Experimental Study of Surface Roughness in CNC Turning Using Taguchi and ANOVA

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Abstract

The work and study aims to optimize the Surface Roughness of material Mild Steel by varying the Cutting speed, Depth of cut and Feed Rate during turning operation carried out in CNC machine. The effect of cutting parameters on surface roughness was studied and analyzed by using Taguchi method and then followed by Analysis of Variance (ANOVA). The ANOVA is used to optimize the results of experiments i.e., to find the minimum Surface Roughness. L27 orthogonal array design has been used for conducting the experiments in Taguchi design. The cutting tool used in this work is Carbide (CNMG-120408-TTR). The Talysurf instrument is used to measure Surface Roughness parameters (Ra, Rq, Rzdin, Rt, Ry and Sm). Ra parameter is used to determine Surface Roughness.

1. Introduction

The objective of modern machining industries is primarily focused on the achievement of high quality, in term of work dimensional accuracy, surface finish because the economy of machining operations plays a key role in competitiveness in the market. The surface roughness has the significant effect, on some non-easily controllable factors such as surface friction, wear, lubricant holding capacity, surface reflection, corrosion resistant. There are many controllable factors which affect the surface roughness i.e., cutting conditions (cutting speed, depth of cut, feed rate), tool variables. Tool variables include the tool material, tool rake angle, nose radius and tool cutting geometry. But it is very difficult to consider all the parameters (cutting and tool variables) that determine the surface roughness during turning operation. The Taguchi design is a statistical tool that helps to investigate the influence of cutting parameters such as cutting speed, feed rate and depth of cut on the surface roughness. Analysis of Variance (ANOVA) is used to optimize the experiments results from Taguchi method i.e., surface roughness.

Ranganath M.S.et al, [1] investigated the parameters affecting the roughness of surface during turning operation on CNC Lathe for the material Aluminium 6061 by Using Taguchi Method and Anova. Designs of experiments were conducted to analyze the effect of cutting parameters (speed, feed and depth of cut) on the surface roughness by using Taguchi design. Taguchi design is the effective tool for robust design it offers a simple and systematic qualitative optimal design to a relatively low cost. The results obtained from experiments by taguchi design used to characterize the main factors affecting surface roughness by the Analysis of Variance (ANOVA) method. The feed and speed are identified as the most influential process parameters on surface roughness. Interactions were observed among the turning parameters. A Systematic approach concluded to design and analyze the experiments, and to utilize the data obtained to the maximum. From the data it has been observed that the increase in cutting speed tends to improve the finish and Finish gets poor as the feed increases, thus the average surface roughness value increases with increase in feed. Ranganath M.S.et al, [2] used artificial neural network model to predict Surface Roughness in Turning Process. Comparison of the experimental data and neural network model results shows that there is no significant difference and neural network model can be used confidently. Machining variables that have a great influence on the surface roughness in turning process such as spindle speed, feed rate and depth of cut were considered as inputs and surface roughness as output. The predicted surface roughness values computed from artificial neural network model are compared with experimental data and the results obtained. Artificial Neural Network can be created using feed forward back propagation technique for simulation of the process. With assurance of accuracy of the predictive capabilities of the neural network; it may be then used for optimization. Almost all experimental studies suggest that ANN is a powerful tool and can be used for more accurate prediction of surface roughness. Ranganath M.S. et al,[3] aims to investigate the effect of the cutting speed, feed rate and depth of cut on surface roughness and material removal rate (MRR) in turning of Aluminium (6061) in dry condition. Out of all the surface condition criteria, Raand Rtare often used to characterize the roughness of machined surfaces. Design of experiments (DOE) were conducted to determine the influence of the turning parameters(cutting speed, feed rate and depth of cut) on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness and the maximum MRR. ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes *t*-test to more than two groups. The ANOVA and F-test revealed that the speed and depth of cut are dominant parameters followed by feed for surface roughness. The optimal combination process parameters for minimum surface roughness are obtained at 710rpm, 0.2

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mm/rev and 0.2mm.Ranganath M.S. et al, [4] investigated the parameters affecting the roughness of surfaces produced in the turning process for the various materials. Taguchi method is used to study design of experiments conducted to analyze the influence of the turning parameters such as cutting speed, feed rate and depth of cut on the surface roughness. The results of the machining experiments were used to characterize the major parameters affecting surface roughness by the Analysis of Variance (ANOVA) method, Taguchi's parametric design is the effective tool for robust design it offers a simple and systematic qualitative optimal design to a relatively low cost. On the basis of the experimental results and analysis, it is concluded that cutting speed has the most dominant effect on the observed surface roughness, followed by feed rate and depth of cut, whose influences on surface roughness are smaller. The results obtained using the Taguchi optimization method revealed that cutting speed should be kept at the highest level, while both feed rate and depth of cut should be kept at the lowest level in order to optimize the surface roughness.

