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Optimization of Surface Roughness Parameters in Turning EN1A Steel on A CNC Lathe Without Coolant

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Abstract

This paper presents the optimization of surface roughness parameters in turning EN1A steel on a CNC lathe. The optimization of machining processes is essential for the achievement of high responsiveness of production, which provides a preliminary basis for survival in today's dynamic market conditions. The quantitative determination of Surface Roughness is of vital importance in the field of precision engineering. Machinability can be based on the measure of Surface Roughness. Surface Roughness depends on the factors such as Speed, Feed and Depth of Cut. In this work, the Taguchi methods, a powerful statistical tool to design of experiments for quality, is used to find the optimal cutting parameters for turning operations. Analysis of Variance has been used to determine the influencing parameters on the output responses. Using Taguchi technique, we have reduced number of experiments from 27 to 9 there by the total cost of the project is reduced by 66.66%. The results obtained are encouraging and the concluding remarks are helpful for the manufacturing industries.

1. Introduction

The machinability of metal is defined as the ease with which a given material may be machined with a specific cutting tool. In other words the most machinable metal is one which will permit the fastest removal of the largest amount of material per cut of a tool with satisfactory finish. The operational characteristics of a cutting tool are generally described by its machinability which has 3 main aspects, tool life, surface finish and power required to cut. The quantitative determination of Surface Roughness is of vital importance in the field of precision engineering. Machinability can be based on the measure of Surface Roughness. Surface Roughness depends on the factors such as Speed, Feed and Depth of Cut. Other factors include cutting tool material, cutting tool geometry, machine condition, work piece material, cutting tool clamping and depend on operation carried out. The presence of coolant affects the Surface Roughness. Therefore an attempt has been made to conduct experimental investigation to optimize the Surface Roughness parameters in turning of EN1A steel on CNC lathe.

In this work, the Taguchi methods, a powerful statistical tool to design of experiments for quality, is used to find the optimal cutting parameters for turning operations. In the present study, experiment has been conducted using 9 pieces of EN1A steel to measure Surface Roughness without coolant. Measurement has been done using Stylus Type Profilometer. In which an attempt has been made to optimize machining parameters i.e., speed, feed and Depth of Cut at three levels i.e., minimum, average and maximum values to obtain better surface finish using Taguchi technique without coolant. Also an attempt has been made to optimize machining parameters i.e., speed, feed and Depth of Cut at three levels i.e., minimum, average and maximum values to obtain better Material Removal Rate without coolant. An attempt has been made to develop regression models for Surface Roughness. In this study Analysis of Variance has been used to determine the influencing parameters on the output responses. Using Taguchi technique, we have reduced number of experiments from 27 to 9 there by the total cost of the project is reduced by 66.66%. Using Taguchi technique, we have reduced time required, man power, material etc. In this study output responses such as Surface Roughness, Material Removal Rate and machining time have been measured. In this study comparison between Actual and Theoretical values of Material Removal Rate has been made.

Traditionally, the selection of cutting conditions for metal cutting is left to the machine operator. In such cases, the experience of the operator plays a major role, but even for a skilled operator it is very difficult to attain the optimum values each time. Machining parameters in metal turning are Speed, feed rate and Depth of Cut. The setting of these parameters determines the quality characteristics of turned parts.
The Finite Element Analysis results are obtained using continuum membrane element.

Turning Operation:

Turning is the removal of material from the outer diameter of a rotating cylindrical work piece by means of single point cutting tool which is held stationary on the tool post and moved parallel to the work piece axis with suitable Speed, Feed and Depth of Cut, Turning is used to produce cylindrical surface on the work piece. In turning the diameter of the work piece, usually to a specified dimension and the length of the work piece remains same. Figure 1. Shows the turning operation.

