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Process parameter Optimization of CNC Turning for Titanium Wrought Alloy

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Abstract—Optimization of machining parameters is valuable to maintain the accuracy of the components and to minimize the cost of machining. Tool wear and Surface finish are important measure for machining cost and the quality of the machined parts respectively. The present work is an experimental investigation to study the effect of machining parameters on tool wear and surface roughness for turning of VT-20 (titanium wrought alloy). The experiments were conducted as per Taguchi's L9 Orthogonal Array on CNC lathe. Cutting parameters of speed, feed and depth of cut were taken as inputs and machining was done by CNMG 120408 insert. Regression models for the responses were prepared by using MINITAB-16 software. It was found that speed has high influence followed by feed and depth of cut has very low influence in achieving the optimum values for tool wear and surface roughness. Finally, experimental and Regression values of responses were compared, it was found that both values are close to each other hence, the regression models prepared were more accurate and adequate.

Keywords—CNC Turning, Titanium wrought alloy, Grey Relational Analysis

I. INTRODUCTION

CNC Turning is one of the most commonly used operations for producing rounded work piece in shorter time at reasonable cost and good surface finish. VT-20 is widely used material in aerospace industry by turning process due its lighter weight. It is highly desirable that products with good surface quality are manufactured with minimum cost. The surface quality of products is generally determined in terms of the measured surface roughness. Tool wear and surface roughness are generally dependent on the cutting parameters such as: cutting speed, feed rate and depth of cut. Proper selection of these control factors is important in order to produce components with good surface finish and high tolerance with minimum cost. In the last few decades, a lot of work has been carried out to improve the product quality and efficiency in machining, still various aspects related to this study are yet to be explored.

Ravindra Thamma [1] has found different models to obtain optimal machining parameters for required surface roughness for an aluminum 6061 work pieces. He concluded that Spindle speed, feed rate, and nose radius have significant control factors for surface roughness. Smoother surfaces will be produced when machined with a larger spindle speed, smaller feed rate, and nose radius Depth of cut has a significant influence on surface roughness. H. M. Somashekara et. al. [2] used control factors e.g. cutting speed, feed rate and depth of cut to optimize Surface Roughness while machining Al 6351-T6 alloy with Uncoated Carbide tool. They used Taguchi Technique to optimize the process parameters and confirmation test were also performed for finding main factors influencing Surface Roughness. They concluded that Speed has a greater influence on the Surface Roughness. Gaurav Vohra et. al. [3] have optimized the machining parameters for boring of aluminum material on CNC turning center e.g. cutting speed, feed rate and depth of cut, to obtain optimal material removal rate and minimum surface roughness by using the Taguchi method. The conclusion found that the spindle speed and depth of cut are the most affecting parameters for metal removal rate and for roughness spindle speed and feed rate are the most affecting parameters. Ranganath M S et. al. [4] have studied the parameters, which affects surface roughness produced during the machining process of aluminum 6061 on CNC turning machine. They used Taguchi Methodology and confirmation test ANOVA to analyze the experimental results. The conclusion found that the feed rate and spindle speed are the most significant process parameters on surface roughness. Biswajit Das et. al. [5] has studied surface roughness affecting parameters on turning operation using CNC turning machine. The mainly affected control factors in experimentation were spindle speed, feed and depth of cut. They found that, the feed rate is the affecting parameter for surface roughness. Md. Tayab Ali et. al. [6] have optimized the machining parameters such as spindle speed, feed rate, and depth of cut for optimization of material Removal Rate (MRR) and Surface Roughness for machining of alloy of Aluminum (AA6063-T6) using carbide tool in dry condition on CNC Lathe .They concluded that the most affecting parameters for surface roughness are feed, cutting speed and least affecting factor is depth of cut. For metal removal rate, the depth of cut and the cutting speed is the most affecting parameters and least affecting factor is feed. Ali Abdallah et. al. [7] had optimized machining parameters for the surface roughness with aluminum alloy 6061 material in CNC Lathe. They uses „response surface methodology‟ on control factors such as feed rate, spindle speed, and depth of cut, and minimize surface roughness and maximize the material removal rate for CNC turning operation. Based on the results of surface roughness it was found that feed rate affects both surface roughness and metal removal rate. The spindle speed is the most significant control factor for surface roughness than metal removal rate. Larger spindle speed results minimum surface roughness and this result can be explained along with other affecting parameters.

