ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 6, Issue 1, January 2017

Experimental Investigation of CNC Turning Process Parameters on AISI 1018 carbon steel

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Abstract: Process planning involves the selection of machining processes and parameters that are to be used to make a part from its initial form to its predetermined final state. Therefore, during process planning, the knowledge of optimal machining conditions for material removal rate and surface roughness is important. Here, Taguchi optimization methodology is used for optimizing the cutting parameters of CNC lathe for machining the AISI 1018 rod material. The machining parameters which are chosen to be evaluated in this study are depth of cut(d),spindle speed(s) and feed rate (f).While, the response factors to be measured are the surface roughness (SR) of the machined surface and the material removal rate(MRR).An L27 orthogonal array is used to analyze the effect of machining parameters on the MRR and SR. The analysis of variance (ANOVA) is applied to study the percentage contribution of each machining parameters while CNC turning of Mild steel material. The present investigation indicates that depth of cut is the most significant factor in case of material removal rate and feed rate is for surface roughness for turning mild steel material.

Key words- **CNC turning, Taguchi method, MRR, Surface roughness, AISI 1018 carbon steel.**

I. INTRODUCTION

The introduction of computer numerical control systems in metal cutting process lead to process automation having very high accuracies and repeatability. It also solved the need for flexibility and adaptability required in manufacturing industries. As the purchasing and operating cost of numerically controlled machine tools when compared to conventional machines are high, there arises a fiscal need to operate them as efficiently as possible to achieve required pay off. Thus in manufacturing industry, product quality, productivity and cost became imperative to economic success.

In any machining operation quality and productivity form two essential but contradictory factors that determine its effectiveness. In order to make sure that high productivity is maintained, the degree quality needs to be undermined and vise-versa. Therefore it becomes critical to simultaneously optimize quality and productivity. In a machining operation, productivity can be expressed as a function of material removal rate, whereas quality of a product can be interpreted in terms of surface finish. The selection of proper combination of machining parameters yields the desired material removal rate (MRR) and surface roughness (Ra). Further the accurate selection of machining parameters becomes vital as the optimal values of response parameters depend on them. In any machining process to obtain the desired outcome, it becomes imperative to minimize the value of Ra and maximize that of MRR. This can be carried out by optimally selecting machining process parameters like spindle speed, feed rate and depth of cut, and therefore a detailed analysis of these parameters becomes crucial to improve the machining characteristics of a CNC machine.

II. LITERATURE REVIEW

Krupal Pawar1 and R. D. Palhade conducted experiment on HSS (M2) work pieces using the three different geometrical carbide inserts of varying nose radius. The influences of cutting speed, feed rate, depth of cut and nose radius are investigated by Taguchi and ANOVA on the surface roughness and Material Removal Rate (MRR). The analysis of the experimental trials highlights that MRR in CNC turning process for HSS (M2) is highly influenced by feed rate and nose radius is most significantly influencing parameter for Ra[1] .Rahul Dhabale and Vijayakumar S. Jatti was used genetic algorithm to optimize the turning process parameters to obtain maximum material removal rate. From the research, it is observed that material removal rate is directly proportional to the spindle speed, feed rate and depth of cut. In these three factors, depth of cut shows maximum influence on the MRR [2].Sanjit Moshat et.al optimized CNC end milling process parameters to provide good surface finish as well as high material removal rate (MRR). Spindle speed, Feed rate and Depth of cut are the process control parameters and L9 orthogonal array is used for experimental design. In the study, the use of principal component analysis based hybrid Taguchi method has been proposed and adopted for solution of multiobjective optimization [3].D Kanakaraja et.al investigated the effects of spindle speed, feed and depth of cut on surface roughness. The researchers attempted to find the influence of turning parameters spindle speed, feed rate, and depth of cut using Analysis of Variance (ANOVA). It was found that feed rate poses major influence on surface roughness and next is followed by spindle speed and depth of cut. From the experiment it is shown that surface roughness increase with the increase of feed rate [4].Pinki Maurya, Dr. Pankaj Sharma and Bijendra Diwaker conducted a study on CNC end milling and attempted to find out the influence of various machining parameters like tool feed, tool speed, tool diameter and depth of cut .In this study, experiments were conducted on AL 6351 –T6 material with three levels and four factors to optimize process parameter and surface roughness. Four factors selected are Tool feed, Tool speed, Tool diameter and Depth of cut. In this experiment it is founded that the parameter has most significant is tool feed [5].Senthil Kumar and Rajendran performed experimentation on Aluminum Hybrid Metal Matrix Composites. NOVA analysis revealed that, feed rate poses major influence on surface roughness and cutting speed for material removal rate [6].Basil M. Eldhose et.al done experiment on CNC turning machine. The response parameters were MRR and surface roughness. For MRR, Depth of cut was the major influential parameter. Within the levels selected; no spindle speed and feed poses considerable change for MRR.But in the case of surface roughness, the contribution of spindle speed and feed were higher than depth of cut [7].Shunmugesh K et.al selected cutting speed, feed and depth of cut as parameters and done experiment on CNC turning centre. The results revealed that the primary factor affecting the surface roughness is feed rate, subsequently followed by speed and depth of cut [8].

