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Optimization of Surface Roughness in Turning Using Taguchi Methodology and Anovo Analysis

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ABSTRACT-This paper challenges on improving the turning process under several machining parameters by Taguchi methodology and ANOVO analysis to develop or implement the quality of machined product. Taguchi optimization methodology is applied to optimize cutting parameters in turning AISI 1040 mild steel bar with high speed steel (HSS) tool without lubricating oil used . The CNC lathe turning machine is used to conduct experiment trials based on the Taguchi method design of experiments (DOE) with orthogonal L_9 array. Taguchi Methodology is a well-organized technique, which gives optimal results in minimum number of trials. The orthogonal array ($L_{9)}$ signal to noise ratio (S/N) and analysis of variance by ANOVO analysis were engaged to find minimum surface roughness (R_a) [1]. The MS bar used are of diameter 32 mm and the length is 40 mm. in this experiments three machining parameters used like spindle speed (RPM) , Feed rate (mm/rev) and depth of cut (mm).

Altered trials are done by changing one parameter and keeping other two fixed so maximum value of each parameter was obtained. Taguchi orthogonal array L_9 is designed with three levels of turning parameters with the help of software Minitab 19. First 9 trials are executed and surface roughness Ra is calculated. Total 9 trials were conducted and by using design of experiment (DOE) L9 orthogonal array formed. After analyzing output variable, optimal machining condition were found. A confirmation test (ANOVA) was used to verify the result, which gives significant turning parameter for machining to minimize the surface roughness [2]

Keywords— Optimization, CNC Turning Machine, Taguchi Methodology, Surface Roughness, L_9 Orthogonal Array, ANOVA, Minitab19.

I. INTRODUCTION

In whole the global world, present market changed into great technological and competitive market. Every consumer want to best finished and quality product and all industries need to improve quality and finishing of the product with increasing their productivity and profit. Both consumers and industries requirement not fulfil at the same time so industries faced the problem to fulfil the consumer's requirement. Hence to full fill the current requirement, an optimization algorithm is needed. In this paper Taguchi method and ANOVO analysis used. The aim of these Algorithms to find out optimum cutting parameters to minimize the surface roughness to get better finished and qualitative product. This paper is successfully tried to enlighten on machine parameters i.e. Speed, Feed and Depth of cut. In section II brief idea of machine parameters given. In second section Taguchi method and ANOVO method is discussed. Section 4 is sharply able to explain about experimental set-up for these algorithms section Five is about result and discussion. Finally last section portrait that useful Taguchi and ANOVO method is.

II. PROCESS PARAMETERS

Turning is a material removal process which is used to create rotational parts by cutting away undesirable material as shown in Fig. 1. The turning process requires a turning machine or lathe, Material Job or material work piece, and cutting tool. The work piece is a piece of re-shaped material that is secured to the fixture, which itself is attached to the turning lathe machine, and permitted to rotate at high speeds. The cutting tool is also secured in the machine. The cutting tool feeds into the rotating work piece and cuts away material in the form of chips to produce the desire shape. [3]

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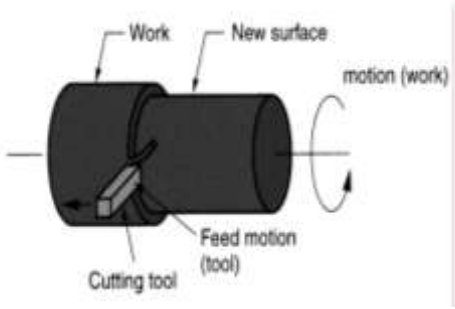

Fig 1: Adjustable parameters in turning operation

The three key factors in any turning operation that can affect the experiments trials or performance are cutting speed, feed rate, and depth of cut.

A. **Speed**

Speed always mentions to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it expresses their rotating speed. But the main feature for a particular turning operation is the surface speed or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute.[4]

$$V = \frac{\pi DN}{1000} \text{ m/min} \qquad \text{(i)}$$

Here, V is the cutting speed in turning, Dis the initial diameter of the work piece in mm, and Nis the spindle speed in RPM.

B. **Feed Rate**

The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in mm per revolution.

$$F = f * N \text{ mm /min} \qquad \text{(ii)}$$

Here, F is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in RPM.[4]

C. **Depth of cut**

The depth of the tool along the radius of the work piece as it makes a cut, as in a turning operation. A large depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is often machined in several steps as the tool moves over at the depth of cut

$$d_{cut} = \frac{D-d}{2} \text{ mm} \qquad \text{(iii)}$$

Here, D and d represent initial and final diameter (in mm) of the work piece respectively.[4]

III. TAGUCHI METHOD

The Taguchi method is statistical tool, adopted to achieve the optimization of parameters and get optimum process conditions to minimize the surface roughness by optimum cutting parameters such as speed, feed and depth of cut. The Taguchi process helps to define the optimum cutting conditions for turning process The Taguchi design of experiments (DOE) was used to optimize the cutting parameters and more detail on Taguchi is mentioned below.