The work and study of this paper aims to optimize the Surface Roughness of material Mild Steel by varying the Cutting speed, Depth of cut and Feed Rate during turning operation carried out in CNC machine. The effect of cutting parameters on surface roughness was studied and analyzed by using Taguchi method and then followed by Analysis of Variance (ANOVA). The ANOVA is used to optimize the results of experiments i.e., to find the minimum Surface Roughness. L27 orthogonal array design has been used for conducting the experiments in Taguchi design. The cutting tool used in this work is Carbide (CNMG-120408-TTR). The Talysurf instrument is used to measure Surface Roughness parameters (Ra, Rq, Rzdin, Rt, Ry and Sm). Ra parameter is used to determine Surface Roughness.

2. Experimental Work

2.1 Material Selection

The selection of AISI 1020 [3] is based upon its low harden ability and low tensile carbon steel with Brinell hardness of 229 and Tensile strength of 410-790 MPa. It has high Mach inability high strength, high ductility and weld ability. It is widely used for producing automotive components and all industrial sectors in order to enhance weld ability and Mach inability properties by turning process, polishing and cold drawing process. Due to the property of low carbon content, it is resistant to induction hardening or flame hardening. As less alloying elements are present, it will not respond to nit riding. But carburizing can be done to enhance case hardness for small sections. Core strength will remain as it has been supplied for all the sections.

Table: 1.

Element	Content
Carbon, C	0.17 – 0.230%
Iron, Fe	99.08 -99.53%
Manganese, Mn	0.30 – 0.60%
Phosphorus, P	≤ 0.040 %
Sulphur, S	≤ 0.050 %

2.2 Experimental Plan

CNC turning center LMW LL20TL3 using CNMG insert of tool nose radius 0.8 mm is used. Machine specifications are given in table.

Table: 2. Machine Specification

Title	Description	Unit	LL20T L3
Capacity	Swing over bed	mm	510
	Chuck dia. max.	mm	200
	Max turning diameter	mm	320
	Max. turning length	mm	310
	Admit between centres	mm	420
Spindle	Spindle nose	type	A2 – 6
	Hole through spindle	mm	61
	Spindle speed	rpm	3500
	Spindle motor power(cont./15min)	kW	7.5/11
Feed system	Cross travel X-axis	mm	185
	Longitudinal travel Z-axis	mm	370
	Rapid traverse rate X/Z-axes	m/min	30 / 30
Turret	No. of stations	Nos.	8
	Tool shank size	mm	25×25
	Maximum boring bar dia.	mm	40
	Turret indexing	type	Hydraulic
Tailstock	Quill dia.	mm	75
	Quill stroke	mm	100
	Quill taper	-	MT-4
CNC system	Controller	-	Fanuc
Machine size	Front x Side	mm	2065 X 1925
	Machine weight (Approx.)	kg	3500

Surface roughness of turned cylindrical job of 40mm diameter was done using Talysurf. Each specimen had 3 segment of 80mm each, with 60mm extra length to hold the job. Each segment was unique in combination of variables; hence we had 27 unique combinations in total. Further each segment‘s roughness measurement was taken in three position namely 20, 40, 60 mm from faced end. Average value of surface roughness was used to compute the result. This was done to even out any possible local changes in surface roughness. Surface Roughness is measured using Taylor Hobson Surtronic 3+ instrument.

2.3 Design of Experiment Approach

Design of experiments (DOE) is a systematic, rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions For data input we have used Taguchi method with L27 array which has three variables with three levels and a response variable i.e., Surface Roughness.

2.4 ANOVA (Analysis of Variance)

Analysis of variance (ANOVA) is a collection of statistical models used in order to analyze the differences between group means and their associated procedures (such as "variation" among and between groups).It is developed by R.A Fisher. The statistical significance of ANOVA is useful for comparing (testing) three or more means (group or variables) .After data input we have to analyze the data obtained by using ANOVA .First we assumed a hypothesis which states that Surface Roughness depend upon corresponding variable. Now we should test this hypothesis.

For Analysis we have to define the hypothesis for each value.

- H_0 = change in input value of this variable will affect the output machining characteristic i.e. Surface Roughness.
- H_1 = change in input value of this variable will not affect the output machining.

Now we will test these hypothesis statistically, there is a tool called an F test, named after Fisher for this hypothesis testing i.e. to see which design parameters have a significant effect on the Surface Roughness.

$$F = \frac{\text{Mean Square Between groups (MSG)}}{\text{Mean Square Between groups (MSE)}}$$

A large value of F indicates evidence against H_0.

