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Experimental study of Effect of Cutting Parameters on Cutting Force in Turning Process

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***Abstract:** The purpose of this paper is to study the effect of cutting parameters on cutting force (Fc) & feed force in turning Process. Experiments were conducted on a precision centre lathe and the influence of cutting parameters was studied using analysis of variance (ANOVA) based on adjusted approach. Based on the main effects plots obtained through full factorial design, optimum level for surface roughness and cutting force were chosen depth of cut, and the interaction of feed and depth of cut significantly influenced the variance. In case of surface roughness, from the three levels of cutting parameters considered Linear regression equation of cutting force has revealed that feed, the influencing factors were found to be feed and the interaction of speed and feed. As turning of mild steel using HSS is one among the major machining operations in manufacturing industry, the revelation made in this research would significantly contribute to the cutting parameters optimization*

***Keywords:** Taguchi, ANOVA, surface roughness, cutting force, feed force interaction effect, main effects.*

INTRODUCTION:

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material as shown in Figure 1.1.The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desire shape.

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:
With the work piece is rotating.
With a single-point cutting tool, and With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.
Among the force components, cutting force and Feed force prominently influences power consumption and the most common equation available for the estimation of

Cutting force is given by (equation 1)1:

$Fc = kc \times DOC \times f$
Where, DOC = Depth of cut (mm), f = feed (mm/rev), kc =
Specific cutting energy coefficient (N/ mm2)

According to equation 1, cutting force is influenced by the depth of cut, feed, and specific cutting energy coefficient. A lot of work is in progress to study this influence and construct the models for different tool and work force material so as to optimize the power consumption.

Another important parameter of research interest is Surface roughness of the work piece produced, as an optimum surface finish would influence performance of mechanical parts and cost of manufacture2-7. The surface finish of any given part is measured in terms of average heights and depths of peaks and valleys on the surface of the work piece8. But there are basically two streams of arguments on the influencing factors of surface roughness. A popularly used model for estimating the surface roughness value is as follows (eqn. 2)9-10.

$$R_a = \frac{0.0321f^2}{r}$$

Where, Ra = ideal arithmetic average (AA) surface roughness (µm), f = feed (mm/rev), r = cutter nose radius (mm).

The second stream of argument introduces speed also as an influencing factor of surface roughness and the governing equation is defined as (equation 3)11. However, both the above two streams of arguments explain the surface roughness partially. Hence, there is always a need to go deeper into the investigation of influencing factors of surface roughness, particularly with respect to the interaction effects such as those between speed, feed, and depth of cut for different combinations of tool and work material.

Tugrul O¨ zel · Tsu-Kong Hsu · Erol Zeren [1] In this study, the effects of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and resultant forces in the finish hard turning of AISI H13 steel Viktor P. Astakhov [2] published studies on metal cutting regard the cutting speed as having the greatest influence on tool wear and, thus, tool life, while other parameters and characteristics of the cutting process

Wei-Wei Liu Li-Jian Zhu Chen-Wei Shan Feng Li [9] This paper presents a cutting force prediction model in the end milling of GH4169 super alloy with carbide tools by orthogonal experiment. The variance analysis is applied to check the significance of the model, accuracy of the model is verified by experiment. The effect of cutting parameters on the cutting force is also studied. The results show that the prediction model is reliable. Among all four parameters the most influential parameter is axial depth of cut, followed by feed per tooth.

Material and Methods

Machine: The experiments were carried out on the precision centre lathe the main spindle runs on high precision roller taper bearings and is made from hardened and precision drawn nickel chromium steel.

The Tool: HSS tool with the alloying elements: manganese, chromium, tungsten, cobalt etc. has comparatively better resistance to heat and wear. Tool length of 80mm (approx.) was taken so as to minimize undesirable vibrations, which would influence cutting force and surface roughness. The lathe tool dynamometer was used for measuring cutting force and cutting process was continued until significant tool wear was observed. The single point HSS tool specifications are as follows in Table – 1

Table – 1: Tool Specification

Back Rake Angle	12º
Side Rake Angle	12º
End Relief	10º
End Cutting Edge Angle	30º
Side Cutting Edge Angle	15º
Nose Radius	0.8mm

Work piece: Work piece of standard dimensions was used for machining: work piece diameter: 40mm, work piece length: 300mm (approx.). Lathe Tool Dynamometer: The instrument used for the measurement of cutting force was IEICOS multi-component force indicator. It comprises of two independent digital display calibrated to display force directly using three component tool dynamometer. This instrument comprises independent DC excitation supply for feeding strain gauge bridges, signal processing systems to process and compute respective force values for direct independent display. Instrument operates on 230V, 50Hz AC mains. To record the force readings, IEICOS multi-component force indicator software was used. The data was obtained through a USB cable connected to the Dynamometer and stored on a computer.