In this paper, process parameters in CNC turning are optimized for machining VT-20. Appropriate selection of the cutting parameters can provide a minimum machining cost. Grey relational analysis was used for optimization.

II. EXPERIMENTATION

2.1. Experimental set-up

During this study, series of experiments on the VT-20 were conducted on CNC lathe (shown in Fig 1) to examine the effect of input machining parameters, such as cutting speed, Feed and depth of cut on tool wear and surface roughness.

Fig -1: CNC Lathe

In this experimental work the CNMG 120408 inserts (CNMG is ISO form, 12-edge length, 04-insert thickness & 08-Corner radius) was used as tool material. The tool flank wear of worn out insert were measured with profile projector and surface roughness was measured with surface tester of Mitutoyo SJ-400 series is used.

2.2. Experiment design

The experiments has been conducted with three controllable factors namely cutting speed, Feed and depth of cut. On the basis of preliminary experiments conducted by using one variable at a time approach the range of input parameters are selected. For this experiment the two factors with its three level design is used. This forms L9 orthogonal array having 9 experimental runs. Machining parameters and their level chosen for this study are presented in Table 1.

Table 1. Machining Parameters and their levels

Parameter	UNIT	LEVELS		
		1	2	3
SPEED	m/min	250	300	350
DOC	mm	0.5	1	1.5
FEED	mm/rev	0.15	0.2	0.25

Design of experiment is an effective tool to design and conduct the experiments with minimum resources. Orthogonal Array is a statistical method of defining parameters that converts test areas into factors and levels. The Table 2 shows the design matrix used in this work.

Table 2. Design Matrix of L9 Orthogonal Array

Sr. No	COADED			ACTUAL		
	Speed	DOC	FEED	Speed	DOC	FEED
1	1	1	1	250	0.5	0.15
2	1	2	2	250	1	0.2
3	1	3	3	250	1.5	0.25
4	2	1	2	300	0.5	0.2
5	2	2	3	300	1	0.25
6	2	3	1	300	1.5	0.15
7	3	1	3	350	0.5	0.25
8	3	2	1	350	1	0.15
9	3	3	2	350	1.5	0.2

2.3. Experimental result

Experiments were conducted as per L9 orthogonal array, assigning various values of the levels to the process parameters. As the objective is to obtain the low tool wear and best surface finish, it is concerned with obtaining smaller value of both tool wear and surface roughness. Hence, the required quality characteristic for tool wear rate and surface roughness is smaller the better, which states that the output must be as low as possible.

Table 3. Experimental results

Sr. No	Speed (m/min)	DOC (mm)	FEED (mm/rev)	TW (mm)	Ra (µm)
1	250	0.5	0.15	0.0770	0.423
2	250	1	0.2	0.1610	0.435
3	250	1.5	0.25	0.1270	0.437
4	300	0.5	0.2	0.1380	0.269
5	300	1	0.25	0.1690	0.328
6	300	1.5	0.15	0.2130	0.439
7	350	0.5	0.25	0.1950	0.194
8	350	1	0.15	0.2730	0.275
9	350	1.5	0.2	0.3590	0.475

III. GREY RELATIONAL ANALYSIS

The grey relational analysis is a widely used analyzing system even when a model is uncertain or the information is incomplete. It provides an efficient solution to complicated interrelationships among multiple performance characteristics. Steps of grey relational analysis are given as follow:

3.1 Normalization

There are three different types of data normalization according to whether we require the LB (lower-the-better), the HB (higher-the-better) and NB (nominal-the-best). The normalization is taken by the following equations.

(a) HB (higher-the-better)

$$x_i(k) = \frac{y_i - min\ y_i\ (k)}{\max y_i(k) - min\ y_i\ (k)} \ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

(b) LB (lower-the-better)

$$x_i(k) = \frac{\max y_i(k) - y_i\ (k)}{\max y_i(k) - min\ y_i\ (k)} \ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

(c) NB (nominal-the-best)

$$X_i^*\ (k) = \frac{y_i\ (k) - y_i}{\max y_i(k) - y_i\ (k)} \ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

Here, i= 1, 2… m; k=1, 2… n

Where x_i (k) is the value after the grey relational generation, min y_i (k) is the smallest value of y_i (k) for the k^{th} response, and max y_i (k) is the largest value of y_i (k) for the k^{th} response. An ideal sequence is x_0 (k) for the responses. The purpose of grey relational grade is to reveal the degrees of relation between the sequences say, [x_0 (k) and x_i (k) , i = 1, 2,3.......,9].