To get the P-value, compare these F value to standard F(I-1,n-I)-distribution for the Hypothesis and give us the P value in tabular form .More the P value more effect of that row variable on Surface Roghness.

3. Results and Discussion

Results were analyzed using Minitab software and all the values are shown in the Table.

Ra = Arithmetic average of absolute values

Rz = Average distance between the highest peak and lowest valley in each sampling length

Using Design of experiment approach we have selected three levels of three variables Speed, Feed, Depth of Cut.

These levels are shown in below table.

Table: 3. Factor Information

Factor	Type	Levels	Values
Speed	Fixed	3	1100, 1350, 1600
DoC	Fixed	3	0.2, 0.4, 0.6
Feed	Fixed	3	0.10, 0.15, 0.20

Magnitude of P-value decides the level of dependency of average surface roughness (Ra) on input variable. Higher is the p-value more the importance.

Table: 4. Result of ANOVA Analysis

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed	2	0.28467	0.14233	1.99	0.163
DoC	2	0.09168	0.04584	0.64	0.537
Feed	2	0.11561	0.05780	0.81	0.460
Error	20	1.43129	0.07156		
Total	26	1.92324			

As shown in above table using ANOVA, p-value of DoC is highest, then feed and minimum for Speed. Hence the order for dependency of Surface Roughness on input variable is DoC, Feed followed by Speed.

3.1 Different Graphs Obtained

Main effects plot for Ra-

It helps to determine the independent effect of speed, DoC, and Feed on average surface roughness (Ra).In Figure No. 3, values of parameters for minimum Ra are: Speed = 1350rpm, DoC = 0.2mm, Feed = 0.15 mm/rev(corresponding to lowest Ra in each case) . Generally minimum value of Ra is considered to be desirable for given parameters. As the speed increase, surface roughness value decrease initially and after reaching the minimum value it increase. But in case of depth of cut it increases with increase in depth of cut. So from the graph we conclude that minimum Ra obtained at Speed = 1350rpm, DoC = 0.2mm, Feed = 0.15 mm/rev.

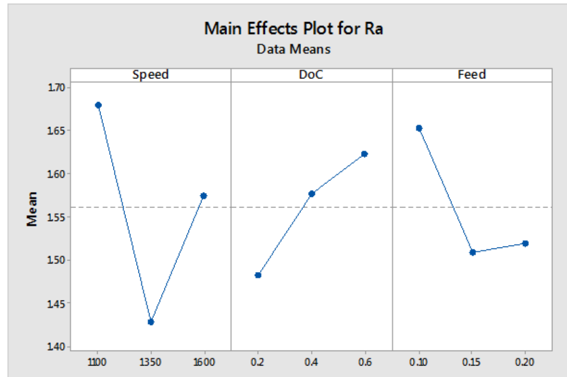

Fig: 1. Main effects plot for Ra

Main effects plot for Rz-

The effect of speed, DoC, and Feed on average surface roughness (Rz) is shown in Figure No.4 ,generally minimum value of Rz is considered to be desirable for given parameters. As the speed increase, surface roughness value decrease initially and after reaching the minimum value it increase. But in case of depth of cut it increases with increase in depth of cut. Surface roughness (Rz) value decreases with increase in feed rate. So from the graph we conclude that minimum Rz obtained at Speed = 1350rpm, DoC = 0.2mm, Feed = 0.2 mm/rev.(corresponding to lowest Ra in each case).

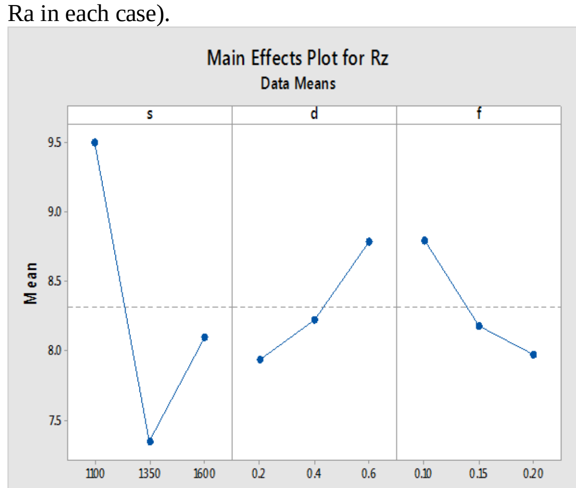

Fig: 2. Main effects plot for Rz

Residual Plots for Ra-

In Fig: 3. Normal Probability Plot shows the deviation of individual values compared with regression model equation. Closely clustered points around the line show low deviation.

Residual Vs fitted value shows how much residual is remaining for each discrete fitted value in the model.

Frequency Vs residual shows frequency of residuals for every value of residual.

Residual Vs Observation order shows residual corresponding to discrete observation order.