Surface Roughness measurement: The instrument used to measure surface roughness was Mitutoyo surface finish tester Cutting Conditions and Experimental Procedure: Among the speed and feed rate combinations available on the Lathe, three levels of cutting parameters were selected. It is given in table

Taguchi design for three levels and three factors (3k) yielded 27 experiments and two replicates were carried out. The standard order, cutting parameters and responses are as shown in the Design of Experiments table30,31. It is given in table - 3.

RESULTS AND DISCUSSION

Force Analysis: Cutting force & feed force increases almost linearly with the increase in depth of cut from 0.25mm to 0.75mm.Optimum conditions are achieved for a feed rate value of 0.18 mm/rev and a DOC value of 0.5mm., which is the main effects plot for cutting force indicates that cutting force is influenced significantly by depth of cut, feed rate, interaction effect of feed and depth of cut and interaction effect of speed, feed and depth of cut, whereas, speed has an insignificant influence on cutting force which is shown in table - 4. Further, the model adequately explains the total variance in cutting parameters and it is also reasonably a good fit R-Sq = 81.53% R-Sq(adj) = 76.19% It can also be noted through ANOVA that Cutting force is not significantly influenced due to the interaction between speed and feed, however, there is an indication that at higher feed rate the influence may be significant.

Table –2: Machining parameters & their levels

Process Parameters	Parameter Designation	DOF	Levels		
			I	II	III
Cutting speed (mm/min)	A	2	28.91	44.13	65.37
Feed (mm/rev)	B	2	0.1	0.18	0.25
Depth of Cut	C	2	0.25	0.5	0.75

Table –3: The DOE table for plain turning operation

St.order	Cutting speed V (m/min)	Feed F (mm/rev)	Depth of cut DOC (mm)	Cutting Force Fc (Kgf)	Feed Force Ff (Kgf)	Surface Finish Ra (µm)
1	28.91	0.1	0.25	26.4	12.4	5.00
2	28.91	0.1	0.5	19.2	5.2	4.52
3	28.91	0.1	0.75	21.3	9.6	5.50
4	28.91	0.18	0.25	13.6	5	8.37
5	28.91	0.18	0.5	18.3	4.3	9.41
6	28.91	0.18	0.75	25.5	11.5	9.34
7	28.91	0.25	0.25	16.8	2.8	10.50
8	28.91	0.25	0.5	24.3	10.3	9.43
9	28.91	0.25	0.75	25.4	11.4	8.66
10	44.13	0.1	0.25	9.6	5	4.64
11	44.13	0.1	0.5	18.2	4.2	7.23
12	44.13	0.1	0.75	22.3	8.3	6.24
13	44.13	0.18	0.25	35.8	21.8	6.44
14	44.13	0.18	0.5	15	9.1	6.87
15	44.13	0.18	0.75	15.6	1.6	8.74
16	44.13	0.25	0.25	21.1	7.1	10.93
17	44.13	0.25	0.5	24.4	10.4	9.93
18	44.13	0.25	0.75	38.2	24.2	9.27
19	65.37	0.1	0.25	9.3	10.2	6.74
20	65.37	0.1	0.5	19.5	5.5	5.00
21	65.37	0.1	0.75	22.3	8.3	4.52
22	65.37	0.18	0.25	16.5	2.5	5.50
23	65.37	0.18	0.5	16.3	2.3	8.37
24	65.37	0.18	0.75	24.3	10.3	9.41
25	65.37	0.25	0.25	16.9	8	9.34
26	65.37	0.25	0.5	24.1	10.1	10.50
27	65.37	0.25	0.75	33.1	19.1	9.43

Table 4 :DOE in face turning operation

21	65.37	0.1	0.75	17.4	5.4	7.98
22	65.37	0.18	0.25	20.4	8.4	8.10
23	65.37	0.18	0.5	15.4	3.4	8.90
24	65.37	0.18	0.75	14.2	2.2	8.43
25	65.37	0.25	0.25	22.9	10.9	4.35
26	65.37	0.25	0.5	15.8	3.8	2.95
27	65.37	0.25	0.75	18.1	6.1	5.44

Statistical Analysis of forces in plain turning operation:

- Main cutting force (Fc) in plain turning operation:

Table 5.2.1 shows that for main cutting force (Fx), the chief contributing factor is the depth of cut followed by feed rate since the P-values lies lesser than 0.005.