III. MATERIAL AND METHODS

AISI 1018 material was used as work piece material of dimension ø32 mm ×150 mm long. In this study, spindle speed, feed rate and depth of cut were considered as machining parameters and turning was carried out. Experiments were designed using L27 Taguchi orthogonal array. Table 1 shows the machining parameters and their levels.

Table 1: Machining parameters with their levels

Level	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	1800	0.10	0.100
2	2000	0.15	0.175
3	2200	0.20	0.250

All Work pieces were machined prior to the experiments to 30 mm by using CNC lathe in order to make all work pieces are in equal dimension and to make the surface free from dirt and rust. Twenty seven equal parts of 150 mm length were selected for the experimentation. CNC lathe, Gedee Weiler Uniturn 300 is used for turning purpose by using orthogonal array. Each specimen is turned up to 100 mm in each trial and response parameters are identified. The response parameters selected for the experiments are Material removal rate and surface roughness. Material removal rate was calculated by using equation 1. Surface roughness of work pieces are measured by using surf test instrument.

$$MRR = \frac{\pi}{4}\left(D_i^2 - D_f^2\right) \times F \times N \qquad \rightarrow (1)$$

Where,
D_i = initial diameter (mm), D_f = final diameter (mm), F= feed rate(mm/rev), N=spindle speed(rpm)
The optimal setting of parameters can be obtained from Taguchi analysis. To determine the effect of each variable on the output, the signal-to-noise ratios or the SN number, are calculated for each experiment. For a smaller the better characteristic, the following definition of the SN ratio can be used.

$$SN_i = -10\, log\left(\sum_{u=1}^{N_i} \frac{y_u^2}{N_i}\right) \qquad \rightarrow (2)$$

For a larger the better characteristic, the following definition of the SN ratio can be used.

ISSN: 2319-5967
ISO 9001:2008 Certified
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$$SN_i = -10\ log\left(\frac{1}{N_i}\sum_{u=1}^{N_i}\frac{1}{y_u^2}\right) \quad \rightarrow (3)$$

Where, i = experiment number, u = trial number, y =observed value, N_i = number of trials for experiment

Here MRR is a larger the better characteristic and surface roughness is a smaller the better characteristic. The S/N ratio was calculated to identify the optimum machining parameter. The significant parameters were found based on Taguchi design methodology by the ANOVA, which indicated the relationship between machining parameters and output performance characteristics.

IV. RESULTS AND DISCUSSION

In order to see the effect of process parameters on the MRR and SR, experiments were conducted using L27 orthogonal array as shown in table 2. The average values of MRR and Surface roughness for each parameter at levels 1, 2 and 3 are plotted in figure 1 and 2 respectively.

Table 2: L27 orthogonal array and observed values

Trial No.	Spindle Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	MRR	S/N ratio MRR	SR	S/N ratio SR
1	1800	0.10	0.100	6.12	15.735	0.75	2.498
2	1800	0.10	0.175	14.40	23.167	1.35	-2.606
3	1800	0.10	0.250	20.34	26.167	0.77	2.270
4	1800	0.15	0.100	4.05	12.149	2.52	-8.028
5	1800	0.15	0.175	8.37	18.454	1.02	-0.172
6	1800	0.15	0.250	41.04	32.264	2.13	-6.567
7	1800	0.20	0.100	6.12	15.735	2.18	-6.769
8	1800	0.20	0.175	38.52	31.713	2.26	-7.082
9	1800	0.20	0.250	45.00	33.064	1.07	-0.587
10	2000	0.10	0.100	9.00	19.084	1.19	-1.510
11	2000	0.10	0.175	26.40	28.432	1.39	-2.860
12	2000	0.10	0.250	25.00	27.958	0.98	0.175
13	2000	0.15	0.100	10.20	20.172	1.14	-1.138
14	2000	0.15	0.175	6.60	16.390	1.16	-1.289
15	2000	0.15	0.250	43.50	32.769	1.21	-1.655
16	2000	0.20	0.100	8.00	18.061	1.50	-3.521
17	2000	0.20	0.175	24.40	27.747	1.78	-5.008
18	2000	0.20	0.250	116.00	41.289	1.87	-5.436
19	2200	0.10	0.100	3.30	10.370	2.05	-6.235
20	2200	0.10	0.175	4.84	13.696	1.16	-1.289
21	2200	0.10	0.250	31.90	30.075	1.30	-2.278
22	2200	0.15	0.100	3.63	11.198	1.56	-3.862
23	2200	0.15	0.175	37.29	31.431	1.48	-3.405
24	2200	0.15	0.250	31.68	30.015	1.36	-2.670
25	2200	0.20	0.100	58.08	35.280	1.64	-4.296
26	2200	0.20	0.175	73.04	37.271	1.94	-5.756
27	2200	0.20	0.250	108.24	40.687	1.61	-4.136