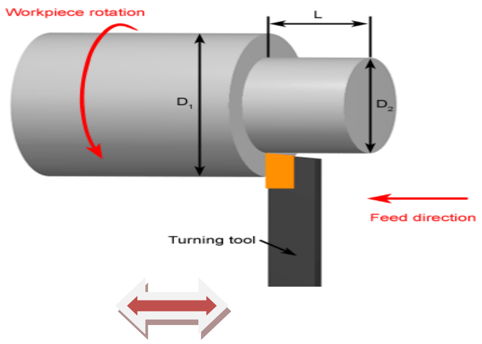

Figure 1: Schematic Representation of Turning Operation

Where,

D1= initial diameter of the work piece before machining
D2= final diameter of the work piece after machining
L = machining length of the work piece

The three primary factors in any basic turning operation are speed, feed, and Depth of Cut.

Speed(N):

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is rotating fast against the stationary cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. Every different diameter on a work piece will have a different Speed, even though the rotating speed remains the same.

Feed:

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

Depth of Cut:

Depth of Cut is practically self explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the Depth of Cut because this layer is being removed from both sides of the work.

2. Tools and equipment:

Work material:

The work material used for this experimentation is EN 1A steel. This material is widely used in the automobile industry. Chemical composition and Mechanical properties of EN 1A steel is shown in Table 1 and Table 2 respectively.

Table 1: Chemical composition of EN 1A steel

	C	**Mn**	**Si**	**P**	**S**
Min	0.07	0.8	0.10	0.07	0.2
Max	0.15	1.2	-	-	0.3

Table 2: Mechanical Properties of EN 1A steel

Condition	**Tensile**	**Yield MPa**	**Elongation %**
Cold drawn	400	290	7-9
Turned & Polished	370	230	18

CUTTING TOOL INSERT USED:

For machining the above work material the following Uncoated Carbide Inserts was used:

- TNMG 16 04 08

Three different tool inserts are used to take into account the effect of nose radius.

Cutting tools are often designed with inserts or replaceable tips (tipped tools). In these, the cutting edge consists of a separate piece of material, brazed, welded or clamped on to the tool body. Common materials for tips include Tungsten Carbide, Polycrystalline Diamond (PCD), and Cubic Boron Nitride (CBN).

Figure 2: Uncoated Carbide Insert

Insert Designation:

The details of cutting insert TNMG 16 04 08 is mentioned below.

T: Insert Shape= Triangle 60^0
N: Clearance Angle= 0^0 No rake
M: Medium Tolerance= d+/-0.05 m+/-0.08 s+/-0.13
G: Insert Type (Pin / Top clamping double sided)
16: means length of each cutting edge is 16 mm
04: stands for nominal thickness of the insert is 4 mm
08: stands for nose radius is 0.8mm

Properties of Carbide Inserts:

They are stable and moderately expensive. It is offered in several "grades" containing different proportions of Tungsten Carbide and binder (usually Cobalt). High resistance to abrasion. High solubility in iron requires the additions of Tantalum Carbide and Niobium Carbide for Steel usage. Its main use is in turning tool bits although it is very common in milling cutters and saw blades. Hardness up to HRC 90. Sharp edges generally not recommended.

CNC Lathe:

CNC Lathe (ACE) which is used for machining thegiven material is shown below in the Figure 3.

Figure 3: CNC Lathe (ACE)

Profilometer:

Figure 4: Profilometer which is used to measure Surface Roughness

For this experimentation process the Profilometer being used is the Mitutoyo SJ-201P which is shown in the Figure 4.

The measurement is done using this equipment; the selected parameter is Ra as it is the most popular and is commonly used in the industries. The roughness is measured in multiple points in the work pieces and the average value is selected for the experimental data.

3. EXPERIMENTATION

Optimization of Machining Parameters (3 factors and 3 level analyses) and studies on Surface Roughness, MRR and Machining Time using TNMG 16 04 08 without Coolant in CNC lathe (ACE) using L9:

In this experiment the turning operation was done on the work piece i.e., EN 1A Steel (Length 100 mm and Diameter 20 mm) on a CNC lathe. TNMG 16 04 08 Insert was used for turning. 3 factors were selected i.e., Speed (rpm), Feed (mm/rev) and Depth of Cut (mm) at 3 levels i.e., (Minimum, Average and Maximum) and coolant was not used. Surface Roughness was measured using Profilometer (Talysurf) and the readings are tabulated in Table 3.

