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Optimization of Process Parameters in Turning of AISI 8620 Steel Using Taguchi and Grey Taguchi Analysis

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ABSTRACT
The aim of this research is to investigate the optimization of cutting parameters (cutting speed, feed rate and depth of cut) for surface roughness and metal removal rate in turning of AISI 8620 steel using coated carbide insert. Experiments have been carried out based on Taguchi L_9 standard orthogonal array design with three process parameters namely cutting speed, feed rate and depth of cut for surface roughness and metal removal rate. The objective function has been chosen in relation to surface roughness and metal removal rate for quality target. Optimal parameters contribution of the CNC turning operation was obtained via grey relational analysis. The analysis of variance is applied to identify the most significant factor. Experiment with the optimized parameter setting, which has been obtained from the analysis, are giving to validate the results.
Keywords – ANOVA, Grey relational analysis, Material removal rate, Surface roughness, Taguchi orthogonal array.

I. INTRODUCTION

Industries around the world constantly focus on the quality of the product. From the Customer's viewpoint quality is very important because the quality of product affects the degree of satisfaction of the consumer during usage of the product. So it is very necessary for the industries to produce the product with good quality. Turning operation is widely used in the today's manufacturing industries and the quality of the surface plays a very important role in the performance of turned part because a good quality turned surface improves fatigue strength, corrosion resistance and creep life of the product. Material removal rate also play a very important role because it affects some factors such as manufacturing lead time, cost, power and quality of the product. It can be increased by increasing the process parameters. Surface roughness and material removal are affected by many factors such as the machining variables, the tool geometry, Work piece and tool material combination, tooling, coolant and Vibrations between the work piece, machine tool and cutting tool. So during machining, it is very difficult to take all the parameters that control the surface roughness and material removal rate. The work material used for this study is AISI 8620 steel.

Nian et al. studied about optimization of turning operations based on the Taguchi method with multiple performance characteristics and the authors employed the orthogonal array, multi-response signal-to-noise ratio, and analysis of variance and from results they conclude that Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters [1]. Noordin et al. described about the performance of a multilayer tungsten carbide tool using response surface methodology (RSM) and finally they found that the feed is the most significant factor that influences the surface roughness and the tangential force [2, 14]. Kirby E. D. et al developed model for the prediction of surface roughness using Fuzzy methodology [3]. Another authors Nalbant et al. studied for finding the optimal cutting parameters for surface roughness in turning of AISI 1030 steel bars using TiN coated tools and they used Taguchi method for optimization and authors conclude that the insert radius and feed rate are the main parameters that influence the surface roughness [4]. Lalwani et al. investigated about the effect of cutting parameters on cutting forces and surface roughness in finish hard turning of MDN250 steel using coated ceramic tool and they used response surface methodology (RSM) and sequential approach using face centered central composite design and they suggested that the depth of cut is most significant factor for feed force and feed rate is most significant factor for surface roughness [7]. Davim et al. developed Surface roughness prediction models using artificial neural network (ANN) and they found that cutting speed and feed rate have most significant effects in reducing the surface roughness, while the depth of cut has the least effect [8]. Asilturk and Akkus used Taguchi method for optimizing the turning parameters to minimize surface roughness and finally they concluded that the feed rate has the most significant effect on Ra and Rz [9]. Kumar et al. investigated about the effect spindle speed and feed rate on surface roughness and they used five different carbon alloy steels named as SAE8620, EN8, EN19, EN24 and EN47 and they suggested that the surface roughness is directly influenced by the spindle speed and feed rate [11]. Gunay and Yucel optimized about the cutting conditions for the average surface roughness (Ra) obtained in machining of high-alloy white cast iron (Ni-Hard) at two different hardness levels (50 HRC and 62 HRC) and from experiment they conclude that cutting speed and feed rate are the most significant factor for surface roughness [13]. Makadia and Nanavati studied about the effect of the main turning parameters on the surface roughness and developed a mathematical prediction model of the surface roughness and they employed Response Surface Methodology (RSM) and found that the feed rate is the main factor followed by tool nose radius that mostly influences the surface roughness [15].

