

Application Of Taguchi Methodology In Optimization Of Surface Roughness During Turning Of Low Carbon Steel

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Abstract

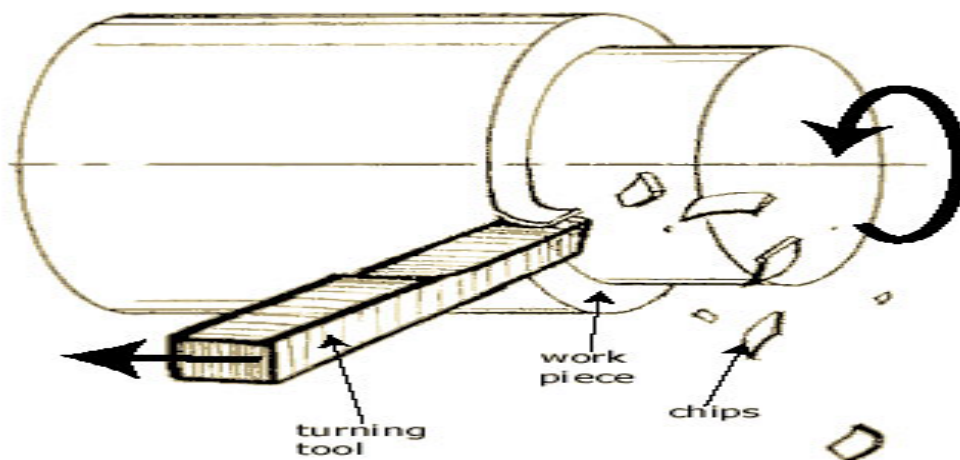
Turning is the most common process associated with the production of cylindrical shapes because of its simplicity, rapidity, and economy. Metal machining has been an interesting topic of research for decades. AISI 1018 has excellent weld ability and produces a uniform and harder case and it is considered as the best steel for the carburised parts. This paper discusses the experimental study on performance characteristics of AISI 1018 low carbon steel during CNC turning process. The experiments are conducted and based on Taguchi L16 orthogonal array by taking cutting speed, feed rate, depth of cut and nose radius. The complete experimental results are discussed and presented in this paper.

Keywords: Analysis of Variance (ANOVA), Design of Experiments (DOE), Degree of freedom (DOF), Orthogonal Array (OA)

1. INTRODUCTION

This paper presents the importance of surface quality and material rate in machining. Machining parameters such as cutting speed, feed rate and depth of cut play a vital role in machining the given work piece to the required shape. These have a major effect on the quality of production, cost of production and production rate; hence their judicious selection assumes significance. The selected machining parameters should yield desired quality on the machined surface while utilizing the machining resources such as machine tool and cutting tool to the fullest extent possible, consistent with the constraints on these resources.

There are many machining process such as drilling, shaping, turning, slotting, grinding etc. During machining, the consumed power is largely converted into heat resulting high cutting temperature near the edge of the tool and the amount of heat generated varies with the type of material. In the present work, turning process has been taken up for the surface roughness and material removal rate optimization. As, the turning process is the most productive process, the study is expected to be quite beneficial. Here, through turning process has been selected for the study to determine the impact of process parameters on the surface roughness and material removal rate.



In the present study, an attempt has been made to investigate on the application of taguchi methodology in optimization of surface roughness during turning of AISI 1018 using tin coated carbide tool. Taguchi analysis is applied to determine the optimal turning parameters to achieve minimum surface roughness value and maximum material removal rate for AISI-1018 alloy steel under varying machining condition.

2. EXPERIMENTATION

The experimental work was started with preparation of work piece followed by turning on CNC machine centre. Measurement of surface roughness was taken on Surtronic 25 and material removal rate was measured by using formula. Turning operations was carried out on a computer numerical control (CNC) lathe machine (Stallion 100 HS) of Hindustan machine tools Ltd. CNC lathe is one of the most versatile and widely used machine tool. The main function of a CNC lathe is to remove metal from a job to give it the required shape and size. The job is securely and rigidly held in the chuck and then turned against a single point cutting tool which will remove metal from the job in the form of chips besides the simple turning operation. In this study, TIN coated carbide tool single point cutting tools is used.