3.2 Determination of deviation sequences, Δ_{0i}

The deviation sequence Δ_{0i} is the absolute the reference sequence x0 (k) and the comparability sequence xi (k) after normalization. It is determined using

$$\Delta_{0i} = |x0\ (k) - xi\ (k)| \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

3.3 Calculation of grey relational coefficient (GRC)

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1.

$$\xi_i(k) = \frac{\Delta_{min} + \theta\ \Delta_{max}}{\Delta_{0i}(k) + \theta\ \Delta_{max}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where, $\Delta_{0i} = \| x_o(k) - x_i(k) \| =$ difference of the absolute value $x_o(k)\ and\ x_i(k)$; θ is the distinguishing coefficient $0 \le \theta \le 1$; $\Delta_{min} = \forall j^{min} \in i \forall k^{min} \| x_o(k) - x_j(k) \|$ = the smallest value of Δ_{0i} ; and $\Delta_{max} = \forall j^{max} \in i \forall k^{max} \| x_o(k) - x_j(k) \|$ = largest value of Δ_{0i} . Comparability sequence and ζ is the distinguishing coefficient. The value of θ can be adjusted with the systematic actual need and defined in the range between 0 and 1, $\theta \in [0, 1]$. It will be 0.5 generally.

3.4 Determination of grey relational grade (GRG):

The overall evaluation of the multiple performance characteristics is based on the grey relational grade. After averaging the grey relational coefficients, the grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where, n = number of process responses.
In this experiment, the normalized tool wear and surface roughness values corresponds to “smaller-the-better” (SB) criterion that can be calculated Using equation 2. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade.

IV. RESULT AND DISSCUSSION

According to Table 4, the factor A, the speed is the most significant controlled parameter for the CNC turning operation followed by feed, and depth of cut with minimization of tool wear and surface roughness. The A1-B1-C3 is an optimal parameter combination of the CNC turning process.

Table 4: Response table for the Grey Relational Grade

Symbols	Parameters	Grey Relational Grade			Main effect	Rank
		Level-1	Level-2	Level-3		
A	SPEED	0.5799	0.5567	0.4339	0.1460	1
B	DOC	0.5294	0.5274	0.4407	0.0887	3
C	FEED	0.5511	0.5019	0.6277	0.1257	2

TW = - 0.320 + 0.00154 Speed + 0.0963 DOC - 0.240 Feed………………………….. (7)

Ra = 0.679 - 0.00117 Speed + 0.155 DOC - 0.593 Feed……………………………. (8)

The optimal combinations of the machining parameter levels was determined from Table 4, as A1 (Speed 250 m/min), B1 (DOC 0.5 mm) and C3 (Feed 0.25 mm/rev). Regression models were prepared and used for prediction of responses. The % errors between experimental and predicted values were found within a range of ±0.20. Confirmatory experiments were performed using the optimum values and it was found that experimental response values were close enough to predicted values. If the optimum setting with speed of 250 m/min, DOC of 0.5 mm and feed of 0.25 mm/rev is used, it gives TW of 0.0531 mm and Ra of 0.3157 µm.

V. CONCLUSION

Based on the experimental and predicted results obtained by Taguchi and Regression methods, the following conclusions can be drawn:

1. The Optimal combination of process parameters for obtaining low tool wear and surface roughness values are cutting speed 250 m/min, depth of cut 0.5 mm and feed 0.25 mm/rev.
2. If the optimum setting is used, it gives TW of 0.0531 mm and Ra of 0.3157 µm.
3. It was found that cutting speed is the most dominant parameter that has high influence on both tool wear and surface roughness followed by feed and depth of cut.
4. Regression models prepared were used for prediction of responses. The % errors between experimental and predicted values were within a range of ±0.20.

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