An Experimental Investigation to Study the Effect of Process Parameters on Surface Roughness in CNC Lathe

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Abstract: **In the Modern manufacturing, the quality of finished parts is defined by many requirements. Surface roughness of a machined part is one such important requirement due to which manufacturers are seeking various methods to improve it. Process input parameters such as cutting speed, depth of cut and feed rate and process output characteristics such as vibration, temperature and cutting force are the most generally considered parameters influencing surface roughness quality of a machined part. Selection and optimization of input process parameters leading to minimized effect of output characteristics on surface roughness is an important aspect in a manufacturing process. This paper focuses on optimization of input process parameters for CNC turning operation to conduct plain turning operation on ferrous material. In this experimental study, set of process parameters were selected based on Taguchi orthogonal array technique and measured surface roughness as output characteristic. Relation between input and output was established using analysis of variance (ANOVA) tool. An attempt has been made to obtain significant factors influencing surface roughness.**

Keywords: Machining parameters, Taguchi method, analysis of variance

1. INTRODUCTION

Surface roughness depends on factors such as vibration, cutting force, temperature etc. In turn these factors can be controlled using process parameters such as cutting speed, depth of cut, feed rate. The optimization of these process parameters finally results in enhanced quality of product. Therefore, prediction or Monitoring of the surface roughness has been an important area of research.

Various experiments have been conducted to study the effect of various parameters on surface roughness. An experimental study on EN 8 steel bars with HSS tool on tool wear monitoring in turning reveals that increase in cutting speed leads to increase in tool wear [1]. A study on Aluminum 6061 material in CNC turning operation with cemented carbide insert type by optimizing process parameters such as tool rake angle, tool nose radius, cutting speed, feed rate, depth of cut results in small increase in feed rate deteriorates surface finish to a large extent as compared to small amount of increase of depth of cut [2]. Similarly a study on the prediction of surface roughness under various conditions of machining parameters during turning operation on lathe by using L9 Taguchi orthogonal array resulted in development of ANN Based Prediction Model [3]. Further, an experimental study was carried out to study the influence of the temperature during turning and drilling operation. The study revealed the influence of technological parameters such as machining regime, tool material, cutting geometry etc. on cutting temperature [4]. A study on Al 6063 aluminum without any cutting fluid and a CCGT-09T30FL turning insert to predict and control of cutting tool vibration in CNC lathe from the experimental results demonstrate that the depth of cut and cutting speed are the main parameters that influence the vibration of cutting tool [5]

2. DESIGN OF EXPERIMENT (DOE)

A preplanned or predesigned and executed experiment can provide a lot of information more than the random experiment. This type of design of experiment includes holding certain factors constant or varying it at a certain levels simultaneously etc. The design of experiments depends on the number of factors and number of levels in each factor. Factorial design and Taguchi orthogonal array are the most frequently used design of experiments methods in experimental studies.

Factorial design: A full factorial design of experiment consists of two or more factors, each with discrete possible values or "levels", and experiments are performed for all possible combinations of these levels across all such factors. Based on these factors they are classified as 2^k factorial designs and 3^k factorial designs.

In 2^k design 2 represents the factors and k represents the number of levels the 2^2 is the simplest among this having two factors A and B, each at two levels. We usually think of these levels as the factor’s low and high levels, it requires 4 tests or runs. In the 2^2 design, it is customary to denote the low and high levels of the factors A and B by the signs − and +, respectively. This is sometimes called the geometric notation for the design. Similarly 3^k factorial has 3 factors and k number of levels simple among them is 3^2 which have 9 runs or tests. As the number of levels in this factors increases the runs or test trials increases and results in investment of more money and time.

An experiment was carried out to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. Full factorial design was designed initially in the presented work considering three cutting parameters or factors such as depth of cut (DOC), feed rate (FR) and spindle speed(SS) with three levels of operation for each factor [6].

Taguchi orthogonal array: As the number of levels and factors increases, the number of trails in an experimental work is also increases which lead to more machining time and cost. A unique technique, called Taguchi orthogonal array tool is used to get an optimal number of experiments there by reducing number trails and hence reducing machining time and cost involved. The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. Using orthogonal arrays significantly reduces the number of experimental configurations. Furthermore, the conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings. Different steps followed in this technique is as follows,

Step1: Identify the main function, side effects, and failure mode
Step2: Identify the noise factors, testing conditions, and quality characteristics
Step3: Identify the objective function to be optimized
Step4: Identify the control factors and their levels
Step5: Select the orthogonal array matrix experiment
Step6: Conduct the matrix experiment
Step7: Analyze the data; predict the optimum levels and performance [7].