Table 5: ANOVA for main cutting force (Fc) in plain turning operation

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	17.82	17.82	8.91	0.22	0.805
Feed Rate	2	192.81	192.81	96.40	2.38	0.003
Depth of Cut	2	236.76	236.76	118.38	2.92	0.002
Error	20	811.81	811.81	40.59		
Total	26	1259.20				

S = 6.37108 R-Sq = 81.53% R-Sq(adj) = 76.19% SS - sum of squares

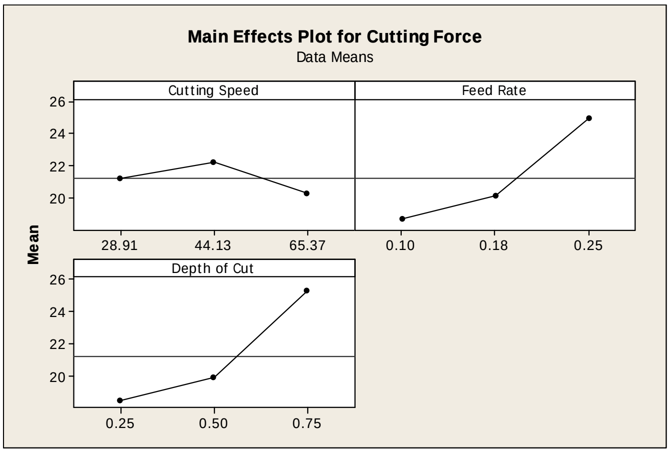

Fig 1.1: Main effects plot for cutting force in plain turning.

Main effect plots (Fig. 5.1) shows almost very less variations in cutting forces when machined from lower speeds to higher speeds. As feed increases, the cutting forces are also increased, and cutting forces are likely to increase also with the depth of cut.

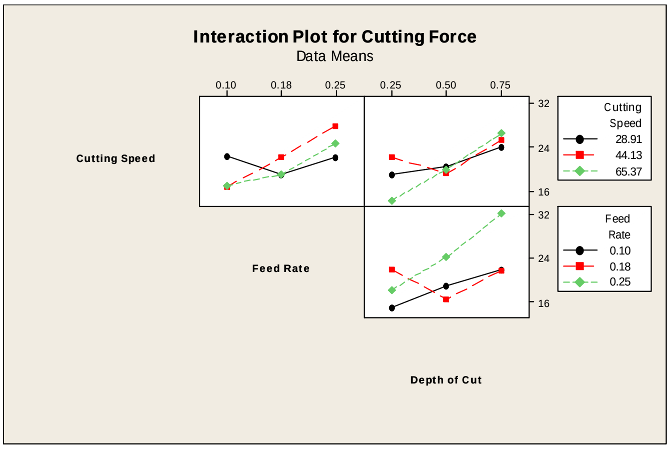

Fig 2: Interaction plot for cutting force in plain turning

Interaction plots reveal that cutting force is increasing with increasing feed rates, the depth of cut is dominant since other parameter, i.e. cutting speed is showing very less variations at higher levels.

- Feed force (Ff) ANOVA for Feed force (Ff) shows that P-value of 0.001 as the most significant factor (depth of cut) that contributes to the Feed force.

Table 6: ANOVA for feed force (Fc) in plain turning operation

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	22.97	22.97	11.49	0.38	0.686
Feed Rate	2	89.97	89.97	44.98	1.50	0.002
Depth of Cut	2	107.05	107.05	53.52	1.79	0.001
Error	20	598.35	598.35	29.92		
Total	26	818.34				