Table 3: L9 Orthogonal Array with Observations without Coolant.

Trial No	Turning Parameter			Output Responses						
	A Cutting Speed (rpm)	B Feed (mm/rev)	C Depth Of Cut (mm)	Surface Roughness, Ra (µm)	Weight of specimen Before Turning (gm)	Weight of specimen After Turning (gm)	Machining Time (actual), t (sec)	Machining Time (theoretical), t (sec)	MRR(a) (mm^3/min)	MRR(t) (mm^3/min)
1	1000	0.1	0.2	3.19	197.301	182.706	70	58	2790.34	1200
2	1000	0.2	0.4	4.19	197.301	181.298	99	72	7474.44	7500
3	1000	0.3	0.6	4.29	197.301	178.660	94	70	14590.11	16800
4	2000	0.1	0.4	3.67	197.301	180.792	85	62	7890.48	7400
5	2000	0.2	0.6	3.79	197.301	178.520	19	26	18650	22600
6	2000	0.3	0.2	3.85	197.301	184.191	14	21	11930.35	11800
7	3000	0.1	0.6	2.84	197.301	177.867	19	28	14758.24	17200
8	3000	0.2	0.2	3.71	197.301	183.532	13	22	11776.78	12800
9	3000	0.3	0.4	3.82	197.301	181.373	11	19	22992.85	33400

To find Minimum number of experiments to be conducted:
For 3 Factors and 3 Levels, the minimum number of Experiments to be conducted is shown in the following Table 3.

Table 4: Factors, Levels and Degrees of Freedom

Factor Code	Factor	No of Levels	Degrees of Freedom
A	Speed	3	2
B	Feed	3	2
C	Depth of Cut	3	2
	Total Degrees of freedom		6
	Minimum number of Experiments		7

Taguchi's standard L9 Orthogonal Array was used do conduct the experimentation. is mentioned below in Table 5.

The formulae used to find MRR (actual), MRR (theoretical) and Machining time theoretical are as follows

1) MRR (a) represents Actual Material Removal Rate in mm^3/min

$$\mathbf{MRR\ (a)} = \frac{(Wi-Wf)X1000X60}{7.85Xt}\ mm^3/min$$

Where,

W_i denotes initial weight of the specimen before machining in gm.

W_f denotes final weight of the specimen after machining in gm.

t denotes machining time in seconds.

2) MRR (t) represents Theoretical Material Removal Rate in mm^3/min

$$\mathbf{MRR\ (t) = f * d * V * 1000\ mm^3/min}$$

Here, f denotes feed in mm/rev, d denotes Depth of Cut in mm and V denotes Speed in m/min

3) To calculate **Machining Time (t) (theoretical)** following formula is used

$$t = \frac{L}{fN}\ min$$

L= length of surface to be machined.

Table 5: Standard L9 Orthogonal Array

Trial No.	Speed (rpm)	Feed (mm/rev)	DEPTH OF CUT (mm)
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

Table 5 shows the standard L9 orthogonal array which is used in the present study.

Table 6: Experimental Conditions

Work piece Material	EN 1A Steel
Lathe Used	CNC Lathe (ACE)
Inserts Used	Uncoated Carbide Insert (KORLOY Make)
Insert Designation	TNMG 16 04 08 (ISO Designation)
Tool holder	MTJNL 25 * 25 * H 16 (ISO Designation)
Speed (rpm)	1000,2000,3000
Feed (mm/rev)	0.1,0.2,0.3
Depth of Cut (mm)	0.2,0.4,0.6
Environment	COOLANT OFF

4. RESULTS AND DISCUSSION

In this experiment turning operation was done on the work piece i.e., EN 1A Steel on a CNC lathe. Uncoated Carbide Insert was used for turning. 3 factors were selected i.e., Speed (rpm), Feed (mm/rev) and Depth of Cut (mm) at 3 levels and coolant was not used. Surface Roughness was measured using Profilometer (Talysurf) and the readings are tabulated in Table 4.