ISSN: 2319-5967
ISO 9001:2008 Certified
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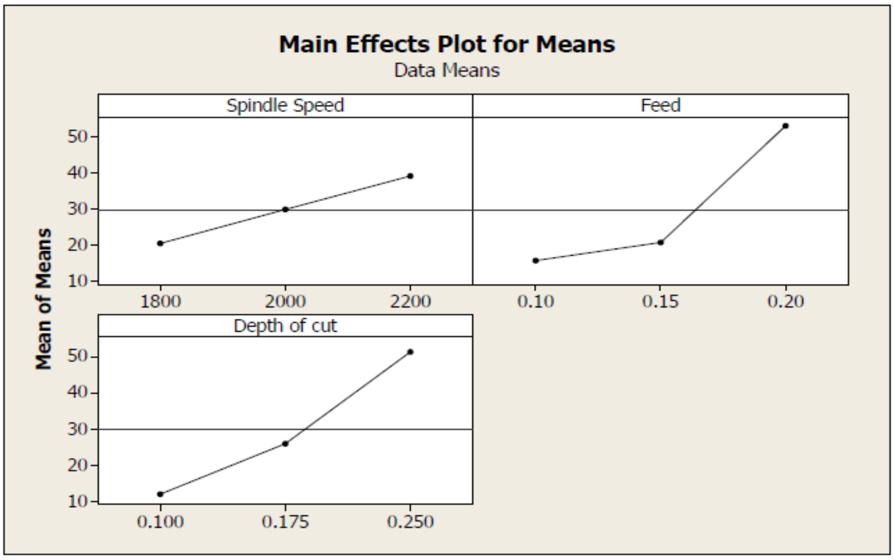

Fig. 1: Main effects plot for means of MRR

Figure 1 show that MRR increase with increase in spindle speed, feed rate and depth of cut. It is known that material removal rate is directly proportional to the spindle speed, feed rate and depth of cut. The same was observed from the experimental results. Spindle speed is the speed at which the work piece rotates. Feed rate is the rate at which the tool advances along its cutting path. Depth of cut is the thickness of the layer being removed (in a single pass) from the work piece. Thus, the volume of material removed increases with increase in depth of cut.