S = 5.46970 R-Sq = 26.88% R-Sq(adj) = 4.95% SS – sum of squares

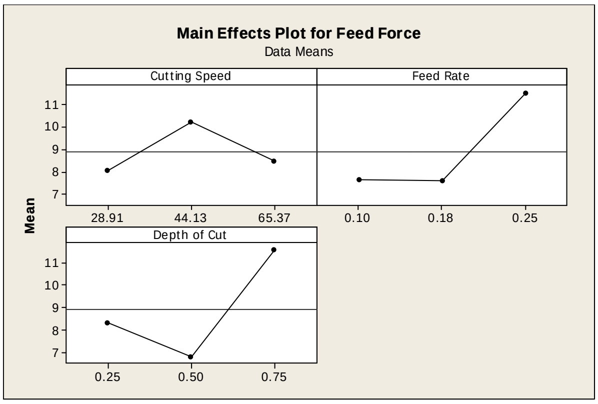

Fig 3: Main effects plot for feed force in plain turning

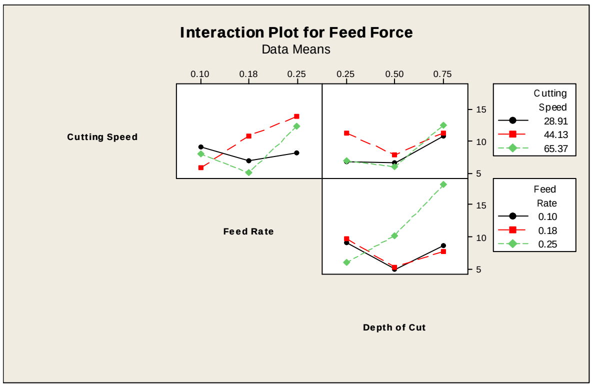

Fig 4: Interaction plot for feed force in plain turning operation

In Fig. 3, it is found that when feed is increased from 0.1 to 0.18 to 0.25, there is a steep linear rise in the feed force from 4 kg to almost 30 kg. Cutting speed and feed rate show very small change in the feed force when shifting from one to another level Feed is found to be dominating. Interaction plots (Fig. 5.4) reveal that radial force is increasing with increasing feed rates, the feed rate is dominant since all other parameters, i.e. cutting speed and to type is showing very less variations at higher levels.

5.2.2 Statistical Analysis of forces in face turning operation s

- Main cutting force (Fc):

Table 5.2.3 shows that for main cutting force (Fx), the chief contributing factor is the depth of cut followed by feed rate since the P-values lies lesser than 0.005.

Table 7: ANOVA for main cutting force (Fc) in face turning operation

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	10.01	10.01	5.01	0.14	0.867
Feed rate	2	199.03	199.03	99.51	2.86	0.001
Depth of cut	2	176.44	176.44	88.22	2.53	0.000
Error	20	696.79	696.79	34.84		
Total	26	1082.26				