Figure 3.1: CNC Lathe machine

The machining experiments were performed on AISI-1018 low carbon alloy steel. The AISI-1018 low carbon alloy steel rod of length 1080 mm and diameter 30 mm size has been used as a work piece material for the present experiments. AISI-1018 low carbon alloy steel has good wear resistance properties. It has various applications like manufacturing of camshafts, fasteners, gears, and chains/chain pins. The AISI-1018 low carbon alloy steel rod of the length of 1080 mm and diameter of 30 mm size is mounted on the power hacksaw machine tool and specimens of the length 40 mm and diameter of 30 mm size are cut. The rod used for cutting the specimens is mounted on the machine. The final dimension of the specimens after cutting is of $\varnothing 30 \times 40$ mm.



Figure3.2: Controller of CNC Lathe machine

In this study, number of experiments required mainly depends on the approach adopted for design of experiment. Thus it is important to have a well-designed experiment plan so that number of experiments required can be minimized. The design suggested by orthogonal array has been implemented to analyze the effect of three independent variables for turning-speed, feed and depth of cut on surface roughness and material removal rate. All of these three parameters viz. speed; feed and depth of cut are the numerical parameters. The machining parameters and their levels are shown in table 2.1.

Table 2.1: Factors and levels of independent variables

Factors	Unit	Type	Levels	
			1	2
Cutting Speed(S)	m/min	numeric	100	200
Feed rate(F)	mm/rev	numeric	0.1	0.2
Depth of cut(D)	mm	numeric	0.1	0.3
Nose radius (R)	mm	numeric	0.4	0.8

Table 2.2 shows the design matrix based on orthogonal array with interaction column. The complete design layout for all experiments is in table 2.3. This demonstrates a total of 16 runs required for complete experiments.

Table 2.2: Design matrix based on orthogonal array with interaction column.

Exp. no.	Cutting Speed(S)	Feed rate(F)	Depth of cut(D)	Nose radius (R)
1	1	1	1	1
2	1	1	1	2
3	1	1	2	1
4	1	1	2	2
5	1	2	1	1
6	1	2	1	2
7	1	2	2	1
8	1	2	2	2
9	2	1	1	1
10	2	1	1	2
11	2	1	2	1
12	2	1	2	2
13	2	2	1	1
14	2	2	1	2
15	2	2	2	1
16	2	2	2	2

Table 2.3: Complete design layout

Exp. no.	Cutting Speed(S)	Feed rate(F)	Depth of cut(D)	Nose radius (R)
1	100	0.1	0.1	0.4
2	100	0.1	0.1	0.8
3	100	0.1	0.3	0.4
4	100	0.1	0.3	0.8
5	100	0.2	0.1	0.4
6	100	0.2	0.1	0.8
7	100	0.2	0.3	0.4
8	100	0.2	0.3	0.8
9	200	0.1	0.1	0.4
10	200	0.1	0.1	0.8
11	200	0.1	0.3	0.4
12	200	0.1	0.3	0.8
13	200	0.2	0.1	0.4
14	200	0.2	0.1	0.8

15	200	0.2	0.3	0.4
16	200	0.2	0.3	0.8

Table 2.4: Experimental results for surface roughness

Exp. no.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Nose radius (mm)	Surface roughness (μm)
1	100	0.1	0.1	0.4	2.31
2	100	0.1	0.1	0.8	1.497
3	100	0.1	0.3	0.4	2.638
4	100	0.1	0.3	0.8	1.702
5	100	0.2	0.1	0.4	3.766
6	100	0.2	0.1	0.8	2.794
7	100	0.2	0.3	0.4	4.431
8	100	0.2	0.3	0.8	3.791
9	200	0.1	0.1	0.4	1.781
10	200	0.1	0.1	0.8	1.362
11	200	0.1	0.3	0.4	2.21
12	200	0.1	0.3	0.8	1.968
13	200	0.2	0.1	0.4	2.502
14	200	0.2	0.1	0.8	2.316
15	200	0.2	0.3	0.4	3.408
16	200	0.2	0.3	0.8	2.773

Table 2.4 shows the measured values of surface roughness. The surface roughness of finished turned work piece has been measured making use of a portable surface tester (Surtronic 25) and the readings were recorded with three times repeated measurements.