II. SCHEME OF EXPERMENT FOR INVESTIGATION

In order to improve the quality characteristics, the present investigation has been made in the following sequences.

- Selection of work piece material.
- Identify the important cutting parameters.
- Find the range of the identified process parameters.
- Select the orthogonal array (design of matrix).
- Conduct the experiments as per the selected orthogonal array.
- Record the quality characteristics (i.e. material property).
- Find the optimum condition for surface roughness and material removal rate.
- Conduct the confirmation test.
- Identify the significant factors.

III. METHODOLOGY EMPLOYED

3.1 GREY RELATIONAL ANALYSIS

3.1.1 DATA PREPROCESSING

Grey data processing must be performed before Grey correlation coefficients. A series of various units must be transformed to be dimensionless. Usually, each series is normalized by dividing the data in the original series by their average. Let the original reference sequence and sequence for comparison be represented as and, *i*=1, 2. . . *m*; *k*=1, 2, . . ., *n* respectively where *m* is the total number of experiment to be considered and *n* is the total number of observation data. Data pre processing converts the original sequence to a comparable sequence. Several methodologies of pre processing data can be used in Grey relation analysis, depending on the characteristics of the original sequence. If the target value of the original sequence is “the-larger-the-better”, then the original sequence is normalized as follows.

$$x_i^*(k) = \frac{x_i^{(O)}(k) - \min.\ x_i^{(O)}(k)}{\max.x_i^{(O)}(k) - \min.x_i^{(O)}(k)} \quad (1)$$

If the purpose is “the-smaller-the-better”, then the original sequence is normalized as follows

$$x_i^*(k) = \frac{\max.x_i^{(O)}(k) - x_i^{(O)}(k)}{\max.\ x_i^{(O)}(k) - \min.x_i^{(O)}(k)} \quad (2)$$

However, if there is “a specific target value” then the original sequence is normalized using.

$$x_i^*(k) = 1 - \frac{\left|x_i^{(O)}(k) - OB\right|}{\max.\ \left\{\max.x_i^{(O)}(k) - OB, OB - \min.\ x_i^{(O)}(k)\right\}} \quad (3)$$

Where, OB is the target value. Alternatively, the original sequence can be normalized the simplest methodology that is the values of the original sequence can be divided by the first value of the sequence, $x_i^{(O)}(1)$.

$$x_i^*(k) = \frac{x_i^{(O)}(k)}{x_i^{(O)}(1)} \quad (4)$$

Where $x_i^{(O)}(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data pre processing, max $x_i^{(O)}(k)$ the largest value of $x_i^{(O)}(k)$, min $x_i^{(O)}(k)$: the smallest value of $x_i^{(O)}(k)$. [7][16]

3.1.2 CALCULATION OF GREY RELATIONAL COEFFICIENT AND GREY RELATIONAL GRADES

Following the data pre processing, a Grey relational coefficient can be calculated using the pre processed sequences. The Grey relational coefficient is defined as follows.

$$\gamma\left(x_0^*(k), x_i^*(k)\right) = \frac{\Delta_{\min.} + \zeta\,\Delta_{\max.}}{\Delta_{0i}(k) + \zeta\,\Delta_{\max.}}$$

$$0 < \gamma\left(x_0^*(k), x_i^*(k)\right) \leqq 1 \quad (5)$$

Where $\Delta_{0i}(k)$ is the deviation sequence of reference sequence $x_0^*(k)$ and comparability sequence $x_i^*(k)$, namely?

$\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right|, \quad \Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left|x_0^*(k) - x_j^*(k)\right|,$

$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left|x_0^*(k) - x_j^*(k)\right|,$

ζ is the distinguishing coefficient, $\zeta \in [0,1]$

A Grey relational grade is a weighted sum of the Grey relational coefficients, and is defined as follows.

$$\gamma\left(x_0^*, x_i^*\right) = \sum_{k=1}^{n} \beta_k \gamma\left(x_0^*(k), x_i^*(k)\right)$$

$$\sum_{k=1}^{n} \beta_k = 1 \qquad (6)$$

Here, the Grey relational grade $\gamma\left(x_0^*, x_i^*\right)$ represents the level of correlation between the reference and comparability sequences. If the two sequences are identical, then the value of the Grey relational grade equals to one. The Grey relational analysis is actually a measurement of the absolute value of data difference between the sequences, and can be used to approximate the correlation between the sequences. [5, 12]

3.2 ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) and F-test (standard analysis) are used to analysis the experimental data as given follows. [5]

Notation: Following Notation are used for calculation of ANOVA method.