Taguchi method is a dominant tool for the design of high quality systems for optimization. It provides simple, efficient and methodical approach to optimize designs for surface roughness, performance, quality and cost [5]. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions [6]. Steps used in Taguchi method are discussed follows:

(1) Documentation of main function, side effects and failure mode.
(2) Documentation of noise factor, testing condition and quality characteristics.
(3) Documentation of the main function to be optimized.
(4) Documentation the control factor and their levels.
(5) Selection of orthogonal array L_9 and matrix experiment.
(6) Conducting the matrix experiment and record the experiments results.
(7) Analysing the data, prediction of the optimum level and performance.
(8) Performing the confirmation experiment. [1]

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 most affect 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 is done on the MINITAB 19 software.[6]

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IV. EXPERIMENTAL ANALYSIS

Turning is precise important machining method in which a cutting tool removes unwanted material in the form of chips from the surface of a rotating cylindrical work piece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. Turning is carried on a lathe that provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at specified rate and depth of cut. Hence three cutting parameters namely speed, feed and depth of cut essential to be determined in a turning operation. The turning operations are done by using a cutting tool. The aim of turning operation is to produce low surface roughness of the parts. Surface roughness is an important factor which improves the quality of product and provides better finishing of the product. Proper selection of optimized cutting parameters for minimum surface roughness. Hence, design of experiments by Taguchi method and ANOVO analysis are used to get optimization cutting parameters to minimize the surface roughness [1]. The experiment was conducted for dry turning operation of AISI 1040 mild steel bars with high speed steel (HSS) tool. The experiments are conduct on CNC lathe. The control factors and their levels are shown in Table 1.

Table 1 : Control factors and levels

Code	Control factors	Levels		
		1	2	3
A	Speed (in rpm)	150	330	630
B	Feed (mm/rev.)	0.4	0.5	0.6
C	Depth of cut (in mm)	0.6	0.7	0.8

Taguchi analysis used code for process parameters are A for speed, B for Feed and C for Depth of cut.

MS bars of diameter 32 mm and length of 40 mm is needed for conducting the experiment have been prepared first. Nine numbers of samples of same material and same dimensions are created. Then, totally different levels of the method parameters nine specimens are turned in CNC turning machine. Once machining done, surface roughness measured exactly with the help of a portable stylus type profile meter, Talysurf (Taylor Hobson, Surtronic 3+, and UK) [7-8]

The results of the experiments are shown in Table 2. Improvement of surface roughness has been created by the help of Taguchi method and ANOVO analysis [5]. Confirmation test also conduct to verifying the optimum results [7-8].

Table 2 Experimental Data Associated to Surface Roughness

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	150	0.4	0.6	2.40	-7.6042
2	150	0.5	0.7	5.80	-15.2686
3	150	0.6	0.8	6.12	-15.7350
4	330	0.4	0.7	5.40	-14.6479
5	330	0.5	0.8	4.92	-13.8393
6	330	0.6	0.6	6.20	-15.8478
7	630	0.4	0.8	3.10	-9.8272
8	630	0.5	0.6	3.97	-11.9758
9	630	0.6	0.7	5.22	-14.3534

V. RESULT AND DATA ANALYSIS

Taguchi Analysis: The analysis is made with the help of software package MINITAB-19 software for DOE of Taguchi method. Using MINITAB-19Taguchi method response table for S/N ratio of Ra and response table for Mean are found. For surface roughness S/N ratio calculate with Smaller is better is shown in Table 3 and Table 4 respectively.

Table 3: Response Table for Signal to Noise Ratios

Smaller is better

Level	Speed	Feed	Depth of cut
1	-12.87	**-10.69**	**-11.81**
2	-14.78	-13.69	-14.76
3	**-12.05**	-15.31	-13.13
Delta	2.73	4.62	2.95
Rank	3	1	2

Table 4 : Response Table for Means

Level	Speed	Feed	Depth of cut
1	4.773	3.633	4.190
2	5.507	4.897	5.473
3	4.097	5.847	4.713
Delta	1.410	2.213	1.283
Rank	2	1	3

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The graph of Ra versus Speed, Ra versus Feed, Ra versus depth of cut for mean is shown in Fig 2 :

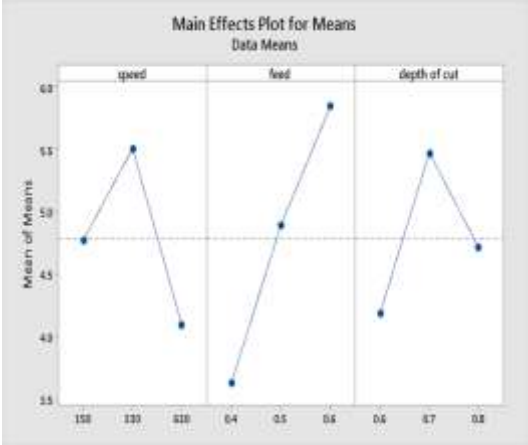

Fig 2 : Main Effect plot for means (Ra)