3. RESULT AND ANALYSIS

A total number of 16 turning experiments were performed as per experimental plan shown in table 2.4. These results are further examined in MINITAB software. After the examination of ANOVA, results show that the parameters are important for response and therefore results are used for further examination.

ANOVA FOR MEAN FOR SURFACE ROUGHNESS

The ANOVA has been carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. The first step of ANOVA is to check the assumptions of ANOVA.

The analysis of variance (ANOVA) is based on two assumptions.

- (1) The variables are normally distributed
- (2) Homogeneity of variance.

To check the assumption of normal distribution, the normal probability plot of the residuals for surface roughness is shown in figure 3.1. The normal probability plot indicates whether the residuals follow a normal distribution or not, if the residuals follow a normal distribution majority of points will follow a straight line except some moderate scatter even with normal data. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.

The figure 3.2 represents residuals versus the predicted surface roughness plot. It tests the assumption of constant variance. The plot should be a random scatter. The figure shows that there is no obvious pattern and it shows unusual structure. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

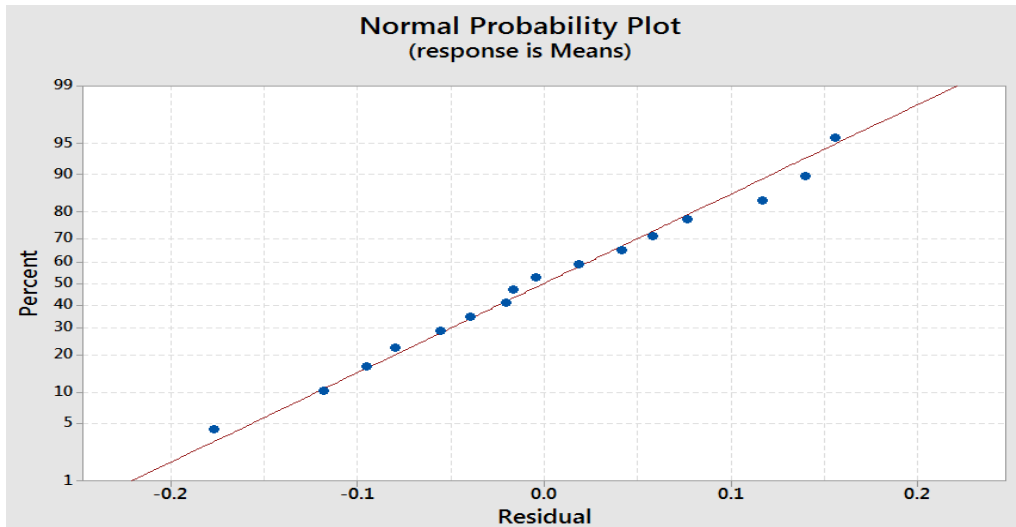


Figure 3.1 Normal probability plot of residuals for surface roughness

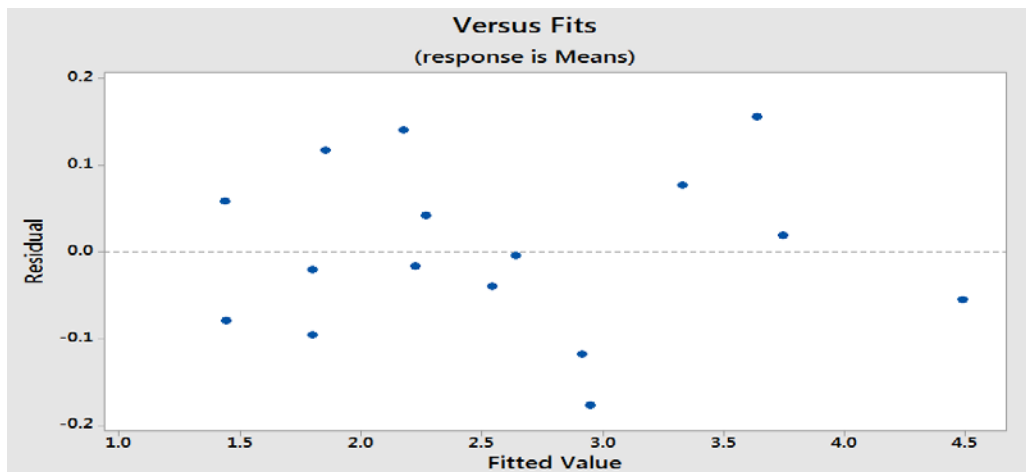


Fig. 3.2 Plot of residuals v/s predicted surface roughness

ANOVA TABLE FOR MEAN FOR SURFACE ROUGHNESS

As mention above, in this work the ANOVA was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. The ANOVA for mean for surface roughness is summarized in Table 3.1.

Table.3.1 Resulting ANOVA table for surface roughness

Source	Degree of freedom	Seq. sum of squares	Adj. mean square	F-Value	p-value Prob > F
Speed	1	1.3277	1.3277	49.2	0.001
Feed	1	6.657	6.657	246.32	0.001
depth of cut	1	1.318	1.318	48.86	0.001
Nose radius	1	1.466	1.466	54.32	0.001
Speed*Feed	1	0.546	0.546	20.25	0.006
Speed*depth of cut	1	0.0026	0.0026	0.1	0.77
Speed*Nose radius	1	0.221	0.221	8.18	0.035
Feed*depth of cut	1	0.133	0.133	4.92	0.047
Feed*Nose radius	1	0.00031	0.00031	0.001	0.97