C.F. = Correction factor
T = Total of all result
n = Total no. of experiments
S_T = Total sum of squares to total variation.
X_i = Value of results of each experiments (i = 1 to 9)
S_Y = Sum of the squares of due to parameter Y (Y = A, B, C)
N_{Y1}, N_{Y2}, N_{Y3} = Repeating number of each level (1, 2, 3) of parameter Y
X_{Y1}, X_{Y2}, X_{Y3} = Values of result of each level (1, 2, 3) of parameter Y
F_Y= Degree of freedom (D.O.F.) of parameter of Y
f_T = Total degree of freedom (D.O.F.)
f_e = Degree of freedom (D.O.F.) of error terms
V_Y = Variance of parameter Y
S_e = Sum of square of error terms
V_e = Variance of error terms
F_Y = F-ratio of parameter of Y
S_Y' = Pure sum of square
C_Y= Percentage of contribution of parameter Y
C_e = Percentage of contribution of error terms
$CF = T^2/n$
$S_T = \Sigma_{i=1 \text{ to } 16} Xi^2 - CF$
$S_Y = (X_{Y1}^2/N_{Y1} + X_{Y2}^2/N_{Y2} + X_{Y3}^2/N_{Y3}) - CF$
f_Y = (number of levels of parameter Y) – 1
f_T = (total number of results)-1
$f_e = f_T - \Sigma f_Y$
$V_Y = S_Y/f_Y$
$S_e = S_T - \Sigma S_Y$
$V_e = S_e/f_e$
$F_Y = V_Y/V_e$
$S_{Y'} = S_Y - (V_e * f_z)$
$P_z = S_{Y'}/S_T * 100\%$,
$P_e = (1- \Sigma P_Y)*100\%$

IV. EXPERIMENTAL DETAILS

4.1. WORK PIECE MATERIAL

In the present study AISI 8620 steel rods are used for turning on CNC Lathe Trainer. The diameter of steel rods was taken 35 mm and length was 100 mm during experiments shown in Fig 2. The work piece material is chosen because of its wide use in automotive industry for ring gears, pinions, helical gears, bearing races, Arbors, bushes, camshafts, kingpins, ratchets, gears, splined shafts etc.

Chemical composition of the material is shown in Table 1. The cutting tool selected for machining the AISI 8620 steel is CVD coated carbide inserts designed as TNMG 160408 GS CA5515.

Table 1 The chemical composition of AISI 8620 steel

Elements	**C %**	**Si %**	**Mn %**	**Cr %**	**Ni %**	**Mo %**
Weight %	**0.20**	**0.25**	**0.80**	**0.50**	**0.55**	**0.20**

4.2. SELECTION OF PARAMETERS AND THEIR LEVELS

In the present study, the experiments plan has three variables of machining, named as cutting speed, feed and depth of cut. [10, 12, 16]

The process parameters and their levels are shown in Table 2.

Table 2 Process parameter and their levels

Para meters	Unit	Nota tion	Levels of parameters		
			Leve l 1	Level 2	Level 3
Cutting speed	m/min	V	150	200	250
Feed rate	mm/re v	F	0.07	0.14	0.21
Depth of cut	Mm	D	0.6	1.2	1.8

The experiments are carried out on a CNC lathe Trainer (MIDAS 8i) as shown in Fig. 1.

CNC lathe Trainer specifications

Type: - CNC lathe MIDAS 8i
Controller: - Fanuc
Turning Length: - 522 mm
Swing Clearance Dia. Over Carriage: - 230 mm
Swing Clearance Dia. Over Way Covers: - 430 mm
Spindle Power: - 9/7.5 KW
Rapid feed Traverse (X & Z Axes): - 30 m/min
Speed Range: - 40-4000 rpm.