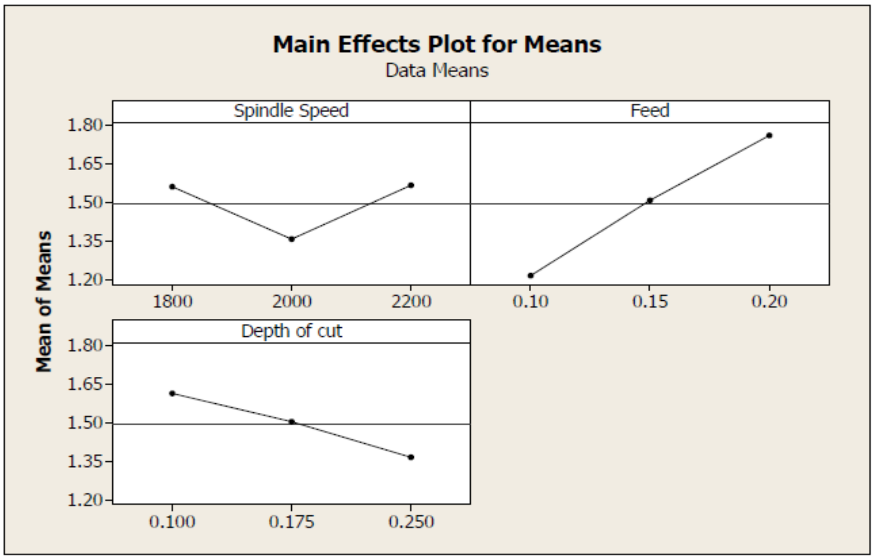

Fig. 2: Main effects plot for means of SR

From figure 2, it is seen that surface roughness first decreases with increase in spindle speed and then increases for the given range. With the increase in feed rate, Ra increases; wheras it decreases with increase in depth of cut. Anova analysis revealed that, within the given range of parameters, feed rate is the most significant parameter that influences surface roughness. For spindle speed and depth of cut, the graphs obtained do not reflect the general behavior, as these parameters are non-significant for the given range.

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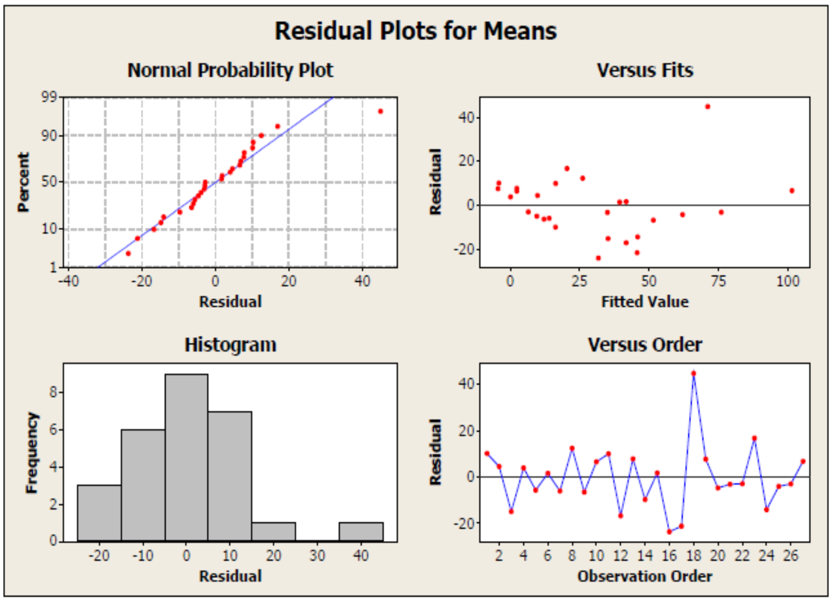

Fig. 3: Residual plot for means of MRR

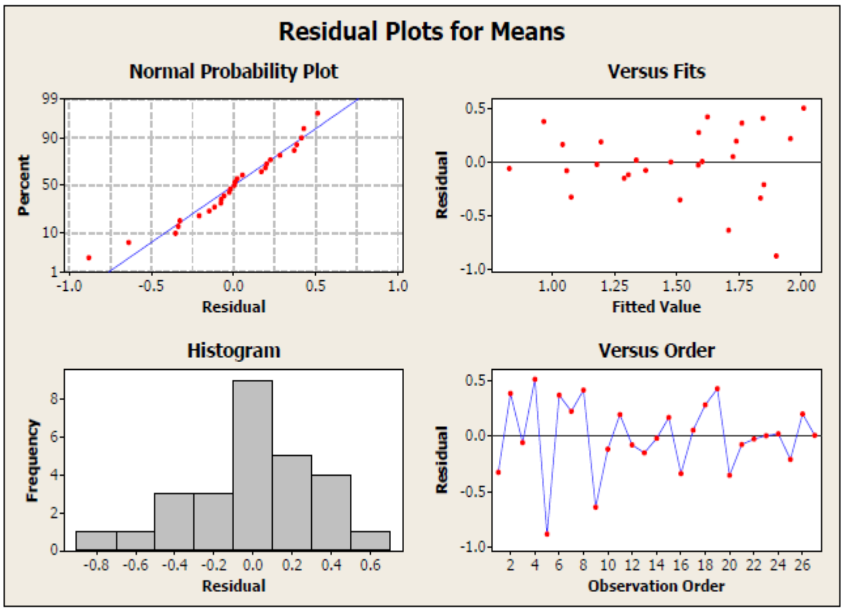

Fig. 4: Residual plot for means of SR

Residual plots are used to evaluate the data for the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. It can be seen from figure 3 and 4 that the residuals follow an approximately straight line in normal probability plot .Since residuals exhibit no clear pattern, there is no error due to time or data collection order. In order to study the significance of the process variables towards MRR and SR, analysis of variance was performed at a confidence interval of 95% i.e. a significance level of 0.05 (table 3 and 4). It was found that feed rate and depth of cut are significant process parameters for MRR. But for surface roughness; feed rate is most significant parameter.

