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Optimizing Turning Process by Taguchi Method Under Various Machining Parameters

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Abstract - *This paper attempts on optimizing the turning process under various machining parameters by Taguchi method to develop or implement the quality of machined product. Taguchi optimization methodology is applied to optimize cutting parameters in turning AISI 1045 steel with coated cemented carbide tool under dry cutting condition. The CNC turning machine is used to conduct experiments based on the Taguchi design of experiments (DOE) with orthogonal L9 array. The orthogonal array, signal to noise ratio (S/N) and analysis of variance were employed to find the maximum material removal rate (MRR) and minimum surface roughness. The experimental results showed that that the optimal combination of parameters for surface roughness are at spindle speed of 620 rpm, feed rate of 0.3 mm/min, depth of cut of 0.7 mm while for material removal rate are at spindle speed of 620 rpm, feed rate of 0.5 mm/min, depth of cut of 0.9 mm. The optimum value of the surface roughness (Ra) comes out to be 2.35 μm. While the optimum value of the material removal rate (MRR) comes out to be 44.15 mm^3/min. Optimum results are finally verified with the help of confirmation experiments.*

Keywords – *Turning Process, Parameters of machining, AISI 1045 steel, Taguchi Method, ANOVA.*

1. INTRODUCTION

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. The ratio between costs and quality of products in each production stage has to be monitored and immediate corrective actions have to be taken in case of Deviation from desired trend. Surface roughness measurement presents an important task in many engineering applications. Many life attributes can be also determined by how well the surface finish is maintained. Machining operations have been the core of the manufacturing industry since the industrial revolution and the existing optimization researches for Computer Numerical Controlled (CNC) turning were either simulated within particular manufacturing circumstances or achieved through numerous frequent equipment operations. These conditions or manufacturing circumstances are regarded as computing simulations and their applicability to real world industry is still uncertain and therefore, a general optimization scheme without equipment operations is deemed to be necessarily developed. Surface roughness is commonly considered as a major manufacturing goal for turning operations in many of the existing researches. The machining process on a CNC lathe is programmed. Many surface roughness prediction systems were designed using a variety of sensors including dynamometers for force and torque. Taguchi and Analysis Of Variance (ANOVA) can conveniently optimize the cutting parameters with several experimental runs well designed.

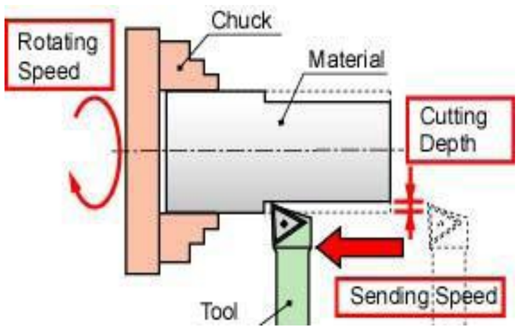

Fig. 1.1 Turning Process Parameters

1.1 Taguchi Method

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions[2].

Steps of Taguchi method are as follows:

(1) Identification of main function, side effects and failure mode.
(2) Identification of noise factor, testing condition and quality characteristics.
(3) Identification of the main function to be optimized.
(4) Identification the control factor and their levels.
(5) Selection of orthogonal array and matrix experiment.
(6) Conducting the matrix experiment.
(7) Analyzing the data, prediction of the optimum level and performance.
(8) Performing the verification experiment and planning the future action. [4]

1.2 Analysis of variance (ANOVA)

Since there are a large number of variables controlling the process, some mathematical models are required to represent the process. However, these models are to be developed using only the significant parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the analysis of variance (ANOVA)[7]. ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response.

2. RESULTS AND ANALYSIS

2.1 Data Collection

MS bars (of diameter 50 mm and length 100 mm) required for conducting the experiment have been prepared first. Nine numbers of samples of same material and same dimensions have been made. Then, using different levels of the process parameters nine specimens have been turned in CNC lathe accordingly. After machining, surface roughness measured precisely with the help of a portable stylus-type profilometer, *Talysurf* (Taylor Hobson, Surtronic 3+, UK).