depth of cut*Nose radius	1	0.00025	0.00025	0.01	0.92
Residual Error	5	0.135	0.027		
Total	15	11.79			

The table 3.1, shows that the value of “Prob. > F” for speed is less than 0.0001 which is less than 0.05, that indicates the speed is significant.

Table 3.2 Reduce ANOVA table for mean for surface roughness

Source	Degree of freedom	Seq. sum of squares	Adj. mean square	F-Value	p-value Prob > F
Speed	1	1.3277	1.3277	77.08	0.001
Feed	1	6.657	6.657	385.94	0.001
depth of cut	1	1.318	1.318	76.55	0.001
Nose radius	1	1.466	1.466	85.11	0.001
Speed*Feed	1	0.546	0.546	31.73	0.001
Speed*Nose radius	1	0.221	0.221	12.81	0.007
Feed*depth of cut	1	0.133	0.133	7.7	0.024
Residual Error	8	0.138	0.01725		
Total	15	11.79			
R-Squared	0.988			Adj R-Squared	0.978

The table 3.2, shows the reduce ANOVA table for mean for surface roughness after elimination of insignificant model terms. From the table it is clear that the value of “Prob. > F” for main effect of speed, feed, depth of cut, nose radius and two-level interaction of speed and feed; speed and nose radius; feed and depth of cut are less than 0.05 so these terms are still significant model terms after elimination of insignificant terms.

MINIMIZATION OF SURFACE ROUGHNESS

Table 3.3 presents the difference between the maximum and the minimum value of the turning parameters for surface roughness values. The most effective factor affecting performance characteristics is obtained by comparing these values. This comparison gives the level of importance of controllable factors over the minimum surface roughness.

Table 3.3: Response table for surface roughness

Factors	Level			
	1	2	Max.-Min.(Δ)	Rank
Speed	2.866	2.29	0.576	3
Feed	1.934	3.223	1.289	1
depth of cut	2.291	2.865	0.574	4
nose radius	2.881	2.275	0.605	2

ANOVA FOR S/N RATIO FOR SURFACE ROUGHNESS

The S/N ratio for smaller the better is used for situation where the target value is zero, such as computer response time, automotive emission, corrosion, surface roughness, tool wear, etc. The equation for smaller the better ratio is

$$(S/N)_{SB} = -10 \log (MSD_{SB}) = -10 \log \left[(\sum y^2) / N \right]$$

The negative sign is used to ensure that the target value gives the best value for the response variable and therefore robust design. Mean standard deviation is given to display the relationship to the loss function.