Studies Related to Surface Roughness without Coolant:

The following studies were conducted associated with Surface Roughness

1. Regression Model For Surface Roughness.
2. General Linear Model for Surface Roughness.
3. Analysis of Variance For Surface Roughness.
4. Response Table of Signal to Noise Ratios for Surface Roughness.
5. Graph showing the Main Effects plot for S/N ratios of Ra.

4.1 Regression Model For Surface Roughness:

Regression Equation is the relationship between dependent variable and one or more independent variables. Dependent variable is the Surface Roughness and independent variables are Speed, Feed and Depth of Cut.

Using MINITAB Software the Regression Model has been developed for the above Experiment.

The regression equation is

Surface Roughness (µm) = 3.33 – 0.000217 Speed (rpm) + 3.77 Feed (mm/rev) + 0.142 Depth of Cut (mm)

If the value of Speed (rpm), Feed (mm/rev) and Depth of Cut (mm) are known, using the above equation we can predict the corresponding value of Surface Roughness (µm).

4.2 General Linear Model for Surface Roughness:

Table 7: General Linear Model for Surface Roughness

Factor	**Type**	**Levels**	**Values**
Speed(rpm)	Fixed	3	1000,2000,3000
Feed(mm/rev)	Fixed	3	0.1,0.2,0.3
Depth of Cut (mm)	Fixed	3	0.2,0.4,0.6

General Linear Model for Surface Roughness is shown in Table 7. Input Parameters for this experiment are Speed, Feed and Depth of Cut at 3 levels and the values are shown in the above Table 7.

4.3 Analysis of Variance for Surface Roughness:

Table 8: Analysis of Variance for Surface Roughness

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**RANK**	**Contribution**
Speed (rpm)	2	1.7727	1.7727	0.8864	1.85	0.351	**2**	**19.64 %**
Feed (mm/rev)	2	6.2228	6.2228	3.1114	6.50	0.133	**1**	**69.00 %**
Depth of Cut (mm)	2	1.0280	1.0280	0.5140	1.07	0.482	**3**	**11.36 %**
Error	2	0.9577	0.9577	0.4788				
Total	8	9.9812			9.42			**100%**

For this experiment, Analysis of Variance was performed is shown in Table 8. to identify the influence of Machining parameters on the output Responses using MINITAB software. Input parameters considered were Speed, Feed and Depth of Cut. Output parameter was Surface Roughness.

Ranking is given based on the value of P (Smaller the value of P, Greater the influence of that parameter on the Output). For this experiment, the input parameters that are influencing the Output parameter (Surface Roughness) in their decreasing order are Feed, Speed, and Depth of Cut. According to the Table 8, Feed has the highest contribution of 69% followed by Speed 19.64% and Depth of Cut 11.36%.

4.4 Response Table of Signal to Noise Ratios for Surface Roughness:

Table 9: Response Table for Signal to Noise Ratios

Levels	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	-11.72	-10.15	-11.06
2	-11.53	-11.80	-11.79
3	-10.70	-12.00	-11.10
Delta	1.02	1.85	0.74
Rank	**2**	**1**	**3**

Above Table 9. shows the Response for Signal to Noise Ratios of the given parameters. For this experiment, the input parameters that are influencing the Output parameter (Surface Roughness) in their decreasing order are Feed, Speed, and Depth of Cut. Response Table is used to cross check the ranking obtained in the Analysis of Variance.