The results of the experiments have been shown in Table. Analysis has been made based on experimental data in the following chapter. Optimization of surface roughness and material removal rate has been made by Taguchi. Confirmatory tests have also been conducted finally to validate optimal results. **Experimental Data Related to Surface Roughness Characteristics**

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/rev), f	Depth of cut (mm), d	Surface roughness, Ra (µm)	S/N ratio of surfaces roughness
1	160	0.3	0.7	2.24	-7
2	160	0.4	0.8	5.67	-15.07
3	160	0.5	0.9	5.93	-15.46
4	320	0.3	0.8	5.34	-14.55
5	320	0.4	0.9	4.87	-13.75
6	320	0.5	0.7	6.07	-15.66
7	620	0.3	0.9	2.91	-9.27
8	620	0.4	0.7	3.78	-11.54
9	620	0.5	0.8	5.05	-14.06

Table No. 1

2.2 Surface Roughness Measurement

The surface roughness test was done by using Mitutoyo surface roughness tester 'Surftest SJ 201' was used. The probe was adjusted to measure the R_a value. The probe was moved a distance of 3mm.

2.3 Material Removal Rate Measurement

Material removal rate is used to determine the amount of material removed per second. It is given by the formula

$$MRR = 1000\ V\ f\ d$$

Where V = Cutting speed (m/min)

f = feed rate (mm/rev)

d= depth of cut (mm)

MRR= Material removal rate (mm^3/ min)

As the conditions for feed, cutting velocity and depth of cut are fixed so this formula is used to calculate the MRR instead of calculating the initial and the final weight, the above formula was used to calculate the MRR.

2.4 Calculations Of S/N Ratios For Surface Roughness Of Table No. 1

Calculation for Table 1.

1. S/N Ratio (Experiment 1) = η_1= -10log [1/n ($\sum Yi^2$)] =-10 log [1/ $(2.24)^2$] = -7

2. S/N Ratio (Experiment t 2) = η_2= -10 log [$(5.67)^2$] = -15.07

3. S/N Ratio (Experiment 3) = η_3= -10 log [$(5.93)^2$] = -15.46

4. S/N Ratio (Experiment 4) = η_4= -10 log [$(5.34)^2$] = -14.55

5. S/N Ratio (Experiment 5) =η_5 = -10 log [$(4.87)^2$] = -13.75

6. S/N Ratio (Experiment 6) = η_6= -10 log [$(6.07)^2$] = -15.66

7. S/N Ratio (Experiment 7) = η_7= -10 log [$(2.91)^2$] = -9.27

8. S/N Ratio (Experiment 8) = η_8= -10 log [$(3.78)^2$] = -11.54

9. S/N Ratio (Experiment 9) = η_9= -10 log [$(5.05)^2$] = -14.06

2.5 Calculations Of S/N Ratios For Material Removal Rate Of Table

Calculation for Table 2

1. S/N Ratio (Experiment 1) = η_1= -10log [1/n ($\sum 1/Yi^2$)] =-10 log [1/$(5.27)^2$] = 14.43

2. S/N Ratio (Experiment t 2) = η_2= -10 log [1/ $(8.03)^2$] = 18.09

3. S/N Ratio (Experiment 3) = η_3= -10 log [1/ $(11.3)^2$] = 21.06

4. S/N Ratio (Experiment 4) = η_4= -10 log [1/ $(12.19)^2$] = 21.79

5. S/N Ratio (Experiment 5) =η_5 = -10 log [1/ $(18.28)^2$] = 25.23

6. S/N Ratio (Experiment 6) = η_6= -10 log [1/ $(17.78)^2$] = 24.99

7. S/N Ratio (Experiment 7) = η_7= -10 log [1/ $(26.28)^2$] = 28.39

8. S/N Ratio (Experiment 8) = η_8= -10 log [1/ $(27.25)^2$] = 28.70

9. S/N Ratio (Experiment 9) = η_9= -10 log [1/ $(38.93)^2$] = 31.80

Measurement of Material Removal Rate (MRR)

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/rev), f	Depth of cut (mm), A	MRR (mm^3/min)	S/N ratio of MRR
1	160	0.3	0.7	5.27	14.43
2	160	0.4	0.8	8.03	18.09
3	160	0.5	0.9	11.30	21.06
4	320	0.3	0.8	12.19	21.79
5	320	0.4	0.9	18.28	25.23
6	320	0.5	0.7	17.78	24.99
7	620	0.3	0.9	26.28	28.39
8	620	0.4	0.7	27.25	28.70
9	620	0.5	0.8	38.93	31.80