The Taguchi method can reduce research and development costs by improving the efficiency of generating information needed to design systems that are insensitive to usage conditions, manufacturing variation, and deterioration of parts. As a result, development time can be shortened significantly; and important design parameters affecting operation, performance, and cost can be identified. Furthermore, the optimum choice of parameters can result in wider tolerances so that low cost components and production processes can be used. Thus, manufacturing and operations costs can also be greatly reduced [8].

3. ANALYSIS OF VARIANCE (ANOVA)

The ANOVA procedure performs analysis of variance (ANOVA) for balanced data from a wide variety of experimental designs. In analysis of variance, a continuous variable, known as a dependent variable it is measured under experimental conditions identified by independent variables. The variation is assumed to be due to effects in the classification, with random error accounting for the remaining variation. ANOVA can be as one way ANOVA and Two ways ANOVA. In general one way ANOVA technique is used to study the effects of a single factor over a variety of levels. But this cannot be used for a multi factor analysis as in this experiment.

In two way ANOVA technique multiple factor along with multiple level can be analyzed we make use of this technique. The F-test in ANOVA is used to assess whether the expected values of a variable within several pre-defined factors and levels differ from each other. F-test can be used to determine type of hypothesis; null hypothesis refers to a general statement or default position that there is no relationship between two measured factors or levels. Rejecting or disproving the null hypothesis and thus concluding that there are grounds for believing that there is a relationship between them is known as alternate hypothesis. Based on the F-test in ANOVA we can determine the factor affecting the output of the experiment and to which amount each of these factors is affecting it [9].

4. EXPERIMENTAL SETUP

The experimental study has been carried out on the prediction of surface roughness under various conditions of machining parameters such as cutting speed, depth of cut and feed rate for a plane dry turning operation on CNC lathe. Machining of mild steel specimens under different machining conditions was carried out and the surface roughness was measured. Using this data analysis was carried using ANOVA method

Number of trials with selected process parameters of cutting speed (A), feed rate (B) and depth of cut (C) were designed by using L9 Taguchi orthogonal array. Tables 1 and 2 provide the level of parameter and number of experiment trial respectively.

Table 1: Process parameter and their levels

Levels	Cutting Speed (A)	Depth of cut (B)	Feed Rate (C)
	m/min	mm	mm/rev
1.	150	0.5	0.1
2.	200	0.75	0.2
3.	250	1.0	0.3

Table 2: Number of trials as per Taguchi L9 orthogonal array

Exp No	A	B	C
1	150	0.5	0.10
2	150	0.75	0.20
3	150	1.0	0.30
4	200	0.5	0.20
5	200	0.75	0.30
6	200	1.0	0.10
7	250	0.5	0.30
8	250	0.75	0.10
9	250	1.0	0.20

The experimental work was carried on CNC turning machine (make: ACE designer) with dry run condition using a carbide cutting tool insert for mild steel material. Figure 1 shows the experimental setup.