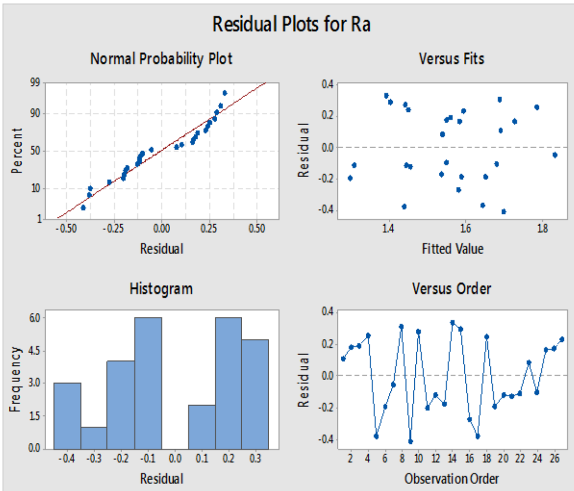

Fig: 3. Residual plot for Ra

Residual Plots for Rz-

In Fig No.6 Normal Probability Plot shows the deviation of individual values compared with regression model equation. Closely clustered points around the line show low deviation.

Regression equation line; Y= a + bX

Where a, b are constants

B= [NΣXY – (ΣX) (ΣY)] / [NΣX^2-(ΣX)^2]

A= [ΣY –bΣX] / N

Where N is number of observations

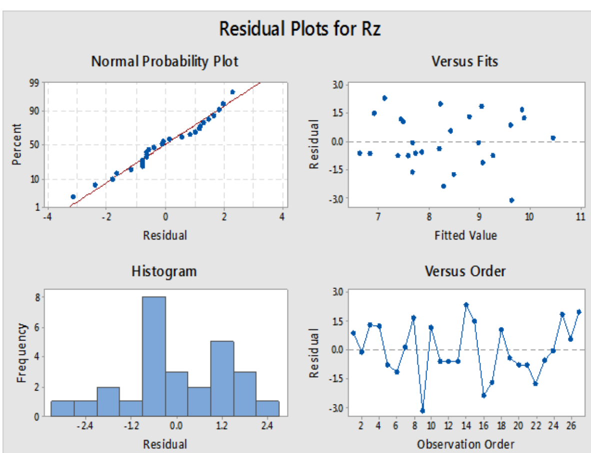

Fig: 4. Residual plot for Rz

Interaction Plot

Regression equation obtained

Rz = 8.317 + 1.190 s_1100 - 0.973 s_1350 - 0.217 s_1600 - 0.377 d_0.2 - 0.095 d_0.4+ 0.472 d_0.6 + 0.479 f_0.10 - 0.140 f_0.15 -0.340 f_0.20

Ra = 1.5556 + 0.1222 s_1100 - 0.1222 s_1350 - 0.0000 s_1600 - 0.0889 d_0.2 + 0.0222 d_0.4 + 0.0667 d_0.6 + 0.1000 f_0.10 - 0.0556 f_0.15 - 0.0444 f_0.20

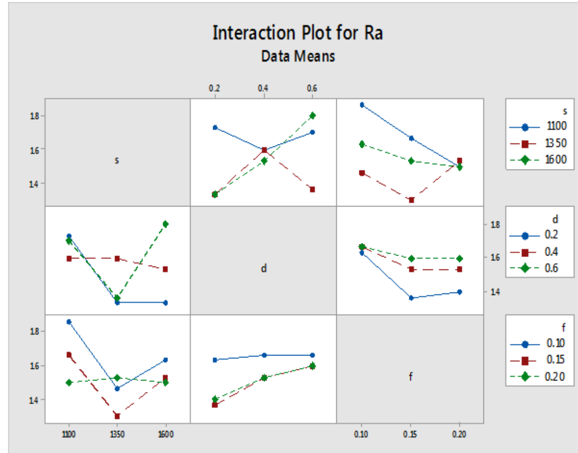

Fig: 5. Interaction plot for Ra

Fig: 6. Interaction plot for Rz

4. Conclusion

Dependence of surface roughness on the input variables speed, feed and depth of cut is to be determined in order to control the quality of machined surface.

1. Strong interactions were observed among the turning parameters. Most significant interactions were found between cutting speed, feed and depth of cut .A systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extend.
2. By employing ANOVA to determine the optimal level of process parameters. It has been observed that depth of cut is the most critical parameter when finish is the criterion. Finish gets poor as the Depth of cut increases, thus the average surface roughness value increases with increase in Depth of cut. The ANOVA and F-test revealed that the depth of cut is dominant parameter followed by feed and speed for surface roughness.
3. The optimal combination process parameter for minimum surface roughness is obtained at 1350 rpm, 0.15 mm/rev and 0.2 mm. The developed model is reasonably accurate.

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