates an interaction effect between them, however the interaction effect is insignificant because of low contrast value.



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## 4.9 Analysis of variance (ANOVA)

The main purpose of the analysis of variance (ANOVA) is the application of a statistical method to identify the effects of individual parameters and their significance for the response variable. Results from ANOVA can determine very clearly the impact of each of parameters on the process results at desired confidence level.

## 4.10 ANOVA for average surface roughness for titanium alloy

Table 5. ANOVA for Average of surface roughness for titanium Alloy

**General Factorial Regression: Response Average versus Speed, Feed, Depth of cut**

Factor Information

Factor	Levels	Values
Speed	2	2300, 3700
Feed	2	4, 6
Depth of cut	2	0.2, 0.3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	0.94854	0.135506	0.79	0.600
Linear	3	0.65438	0.218128	1.28	0.305
Speed	1	0.47702	0.477020	2.79	0.108
Feed	1	0.00139	0.001391	0.01	0.929
Depth of cut	1	0.17597	0.175973	1.03	0.320
2-Way Interactions	3	0.23088	0.076960	0.45	0.719
Speed*Feed	1	0.01106	0.011063	0.06	0.801
Speed*Depth of cut	1	0.18316	0.183164	1.07	0.311
Feed*Depth of cut	1	0.03665	0.036653	0.21	0.647
3-Way Interactions	1	0.06328	0.063279	0.37	0.548
Speed*Feed*Depth of cut	1	0.06328	0.063279	0.37	0.548
Error	24	4.09752	0.170730		
Total	31	5.04606			

The above table shows that the p-value for linear model, 2-way interaction and for 3-way interaction are greater than 0.05. Therefore it infers that all the factors for all the combination of interaction are insignificant.

## 4.11 ANOVA for range of surface roughness for titanium alloy

Table 6. ANOVA for range of surface roughness for titanium alloy

**General Factorial Regression: Range versus Speed, Feed, Depth of cut**

Factor Information

Factor	Levels	Values
Speed	2	2300, 3700
Feed	2	4, 6
Depth of cut	2	0.2, 0.3

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	0.277800	0.039686	1.66	0.166
Linear	3	0.095512	0.031837	1.33	0.287
Speed	1	0.059512	0.059512	2.49	0.127
Feed	1	0.007200	0.007200	0.30	0.588
Depth of cut	1	0.028800	0.028800	1.21	0.283
2-Way Interactions	3	0.069475	0.023158	0.97	0.423
Speed*Feed	1	0.010513	0.010513	0.44	0.513
Speed*Depth of cut	1	0.004512	0.004512	0.19	0.668
Feed*Depth of cut	1	0.054450	0.054450	2.28	0.144
3-Way Interactions	1	0.112813	0.112813	4.73	0.040
Speed*Feed*Depth of cut	1	0.112813	0.112813	4.73	0.040
Error	24	0.572950	0.023873		
Total	31	0.850750			

The above table shows that the p-value for linear model, 2-way interactions are greater than 0.05 and for 3-way interaction is less than 0.05. Therefore it infers that 3-way interactions factors for combination of interaction are significant.



#### 4.12 ANOVA for face average of surface roughness for titanium alloy

Table 7. ANOVA for face average of surface roughness for titanium alloy  
**General Factorial Regression: Face Avg versus Speed, Feed, Depth of cut**

Factor Information						
Factor	Levels	Values				
Speed	2	2300, 3700				
Feed	2	4, 6				
Depth of cut	2	0.2, 0.3				
Analysis of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	
Model	7	0.17152	0.024503	0.67	0.695	
Linear	3	0.00947	0.003157	0.09	0.967	
Speed	1	0.00085	0.000851	0.02	0.880	
Feed	1	0.00001	0.000007	0.00	0.989	
Depth of cut	1	0.00861	0.008613	0.24	0.632	
2-Way Interactions	3	0.08746	0.029153	0.80	0.508	
Speed*Feed	1	0.04844	0.048438	1.32	0.261	
Speed*Depth of cut	1	0.03611	0.036113	0.99	0.330	
Feed*Depth of cut	1	0.00291	0.002907	0.08	0.780	
3-Way Interactions	1	0.07459	0.074595	2.04	0.166	
Speed*Feed*Depth of cut	1	0.07459	0.074595	2.04	0.166	
Error	24	0.87822	0.036592			
Total	31	1.04974				

The above table shows that the p-value for linear model, 2-way interaction and for 3-way interaction is greater than 0.05, there fore it inferse that significant role for the factors combinations of speed\*feed\*depth of cut.

#### 4.13 ANOVA for sstandard deviation of surface roughness for titanium alloy

Table 8. ANOVA for standard deviation of surface roughness for titanium alloy  
**General Factorial Regression: Std Dev versus Speed, Feed, Depth of cut**

Factor Information						
Factor	Levels	Values				
Speed	2	2300, 3700				
Feed	2	4, 6				
Depth of cut	2	0.2, 0.3				
Analysis of Variance						
Source	DF	Adj SS	Adj MS	F-Value	P-Value	
Model	7	0.041280	0.005897	1.66	0.167	
Linear	3	0.013472	0.004491	1.26	0.310	
Speed	1	0.008952	0.008952	2.52	0.126	
Feed	1	0.000798	0.000798	0.22	0.640	
Depth of cut	1	0.003723	0.003723	1.05	0.317	
2-Way Interactions	3	0.011370	0.003790	1.07	0.382	
Speed*Feed	1	0.001708	0.001708	0.48	0.495	
Speed*Depth of cut	1	0.000866	0.000866	0.24	0.626	
Feed*Depth of cut	1	0.008796	0.008796	2.47	0.129	
3-Way Interactions	1	0.016438	0.016438	4.62	0.042	
Speed*Feed*Depth of cut	1	0.016438	0.016438	4.62	0.042	
Error	24	0.085383	0.003558			
Total	31	0.126663				

The above table shows that the p-value for linear model, 2-way interactions are greater than 0.05. but for 3-way interactions the p-values are less than 0.05. There for it infers that all the factors for all the combination of 3-way interaction are insignificant.

### V. CONCLUSION

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

1. ANOVA table for range and standard deviation of surface roughness for titanium alloy shows that combinations of 3-way interactions plays a significant role, since its p-value is less than 0.05.
2. Even the main effects plot shows that speed is insignificant for average surface roughness of titanium alloy.
3. The best process of optimal parameters are as shown
  - a. Depth of cut with 0.2mm, Speed with 3700rpm and feed with 04mm/rev.
  - b. Depth of cut with 0.2mm, Speed with constant with 04mm/rev.
  - c. Depth of cut with 0.3mm, speed with constant with 06mm/rev

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