S = 5.90249 R-Sq = 35.62% R-Sq(adj) = 16.30%

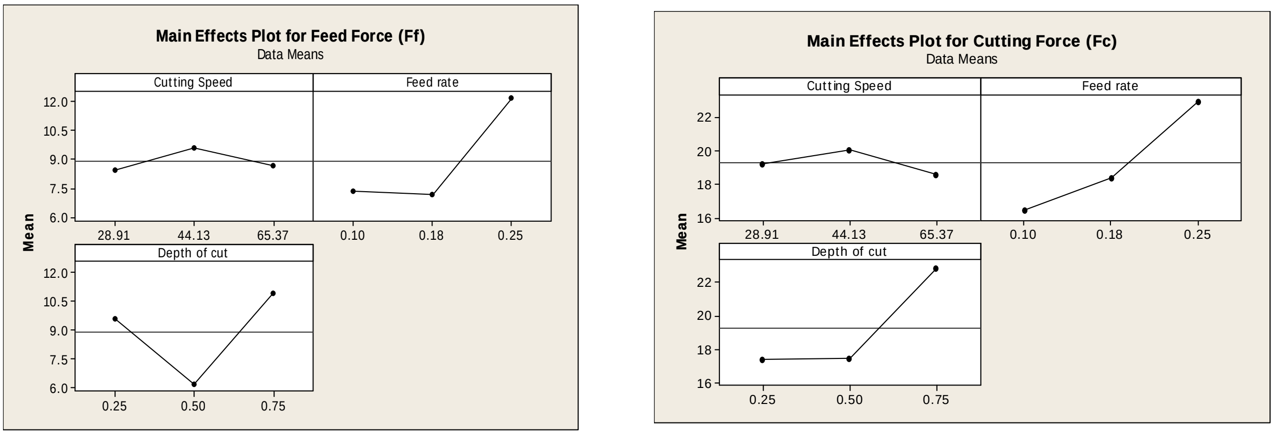

Fig 5: Main effects plot for cutting force in face turning

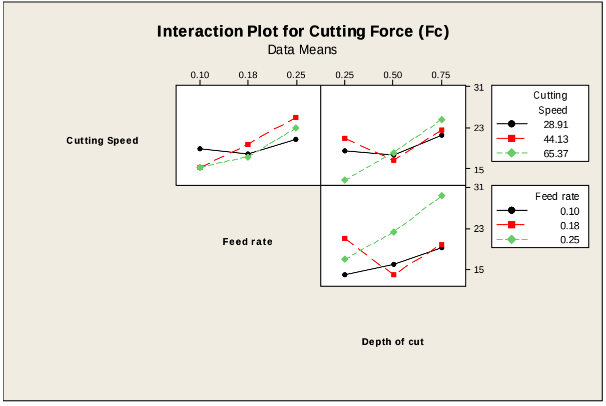

Fig 6: Interaction plot for cutting force in plain turning

Main effect plots (Fig. 5.5) shows almost very less variations in cutting forces when machined from lower speeds to higher speeds. As feed increases, the cutting forces are also increased, and cutting forces are likely to increase also with the depth of cut.

Interaction plots reveal that cutting force is increasing with increasing feed rates, the depth of cut is dominant since other parameter, and i.e. cutting speed is showing very less variations at higher levels.

- Feed force (Ff)

Result and Discussion

ANOVA for Feed force (Ff) shows that P-value of 0.00 as the most significant factor (feed) that contributes to the Feed force.

Table 8 : ANOVA for feed force (Ff) in face turning operation

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	7.01	7.01	3.50	0.13	0.876
Feed rate	2	147.53	147.53	73.76	2.80	0.000
Depth of cut	2	105.62	105.62	52.81	2.00	0.161
Error	20	527.74	527.74	26.39		
Total	26	787.89				

S = 5.13684 R-Sq = 33.02% R-Sq (adj) = 12.92% SS- Sum of Squares

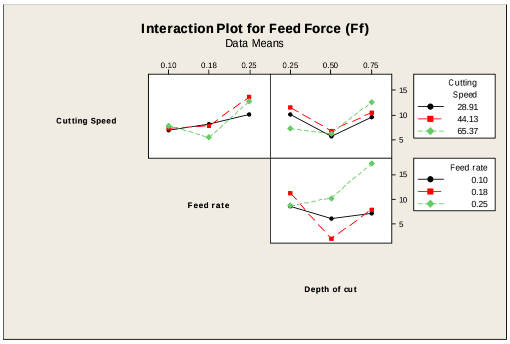

Fig 8 : Interaction plot for feed force in face turning

In Fig. 8, it is found that when feed is increased from 0.08 to 0.12 to 0.18, there is a steep linear rise in the radial force from 16 kgf to almost 32 kgf Cutting speed and feed rate show very small change in the radial force when shifting from one to another level Feed is found to be dominating. Interaction plotsreveal that radial force is increasing with increasing feed rates, the feed rate is dominant since all other parameters, i.e. cutting speed and to type is showing very less variations at higher levels.

Statistical Analysis of Surface Roughness (Ra) in plain turning:

Statistical ANOVA shown in Table , indicate that feed rate is the most significant factor for surface roughness which has P-value of 0.000.

Table 9 : ANOVA for Surface finish (Ra) in plain turning operation:

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	2.695	2.695	1.348	1.27	0.302
Feed rate	2	61.996	61.996	30.998	29.25	0.000
Depth of cut	2	1.242	1.242	0.621	0.59	0.566
Error	20	21.198	21.198	1.060		
Total	26	87.130				