The graph of Ra versus Speed, Ra versus Feed, Ra versus depth of cut for S/N ratio is shown in Fig 3:

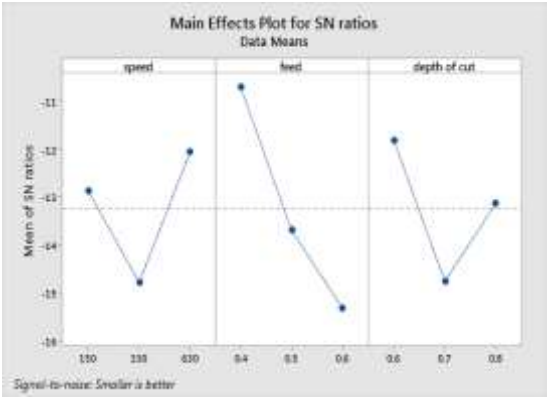

Fig 3: Main Effect Plot for S/N Ratio (Ra)

The analysis is made with the help of software package MINITAB 19. The main effect of plot is shown in Fig 02 and Fig 03. It shows the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish. According to this main effect plot, the optimal conditions for minimum surface roughness are speed at level 3 (630 RPM), feed rate at level 1 (0.4 mm/rev) and depth of cut at level 1 (0.6 mm) according to figure 02 and the optimal conditions for minimum surface roughness are speed at level 2 (330 RPM), feed rate at level 1 (0.6 mm/rev) and depth of cut at level 1 (0.7 mm) according to figure 03. Here two optimization conditions occur so it is necessary to use ANOVO analysis to pick most optimum solution from these two optimum solutions getting from Taguchi analysis. Two optimum condition from Taguchi analysis are shown in Table 5

Table 5:Two optimum condition from Taguchi analysis

Optimum condition 1	**Optimum condition 2**
A3B1C1 A : Speed B : Feed C : Depth of cut	A2B3C2 A : Speed B : Feed C : Depth of Cut
A = 630 rpm B = 0.4 mm/rev C = 0.6 mm	A = 330 rpm B = 0.6 mm/rev C = 0.7 mm

ANOVO Analysis:

ANOVO analysis is a powerful tool which analysis the variance and given most significant factor whose affect the required condition i.e. Surface roughness

Analysis of Variance for Transformed Response

Table 6 ANOVA results for surface roughness

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Speed	2	260.7	130.36	1.90	0.344
Feed	2	572.6	286.29	**4.18**	0.193
Depth of cut	2	154.0	76.99	1.12	0.471
Error	2	137.0	68.48		
Total	8	1124.2			

ANOVO analysis used to find out the most significant factor which affects the surface finish. By using MINITAB 19 software ANOVO analysis done and generate ANOVA results for surface roughness is shown in Table 7. Larger is that the F price higher is that the most significance parameters which affect the surface roughness. Table 7 show that Feed is most significant after that Speed and Depth of cut so both Taguchi and ANOVO analysis given the optimum solution is that speed 630 rpm, feed 0.4 mm/rev and depth of cut is 0.6 mm.

So optimum process for minimum surface roughness is A3B1C1. This process not getting in 9 experiments done according to Taguchi Orthogonal array L_9 so a Confirmation Test conduct with optimum condition. The confirmation experiments result shown in table 7.

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Table 7: Confirmation experiments data with optimum condition

Experiment no.	Spindle speed (rpm), N	Feed rate (mm/rev), f	Depth of cut (mm), d	Surface roughness, Ra (µm)	Average of Ra (µm)
1	630	0.4	0.6	2.2961	2.3048
2	630	0.4	0.6	2.3045	
3	630	0.4	0.6	2.3276	
4	630	0.4	0.6	2.3019	
5	630	0.4	0.6	2.2937	

The predict result analysis for optimum condition by Taguchi analysis with the help of MINITAB – 19 software. The confirmation experiments and predicts optimum condition for minimum surface roughness is shown in Table 8.

Table 8: Confirmation test data and predict data for minimum surface roughness

Experiment result	Predict result	Percentage change
A3B1C1	A3B1C1	
2.3048	2.3356	1.34%

VI. CONCLUSION AND FUTURE SCOPE

The following final conclusions are based on the experimental study and experiments conducted on turning AISI 1040 mild steel bars with high speed steel tool on CNC turning lath with three levels by using Taguchi technique and ANOVO analysis to determine the optimal level of process parameters to minimize the surface roughness.

1. The ANOVA analysis and F-test discovered that the feed is most significant parameter followed by speed and last one depth of cut for surface roughness.
2. The optimal combination process parameters for minimum surface roughness is achieved at 630 rpm, 0.4 mm/rev and 0.6 mm.
3. Taguchi methodology and ANOVO analysis gives an efficient simple approach to find the optimum operating conditions [6].

FUTURE SCOPE

In this present paper discussed only three parameters are studied in accordance with their effects like speed, feed rate, depth of cut. Another factors like tool radius, cutting conditions (dry or wet), Energy consumption, tool life, power consumption etc. also can be studied by Taguchi method and ANOVO analysis.

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