In the present work, for surface roughness, the smaller the better S/N ration has been applied to identify the main influencing factor that affects the surface roughness. The ANOVA for S/N ratio for surface roughness has been carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%.

The normal probability plot of the residuals for S/N ratio for surface roughness is shown in figure 3.3. The normal probability plot indicates whether the residuals follow a normal distribution or not. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.

The figure 3.4 represents residuals versus the predicted S/N ratio for surface roughness plot. It tests the assumption of constant variance. The figure shows that there is no obvious pattern and it shows unusual structure. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

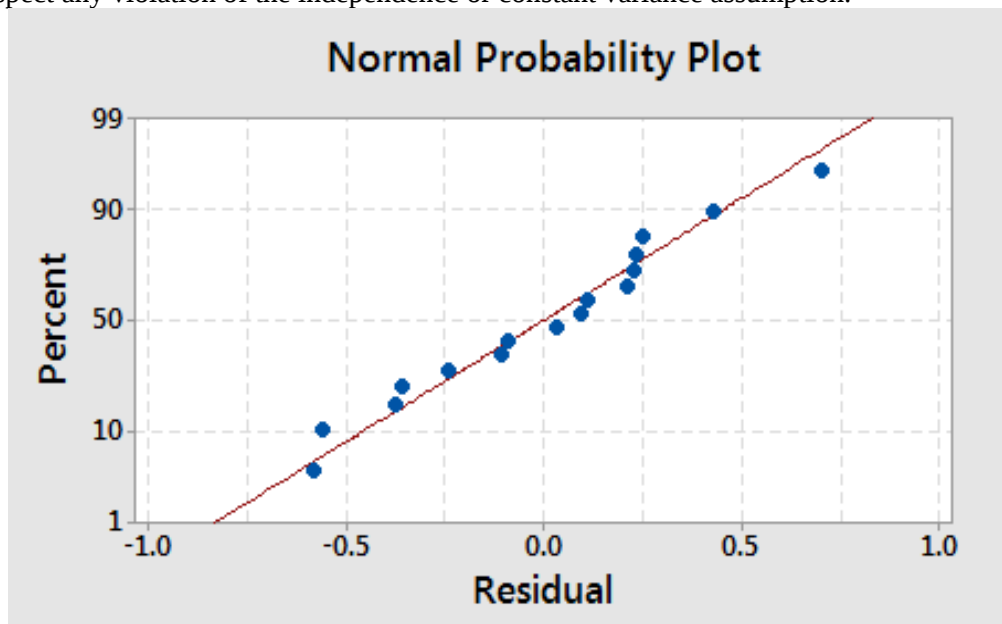


Figure 3.3 Normal probability plots of residuals for S/N ratio for surface roughness