Fig. 1 Photograph of CNC lathe Trainer

Fig. 2 Actual Work piece

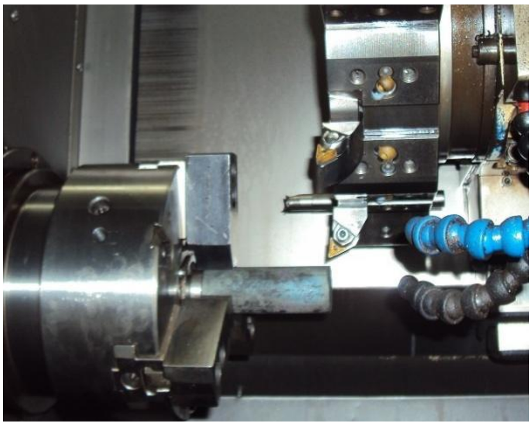


Fig. 3 Photograph of Actual experimental setup

4.3. MEASUREMENTS OF QUALITY CHARACTERSTICS

Surface roughness and material removal rate are the important measure of product performance and quality. In this research work measurement of surface roughness were performed by a Mitutoyo SJ-201 P surface roughness tester (Japan) with a 2.5 mm sampling length and drive speed measuring 0.25-0.50 mm/sec shown in Fig 4. The measurements are repeated three times at different locations and average value is used in research work. The material removal rate is also calculated in this research work.

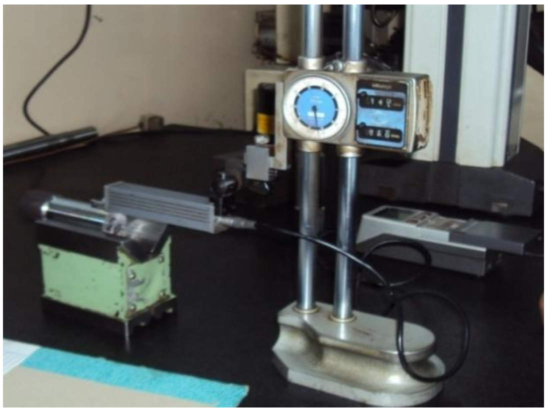


Fig. 4 Actual Photograph of surface roughness tester

4.4. DESIGN OF EXPERIMENT

Experimental design by full factorial design with three factors and three levels involves 27 numbers of experiments. The number of experiment increases with increase of process parameters and take lots of time and cost. The degree of freedom is defined as the numbers of comparisons between machining parameters that need to be made to determine, which level is better and specifically how much better it is. As per Taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degrees of freedom (DOF) and OA (Orthogonal Array) to be selected must satisfy the following conditions: D.O.F. of O.A. selected ≥ D.O.F. required. The experiment under consideration has 6 D.O.F. and therefore requires an O.A with 8 or more D.O.F. Hence an O.A. with at least 9 experiments is to be selected to estimate the effect of each factor and the desired interaction. [4, 6, 16]

For such kind of situation Taguchi L_9 orthogonal array is used as shown in Table 3.

Table 3 Taguchi L_9 orthogonal array

S. No.	Factor A	Factor B	Factor C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

V. EXPERIMENTAL RESULTS

All the analysis was made by using statistical software. Table 4 displays the Experimental results in terms of process parameters and measured values of surface roughness and material removal rate. Table 5 shows the values of pre processed data results and Grey relational coefficient which is obtained from experimental data. Table 6 shows the values of Grey Relational Grade and Table 7 displays the response table for means of Grey Relational Grade.