Table No. 2

2.6 Signal –To - Noise Ratio

Parameters that affect the output can be divided in two parts: controllable (or design) factors and uncontrollable (or noise) factors. The value of controllable factors can be adjusted by the designer but the value of uncontrollable factors cannot be changed because they are the sources for variation because of operational environment. The best setting of control factors as they influence the output is determined by performing experiments. Smaller-the-Better is used for surface roughness and Bigger-the-Better is used for material removal rate because we minimize the surface roughness and maximize the material removal rate.

2.7 Measurement Off-Value Of Fisher's F Ratio

The F values determine the significance of the parameters. Larger the F value, the greater the effect on the performance characteristic due to the change in that process parameter, F value is defined as:

$$F = \frac{MS\ for\ the\ term}{MS\ for\ the\ error\ term}$$

2.6 Anova For Surface Roughness

Results obtained for the surface roughness are shown in the Table 1. The results for surface roughness were obtained from the 9 experiments performed of Taguchi. The experimental results analyzed with ANOVA are shown in the Table 3. The F value calculated through MINITAB 15 software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%). The results show that only feed is the most significant factor.

Table No. 3: Analysis of Variance for Means of Surface Roughness (Ra)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle speed (rpm), N	2	3.4417	3.4417	1.7208	2.11	0.322
Feed rate (mm/rev), f	2	7.2395	7.2395	3.6197	4.43	0.184
Depth of cut (mm), d	2	2.6564	2.6564	1.3282	1.63	0.381
Error	2	1.6347	1.6347	0.8173		
Total	8	14.9723				
S = 0.904071		**R-Sq = 89.08 %**		**R-Sq (adj) = 56.33%**		

2.7 Main Effect Plots For Surface Roughness

Main effect plots for surface roughness are shown in the figure2.1. Main effect plot shows the variation of surface roughness with respect to Spindle speed, feed rate and depth of cut. X axis represents change in level of the variable and y axis represents the change in the resultant response.

Figure 2.1: Main effects plot for means for surface roughness

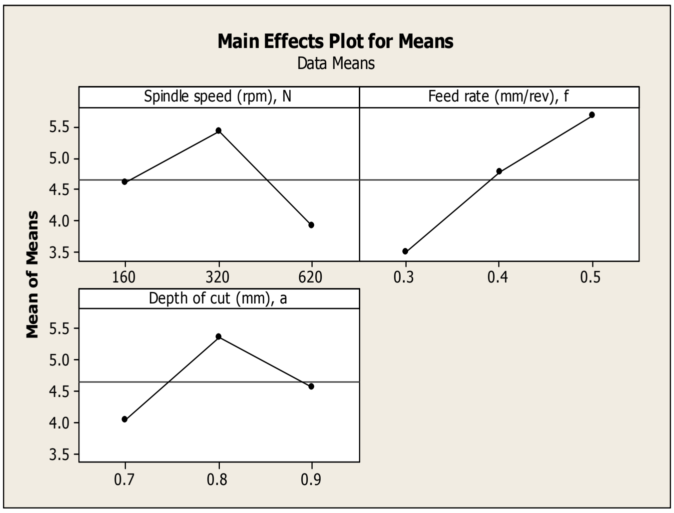

Figure 2.1: Main effects plot for S/N ratios for surface roughness

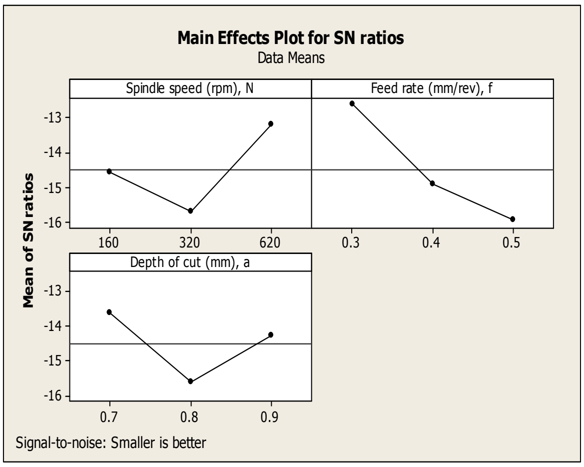

Figure 2.2

2.8 Anova For Material Removal Rate (MRR)

Results obtained for the material removal rate (mrr) are shown in the Table 2. The results for material removal rate (mrr) were obtained from the 9 experiments performed of Taguchi. The experimental results analyzed with ANOVA are shown in the Table 3. The F value calculated through MINITAB software is shown in the second last column of ANOVA table which suggests the significance of the factors on the desired characteristics. Larger is the F value higher is the significance (considering confidence level of 95%).