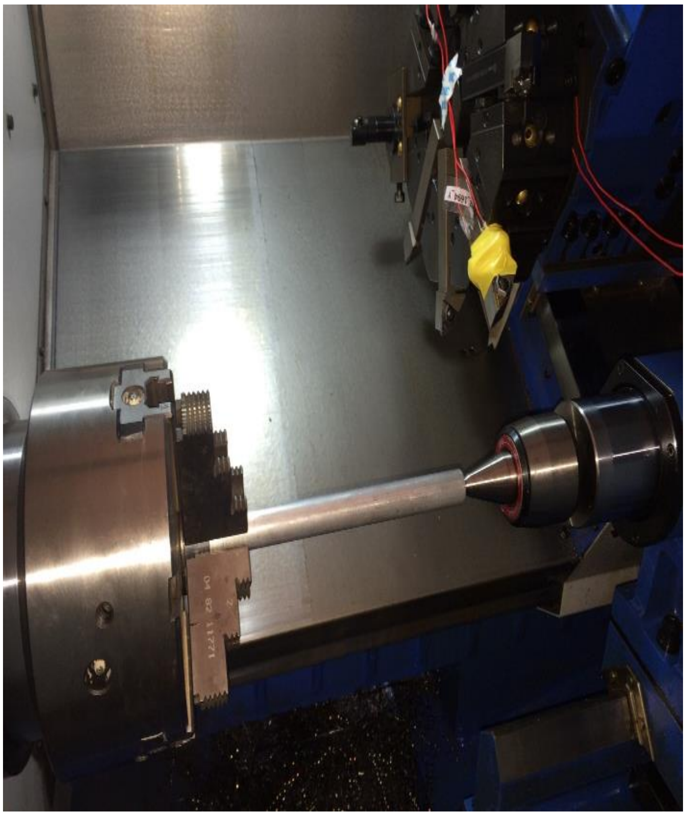

Figure 1: The experimental setup

A 20mm diameter mild steel specimen was turned for a length of 25mm in each trial. Surface roughness of turned portion of the work piece was measured using Mitutoyo SJ-201 instrument. The measured values of surface roughness are as shown in the Table 3.

Figure 3: Surface measurement setup

Table 3: Measured surface roughness

Exp No.	Surface Roughness (Ra) in µm
1	4.29
2	5.82
3	11.03
4	7.39
5	12.93
6	4.22
7	7.68
8	4.16
9	5.46

5. RESULTS AND DISCUSSION

The relationship between input and output parameters is built using ANOVA tool, for which cutting parameters such as depth of cut, feed rate, and spindle speed were considered as input, surface roughness R_a is considered as output parameter. In the ANOVA results, F-test values were used at 95% confidence level to decide the significant factors affecting the process and percentage contribution. The various cutting condition has been analyzed using Statistica software. As per ANOVA analysis, for a particular cutting parameter the p value less than 0.05 (5%) and larger F value indicates that the statistically significant effects on the performance of that parameter. The ANOVA results for full factorial design for surface roughness are as shown in Table 4.

Table 4: ANOVA results for Taguchi design on Surface Roughness

	SS	**DOF**	**MS**	**F**	**p**
Cutting Speed(CS) (m/min)	8.74702	2	4.37351	1.63220	0.379910
Depth of Cut (DOC) (mm)	2.14056	2	1.07028	0.39943	0.714576
Feed rate (FR) (mm/rev)	62.67575	2	31.33788	11.69537	0.078769
Error	5.35902	2	2.67951		

From the Table 4 it is clear that feed rate has a more significant effect on the surface roughness while cutting speed and depth of cut has no significant effect on the surface roughness. A curve predicting the behavior of various cutting parameter on the surface roughness has been used in this study.

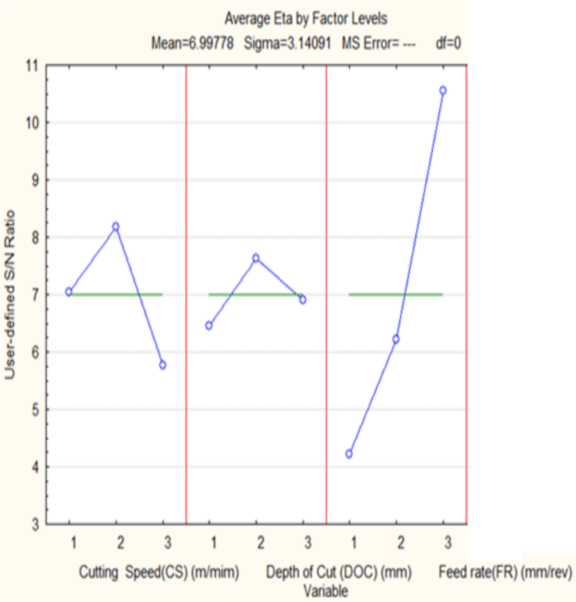

Figure 4: Curve predicting the behavior of cutting parameter on surface roughness

From the curve it can be seen that signal to noise ratio is quite high in the feed rate as compared to others, which indicates that its effect on surface roughness is more than other factors.

6. CONCLUSION

This study describes the method involved to optimize the cutting parameters such as depth of cut, feed rate and spindle speed in CNC lathe for better surface finish during dry turning operation. Taguchi orthogonal array and Analysis of variance tools are effectively used in this study to select the optimum experimental trials and analyze the relationship between input and output parameters. This study reveals that feed rate has more significance on surface roughness than other cutting parameters. Further, optimization of cutting parameters can include other output characteristics like vibration, temperature, etc., and its effect on overall productivity.

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