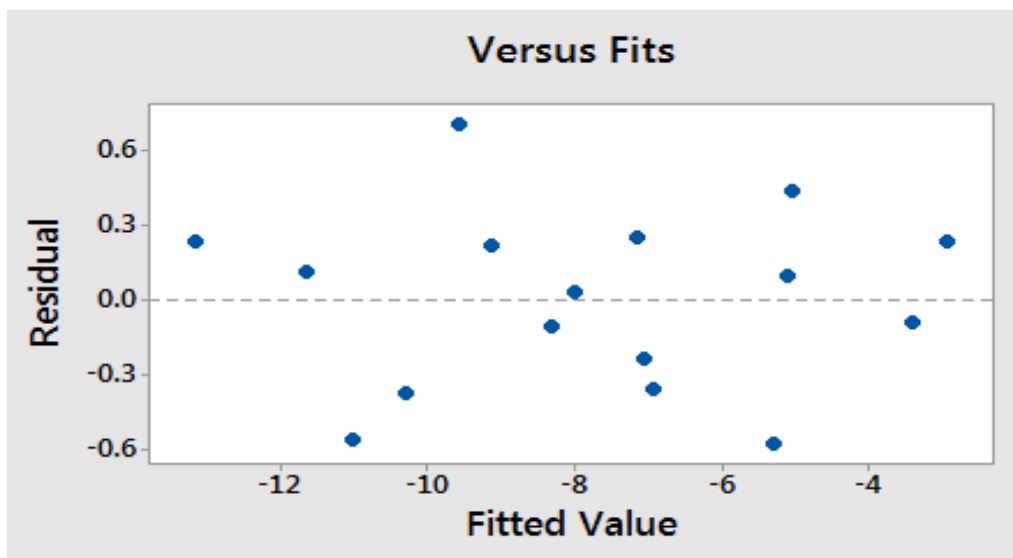


Fig. 3.4 Plot of residuals v/s predicted S/N ratio for surface roughness

ANOVA TABLE FOR S/N RATIO FOR SURFACE ROUGHNESS

As mention above, in this work, the ANOVA for S/N ratio for surface roughness has been carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. . The ANOVA for S/N ratio for surface roughness is summarized in the given Table 4.4

The table 3.4, shows that the value of “Prob. > F” for speed is less than 0.0001 which is less than 0.05, that indicates the speed is significant.

Table 3.4 Resulting ANOVA table for S/N ratio for surface roughness

Source	Degree of freedom	Seq. sum of squares	Adj. mean square	F-Value	p-value Prob > F
Speed	1	11.448	11.448	29.92	0.003
Feed	1	78.456	78.456	205.07	0.0001
depth of cut	1	15.31	15.31	40.02	0.001
Nose radius	1	18.751	18.751	49.01	0.001
Speed*Feed	1	2.908	2.908	7.6	0.04
Speed*depth of cut	1	0.558	0.558	1.46	0.281
Speed*Nose radius	1	2.047	2.047	5.35	0.039
Feed*depth of cut	1	0.059	0.059	0.15	0.711
Feed*Nose radius	1	1.266	1.266	3.31	0.129
depth of cut*Nose radius	1	0.123	0.123	0.32	0.595
Residual Error	5	1.913	0.3826		
Total	15	132.84			

Table 3.5 Reduce ANOVA table for S/N ratio for surface roughness

Source	Degree of freedom	Seq. sum of squares	Adj. mean square	F-Value	p-value Prob > F
Speed	1	11.448	11.448	26.29	0.001
Feed	1	78.456	78.456	180.15	0.0001
depth of cut	1	15.31	15.31	35.15	0.0001
Nose radius	1	18.751	18.751	43.06	0.0001
Speed*Feed	1	2.908	2.908	6.68	0.029
Speed*Nose radius	1	2.047	2.047	4.7	0.028
Residual Error	9	3.919	0.43544		
Total	15	132.84			
R-Squared	0.97			Adj R ²	0.951

The table 3.5, shows the reduce ANOVA table for S/N ratio for surface roughness after the elimination of insignificant model terms. From the table it is clear that the value of “Prob. > F” for main effect of speed, feed, depth of cut, nose radius and two-level interaction of speed and feed; speed and nose radius are less than 0.05 so these terms are still significant model terms after elimination of insignificant terms.

MINIMIZATION OF SURFACE ROUGHNESS USING S/N RATIO

Table 3.6 presents the difference between the maximum and the minimum value of the turning parameters for S/N ratio for surface roughness values. The most effective factor affecting performance characteristics is obtained by comparing these values. This comparison gives the level of importance of controllable factors over the minimum surface roughness. The most effective controllable factor corresponds to the maximum of these values. Thus the feed has been found most significant parameter that affects the surface roughness followed by nose radius, speed and depth of cut. Same results has been obtained as obtained through means for surface roughness

Table 3.6: Response table for S/N ratio (minimum is best) for surface roughness

Factors	Level		Max.-Min.(Δ)	Rank
	1	2		
Speed	-8.596	-6.904	1.692	3
Feed	-5.536	-9.965	4.429	1
depth of cut	-6.722	-8.228	1.506	4
nose radius	-8.833	-6.668	2.165	2

EFFECT OF TURNING PARAMETERS ON RESPONSE

To investigate the effect of turning parameters on surface roughness, different curves (main effect and interactions) have been plotted between the turning parameters and response.