Table 3: Analysis of variance table for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle speed	2	1569	1569	784.4	2.56	0.109
Feed	2	7396	7396	3698.1	12.07	0.001
Depth of cut	2	7168	7168	3584.1	11.70	0.001

Spindle speed*feed	4	2376	2376	594.0	1.94	0.153
Residual error	16	4903	4903	306.5		
Total	26	23412				

Table 4: Analysis of variance table for SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle speed	2	0.2550	0.2550	0.1275	0.74	0.493
Feed	2	1.3419	1.3419	0.6709	3.89	0.042
Depth of cut	2	0.2774	0.2774	0.1387	0.80	0.464
Spindle speed*feed	4	1.0086	1.0086	0.2521	1.46	0.260
Residual error	16	2.7572	2.7572	0.1723		
Total	26	5.6401				

The response tables (table 5 and 6) shows the average of each response characteristic for each level of each factor. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. From table 5, the ranks and the delta values show that depth of cut has the greatest effect on material removal rate and is followed by feed rate and spindle speed. Response table for surface roughness (table 6) shows that feed rate poses major effect on surface roughness and is followed by depth of cut and spindle speed

Table 5: Response table for means of MRR

Level	Spindle Speed	Feed	Depth of cut
1	20.44	15.70	12.06
2	29.90	20.71	25.98
3	39.11	53.04	51.41
Delta	18.67	37.34	39.36
Rank	3	2	1

Table 6: Response table for means of SR

Level	Spindle Speed	Feed	Depth of cut
1	1.561	1.216	1.614
2	1.358	1.509	1.504
3	1.567	1.761	1.367
Delta	0.209	0.546	0.248
Rank	3	1	2

As MRR is the “higher the better” type quality characteristic and from the table 7and from figure 1 that the third level of spindle speed, third level of feed rate, and third level depth of cut provide maximum value of MRR.As surface roughness is the “smaller the better” type quality characteristic and from table 8 and figure 2,it can be seen that second level of spindle speed, first level of feed and third level of depth of cut provide minimum value of surface roughness. The optimum values of MRR and SR can be predicted by using taguchi approach. The estimated mean of MRR can be determined as:

μ_{MRR} =A3+B3+C3-2T

Where,

T=overall mean of MRR=29.81 mm^3/min

A3=average value of MRR at the third level of spindle speed=39.11 mm^3/min

B3=average value of MRR at the third level of feed=53.04 mm^3/min

C3=average value of MRR at the third level of depth of cut=51.41 mm^3/min

Substituting the value in the equation 2.

μ_{MRR} =39.11+53.04+51.41-2×29.81

=83.94 mm^3/min

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 6, Issue 1, January 2017

The same approach is used to find out estimated mean of surface roughness also. Then the predicted value of SR become,

μ_{SR} =0.9508 µm

In order to validate the results three runs of confirmation experiments were carried out at the optimal setting of input parameters. The values obtained after experiment poses less than 5% error with the predicted mean. Table 7 shows the confirmation results with predicted values.

Table 7: Predicted optimal values and results of confirmation experiments

Performance measure	Optimal set of parameters	Predicted optimal value	Actual value
MRR(mm^3/min)	A3 B3 C3	83.94	86.35
SR(µm)	A2 B1 C3	0.9508	1.051

V. CONCLUSION

The experiments are conducted on mild steel work pieces and the influences of spindle speed, feed rate and depth of cut are investigated by Taguchi and ANOVA on the surface roughness and Material Removal Rate (MRR). Based on the results obtained, the following conclusions can be drawn:

1. The analysis of the experimental trials highlights that MRR in CNC turning process for mild steel is highly influenced by depth of cut followed by feed rate. It is observed that the feed rate is most significantly influencing parameter on the surface roughness followed by depth of cut.

2. ANOVA analysis for MRR shows that depth of cut and feed rate, significantly affect material removal rate. While in the case of surface roughness, feed rate is significant parameter.

3. The optimum parameters level setting for maximum MRR is found to be A3=2200 rpm, B3 = 0.20 mm/rev and C3= 0.250 mm. The optimum parameters level setting for minimum Ra is found to be A2 =2000 rpm, B1= 0.10 mm/rev and C3 = 0.250mm.

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ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 6, Issue 1, January 2017

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