Table 4 Experimental results for optimization

Exp. No.	V	F	D	R_a	MRR
1	150	0.07	0.6	0.64	6.3
2	150	0.14	1.2	0.88	25.2
3	150	0.21	1.8	1.65	56.7
4	200	0.07	1.2	0.79	16.8
5	200	0.14	1.8	1.06	50.4
6	200	0.21	0.6	1.54	25.2
7	250	0.07	1.8	0.86	31.5
8	250	0.14	0.6	0.93	21
9	250	0.21	1.2	1.67	63

Table 5 Grey Relational Analysis Calculations

Exp. No.	Pre processed data results		Grey relational coefficient	
	R_a	MRR	R_a	MRR
1	1	0	0.333	1
2	0.766	0.333	0.394	0.600
3	0.019	0.888	0.963	0.360
4	0.854	0.185	0.369	0.729
5	0.592	0.777	0.457	0.391
6	0.126	0.333	0.798	0.600
7	0.786	0.444	0.388	0.529
8	0.718	0.259	0.410	0.658
9	0	1	1	0.333

Table 6 Grey Relational Grades

Exp. No.	V	F	D	Grey Relational Grade
1	1	1	1	0.666
2	1	2	2	0.497
3	1	3	3	0.661
4	2	1	2	0.549
5	2	2	3	0.424
6	2	3	1	0.699
7	3	1	3	0.458
8	3	2	1	0.534
9	3	3	2	0.666

Table 7 Response Table for means of grey relational grade

Levels	Factors		
	V	F	D
1	0.608	0.558	0.633
2	0.557	0.485	0.571
3	0.553	0.675	0.514
DELTA	0.055	0.190	0.119
RANK	3	1	2

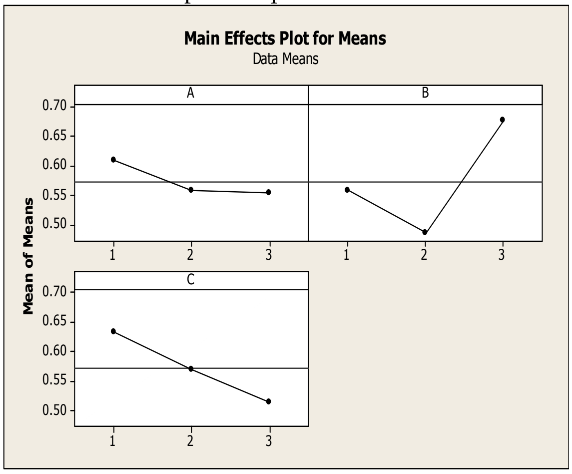
VI. ANALYSIS OF VARIANCE (ANOVA)

The purpose of ANOVA is to see which process parameters are statistically significant. Table 8 shows Analysis of variance for Grey relational grade and Figure 5 displays the Graph between the Grade relational grade and process parameters. The notations used in this graph are A for cutting speed, B for feed rate and C for depth of cut.

Table 8 Analysis of variance (ANOVA)

Factors	DOF	SS	MS	F	P	Remarks
V	2	0.0057	0.0028	2.73	0.268	
F	2	0.0554	0.0277	26.71	0.036	Significant
D	2	0.0211	0.0106	10.20	0.089	
Error	2	0.0021	0.0010			
Total	8	0.0842				

Fig. 5 Graph between Grade relational grade and process parameters



VII. RESULT AND DISCUSSION

After identifying the most influential parameters, the last phase is to verify the surface roughness and material removal rate by conducting the confirmation experiments. The V_1-F_3-D_1 is an optimal parameter combination for turning operation via grey relational analysis. Therefore, from the Fig.5 the condition [$\mathbf{V_1}$-$\mathbf{F_3}$-$\mathbf{D_1}$] of the optimal process parameters of the turning operation was treated as a confirmation test. If the optimal setting for AISI 8620 steel with cutting speed 150 (m/min), feed rate 0 .21 (mm/rev) and depth of cut 0.6 (mm) is used then the final work piece gives the surface roughness 0.60 (µm) is minimum, the material removal rate 70 (Cm^3/min) is maximum.

VIII. CONCLUSION

In the present study, Taguchi optimization technique pair with grey relational analysis has been adopted for evaluating parametric complex to carry out acceptable surface roughness lower is better, material removal rate higher is better of the AISI 8620 steel during turning on a CNC Lathe Trainer. After identify the optimal process parameters setting for turning operation, ANOVA is also applied for finding the most significant factor during turning operation. In this study it is concluded that the feed rate is the most significant factor for the surface roughness and material removal rate together, as the P-value is less than 0.05. Cutting speed and depth of cut is found to be insignificant from the ANOVA study.

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