S = 1.02951 R-Sq = 75.67% R-Sq(adj) = 68.37% SS-Sum of Squares

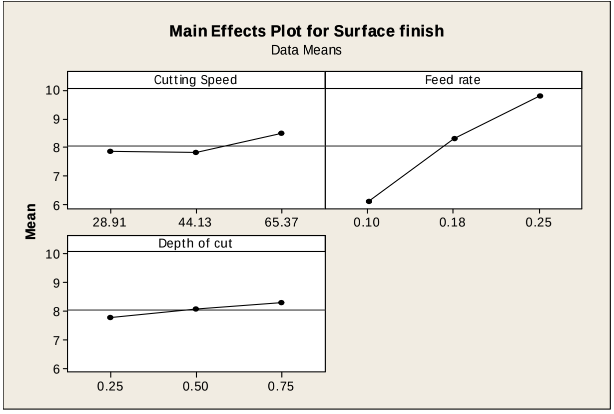

Fig 9 : Main effects plot for surface finish in plain turning

The main effect plot (Fig. 9) shows that cutting speed has almost no effect on the surface roughness at higher levels. Feed rate has linear relationship with the surface roughness, it increases as feed rate is increased due to the fact that more forces of the tool on the workpiece due to higher feed rates tends to lose the surface finish, so for good surface quality, a low feed rate is essential

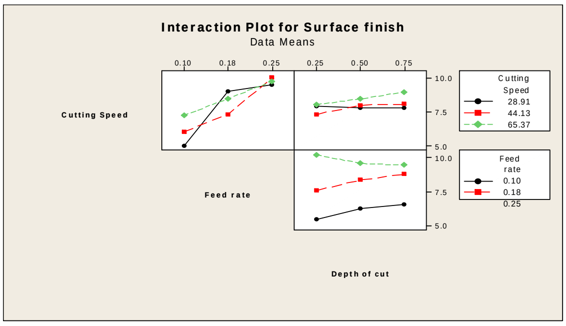

Fig 10 : Interaction plot for surface finish in plain turning

The interaction plot as shown in Fig10 indicates that at higher speeds and higher feeds, the surface roughness increases and Surface roughness values decreases as speeds increases from 44.13 to 65.37 m/min.5.2.3 b) Statistical Analysis of Surface Roughness (Ra) in face turning: Statistical ANOVA shown in Table 5.2, indicate that feed rate is the most significant factor for surface roughness which has P-value of 0.000.

Table 10: ANOVA for Surface finish (Ra) in face turning operation:

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	7.297	7.297	3.649	2.02	0.158
Feed rate	2	73.479	73.479	36.739	20.38	0.000
Depth of cut	2	8.618	8.618	4.309	2.39	0.117
Error	20	36.048	36.048	1.802		
Total	26	125.442				

S = 1.34253 R-Sq = 71.26% R-Sq(adj) = 62.64%e SS- Sum of Squares

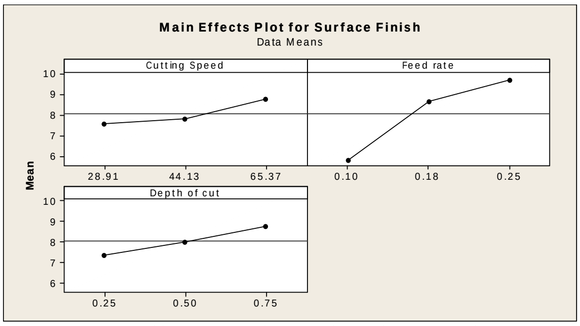

Fig 11 : Main effects plot for surface finish in face turning

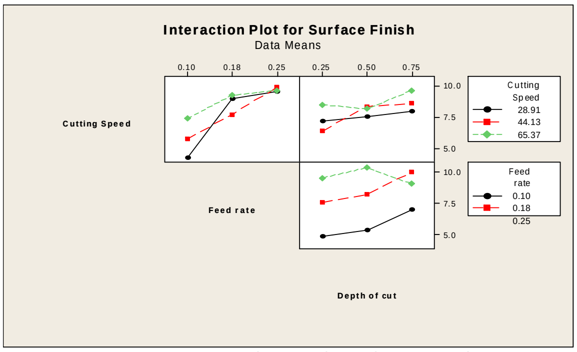

Fig 12 : Interaction plot for surface finish in face turning

CONCLUSION

From the experiments it is shown that the feed rate has significant influence on both the Cutting force and Surface roughness. Cutting Speed has no significant effect on the cutting force as well as the surface roughness of the chosen work piece. Depth of cut has a significant influence on cutting force, but an insignificant influence on surface roughness. In turning process optimization with respect to power consumption, the focus should be on choosing an appropriate combination of feed rate and depth of cut. Optimum surface roughness can be achieved by selecting relatively higher values of speed (>65.37m/min), higher values of depth of cut (>0.75mm), and relatively lower values of feed rate (<0.10mm/rev).

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