EFFECT OF TURNING PARAMETERS ON SURFACE ROUGHNESS

Influence of turning parameters on surface roughness is shown in fig. 3.1. The result shows that the surface roughness continuously decreases as the cutting speed increases from 100 m/min to 200 m/min because as the cutting speed increases, temperature during cutting also increases, which softens the material to enhance the cutting performance leading to reduced surface roughness. The figure between the feed and surface roughness shows that the surface roughness continuously increases as the feed increases from 0.1 mm/rev to 0.2 mm/rev. This is due to the fact that at higher feed rate, tool traverses the work piece too fast, resulting in deteriorated surface quality and also high feed increases the chatter, which leads to higher surface roughness. Influence of depth of cut on surface roughness is shown in fig. 3.1. It is clear from the plot that as the depth of cut increases from 0.1 mm to 0.3 mm the value of surface roughness also increases. This result is due to the fact that, as the depth of cut increased, the tool displacement is bigger along the machined surface, removing a higher amount of material, making the furrows deeper and broader. The influence of nose radius on surface roughness has also been shown in figure 3.1. It is visible from the plot that as the nose radius increases from 0.4 mm to 0.8 mm, the value of surface roughness decreases.

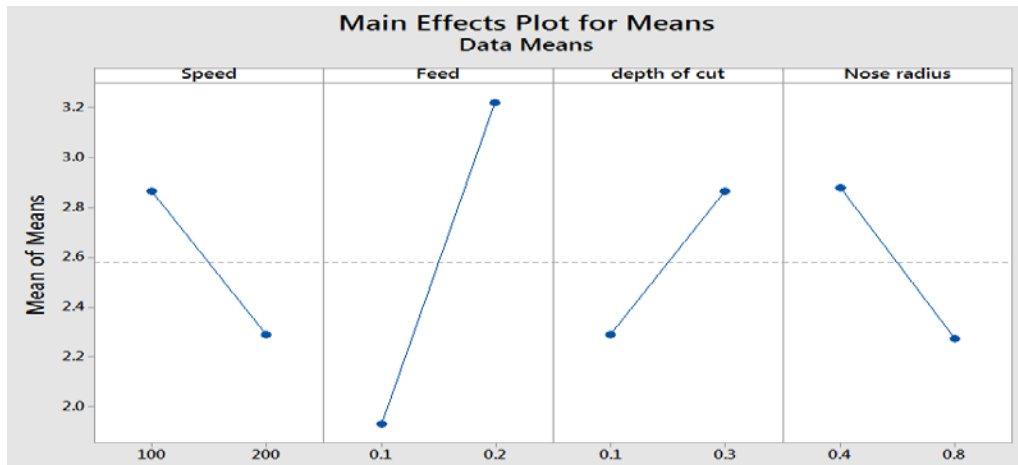


Fig. 3.1 Plot between surface roughness and turning parameters

4. CONCLUSION

Turning experiments were conducted on a CNC lathe machine using carbide cutting tool on AISI1018 low carbon alloy steel as work material. L16 orthogonal array was used for different combinations of turning experiments. The surface roughness was selected as responses under different cutting conditions for combinations of turning parameters. The present work successfully demonstrated the application of taguchi optimization of process parameters in turning of AISI 1018 low carbon alloy steel.

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

1. Feed is the main significant parameter for surface roughness.
2. The order of importance of the controllable factors to surface roughness in the turning parameters can be listed in sequence: feed, nose radius, cutting speed, and depth of cut.
3. The increase in cutting speed produces better surface finish (i.e. surface roughness).
4. The increase in nose radius produces better surface finish (i.e. surface roughness).
5. The decrease in feed produces better surface finish (i.e. surface roughness).
6. The decrease in depth of cut produces better surface finish (i.e. surface roughness).
7. The optimal level of machining parameters setting for improved surface roughness is 200 m/min cutting speed; 0.8 mm of nose radius; 0.1 mm/rev of feed and 0.1 mm of depth of cut.

8. The experimental results for optimal setting show that there is a considerable improvement in the performance characteristics of machining process. This technique does not involve any complicated theory and thus can be employed by the engineers without a strong statistical background.

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