4.5 Graph showing the Main Effects Plot for S/N ratios of Ra:

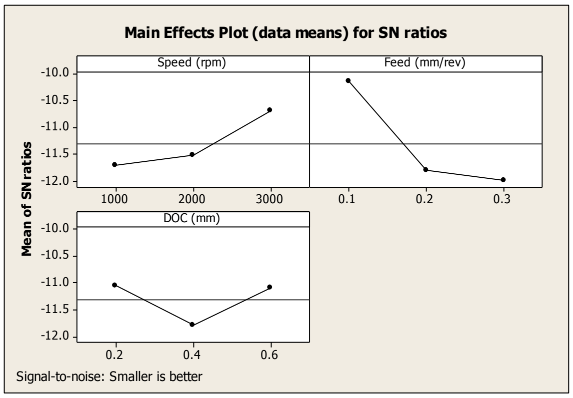

Figure 5: S/N ratio values for Surface Roughness

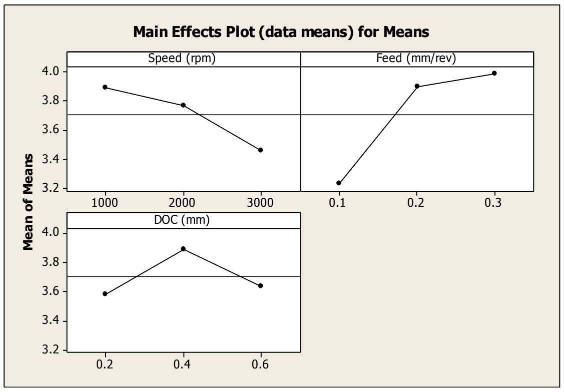

Figure 6: Mean values for Surface Roughness

Highest S/N ratio gives optimum machining parameter. Hence from Figure 5 and Figure 6 it can be observed that optimum values of machining parameters to get minimum Surface Roughness are Speed (3000 rpm), Feed (0.1mm/rev) and Depth of Cut (0.2mm).

Confirmation Test: Turning was conducted at optimum cutting parameters i.e., Speed 3000 rpm, feed 0.1mm/rev and Depth of Cut 0.2mm and found that Surface Roughness as 1.94 µm.

4.6 To Study the Comparison of Actual And Theoretical Values of MRR:

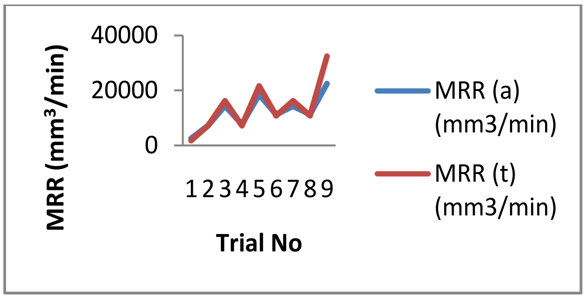

Figure 7: shows the comparison of Actual and Theoretical values of MRR

From Figure 7 it can be seen that for all the trials of this experiment, Theoretical value of Material Removal Rate is more compared to Actual values of Material Removal Rate. Further it can be observed that Material Removal Rate is Maximum when the values of Speed, Feed and Depth of Cut are at maximum levels i.e., 3000 rpm, 0.3 mm/rev and 0.4 mm respectively. Also it can be observed that Material Removal Rate is Minimum when the values of Speed, Feed and Depth of Cut are at minimum levels i.e., 1000 rpm, 0.1 mm/rev and 0.2 mm respectively.

5. CONCLUSION

1. Regression Model has been developed for Surface Roughness without coolant relating Speed, Feed and Depth of Cut to predict the value of the surface roughness.
2. The Analysis of Variance was performed to identify the influence of Machining Input parameters considered were Speed, Feed and Depth of Cut on the output Responses Surface Roughness using MINITAB software. Based on the Analysis of Variance the input parameters that are influencing the Output parameter Surface Roughness in their decreasing order are Feed, Speed and Depth of Cut.
3. Feed has the highest contribution of 69% followed by Speed 19.64% and Depth of Cut 11.36%.
4. The optimum values of machining parameters to get Optimum Surface Roughness are Speed of 3000 rpm, Feed of 0.1mm/rev and Depth of Cut of 0.2mm. Surface Roughness is found that is 1.94 µm. And average Surface Roughness is found to be 3.70 µm.
5. The Material Removal Rate is Maximum i.e., 22992.85 mm^3/min when the values of Speed, Feed and Depth of Cut are 3000 rpm, 0.3 mm/rev and 0.4mm respectively. And Machining Time is 11 sec i.e., Minimum at this level.
6. The Material Removal Rate is Minimum i.e., 2790.34 mm^3/min when the values of Speed, Feed and Depth of Cut are 1000 rpm, 0.1 mm/rev and 0.2 mm respectively. And Machining Time is 70 sec i.e., 1.5 times the Average at this level.
7. The average Material Removal Rate is 12540.06 mm^3/min.

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