The results show that only feed is the most significant factor. In the Table 4.6 ranks have been given to the various factors. Higher is the rank higher is the significance. Spindle speed is the most significant factor.

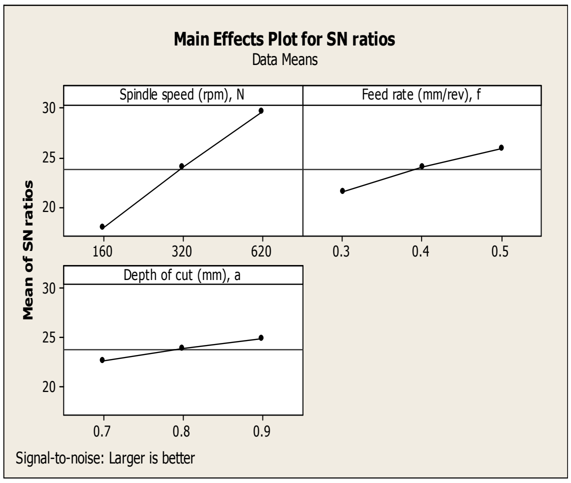

Fig 2.3: Main effects plot for S/N ratios for Material removal rate (MRR)

2.8 Confirmation Test

The last step of Taguchi parameter design is to verify and predict the improvement of surface roughness (response) using optimum combination of cutting parameters.

The predicted optimal value (η_{opt}) can be calculated by means of additive law.

$$\eta_{opt} = m + \sum_{j=1}^{n} [(m_{i,j})_{\max} - m]$$

Where m= overall mean of η with nine trials; (m_{ij}) max = S/N ratio at optimal level and parameter; n is the number of main designing parameters that affect the machining process.

3.CONCLUSION AND FUTURE SCOPE

The following conclusions are done from the study

- It has been found that feed rate is found to be the most significant factor & its contribution to surface roughness is 47.51 %. The best results for surface roughness (lower is better) would be achieved when AISI 1045 work piece is machined at spindle speed of 620 rpm, feed rate of 0.3 mm/rev and depth of cut of 0.7 mm. With 95% confidence interval.
- The Surface roughness is mainly affected by feed rate, depth of cut and spindle speed. With the increase in feed rate the surface roughness also increases, as the depth of cut increases the surface roughness first increase and decrease and as the spindle speed increase surface roughness decreases.
- From ANOVA analysis, parameters making significant effect on surface roughness are feed rate and depth of cut.
- Optimal machining parameters for minimum surface roughness were determined. The percentage error between experimental and predicted result is 6.83 %.
- The parameters taken in the experiments are optimized to obtain the minimum surface roughness possible. The optimum setting of cutting parameters for high quality turned parts is as :-
    1. Spindle speed = 620 rpm
    2. Feed rate = 0.3 mm/ rev
    3. Depth of cut = 0.7 mm
- From ANOVA analysis, parameters making significant effect on material removal rate are feed rate and spindle speed.
- Optimal machining parameters for maximum material removal rate were determined. The percentage error between experimental and predicted result is 0.7 %.
- The parameters considered in the experiments are optimized to attain maximum material removal rate. The best setting of input process parameters for defect free turning (maximum material removal rate) within the selected range is as follows:-
    1. Spindle speed = 620 rpm
    2. Feed rate = 0.5 mm/ rev
    3. Depth of cut = 0.9 mm

3.1 Scope For Future Work

In this present study only three parameters have been studied in accordance with their effects. Other factors like Nose radius, Types of Inserts, cutting conditions (dry or wet) etc. can also be studied. Also, the other outputs like power consumption, tool life, cutting forces etc. can also be added.

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