Optimization of Surface Roughness and Material Removal Rate in CNC Turning of En 8 Steel Using Taguchi Method

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Abstract— CNC turning is one among the metal cutting process in which quality of the finished product depends mainly upon the machining parameters such as feed, speed, depth of cut, type of coolant used, types of inserts used, tool geometry etc. This paper outlines an experimental study to optimize the effects of cutting parameters of CNC turning on surface finish and Material removal rate (MRR) of EN8 alloy steel work material by employing Taguchi techniques. The Taguchi parameter design method is an efficient experimental method in which a response variable can be studied, using fewer experimental runs as compared to factorial design method. The control parameters for this operation included: cutting speed, feed rate and depth of cut. Response variable for optimization are Surface roughness and Material removal rate. The experimentation plan is designed using Taguchi's L9 Orthogonal Array (OA) and Minitab 16 statistical software is used. Optimal cutting parameters for, minimum surface roughness (SR) and maximum material removal rate were obtained. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment.
Key words: Taguchi method, Surface roughness, Material removal rate (MRR), CNC Turning, Orthogonal array(OA), ANOVA, Depth of cut (DOC)

I. INTRODUCTION

In today's rapidly changing scenario in manufacturing industries, applications of optimization techniques in metal cutting processes is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality product in the market. Turning is extensively used among all the cutting processes in manufacturing industries. The increasing importance of turning operations is achieving new dimensions in the present industrial era, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts. Surface finish is one of the most critical quality measures in mechanical products [1]. MRR is also an important measure for improving productivity.

EN8 is a medium carbon steel, good tensile strength, also known as 080M40 and is an unalloyed medium carbon steel. It is normally suitable for stressed pins, shafts, studs and keys among other uses. It is available as normalized or rolled and is supplied as plate, round hot rolled, hexagon, flats, and square and round drawn or turned [2] It is an unalloyed medium carbon steel grade with reasonable tensile strength.

This study helpful in evaluating optimum machining parameter like cutting speed, feed and depth of cut for surface roughness and MRR for the turning EN 8 steel on CNC Lathe machine. Design of experiment techniques, Analysis of variance (ANOVA) i.e. Taguchi 's technique has been used to accomplish the objective. L9 orthogonal array used for conducting the experiments and result analysis. Taguchi's parameter optimization method is used to evaluate best possible combination for minimum surface roughness and maximum MRR during turning. This study presents an experimental investigation into the effect of various process and tool dependent parameters on cutting forces.

II. TAGUCHI TECHNIQUE

It is a statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering [3] biotechnology [4], marketing and advertising It includes both upstream and shop-floor quality engineering [5]. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production and market place. Shop-floor techniques provide cost-based, real time methods for monitoring and maintaining quality in production. [6] Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only. [7] In this design analysis each factor is evaluated independent of all other factors [8] Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. [9]

III. EXPERIMENTATION

A. *Work Piece Material:*

The work material selected for the study was EN8 is a medium carbon steel, good tensile strength, also known as 080M40 and is an unalloyed medium carbon steel. It is normally suitable for stressed pins, shafts, studs and keys among other uses.

EN8 Specification Chemical composition	
Carbon	0.36-0.44%
Silicon	0.10-0.40%
Manganese	0.60-1.00%
Sulphur	0.050 Max
Phosphorus	0.050 Max
Chromium	-
Molybdenum	-
Nickel	-

Table 1: EN8 Chemical composition

B. Bexperimental Setup and Insert used:

CNC Lathe: CONCEPT CNC 2-AXIS TURNING MACHINE
FANUC Control Based Panel
Spindle Speed Range: 100 Rpm Minimum, 3000 Rpm Maximum
Feed Rate Range: 0.0025 –02 Mm Per Rev
WNMG Insert Is Used

Fig. 4: WNMG Insert

IV. Selection of Process Parameter

The selection of parameters of interest was based on some experiment preliminary. The following process parameters were thus selected for the present work i.e. Depth of cut(mm) Feed (mm/rev) and Cutting speed. (m/min)

S. No.	Symbol	Process Parameter	Unit
1	A	Depth of Cut	mm
2	B	Feed rate	mm/rev
3	C	Cutting Speed	m/min

Table 2: Selection of process parameters with code & units

One of the important attributes of Taguchi parameter design is it could also consider uncontrollable (Noise) factors in the analysis. As for the input signal to the CNC turning process, the initial work piece diameter is 16 ± 0.1 mm.

V. Response Variable

In this experiment Surface roughness and MRR are considered as response variable or output variable. Surface roughness can broadly be described as the geometric features of the surface. Surface roughness measurement is carried out by using a portable stylus-type profilometer. This instrument is a portable, self-contained instrument for the measurement of surface Roughness. The parameter reading evaluations are microprocessor based. The Roughness measurements, in the transverse direction, on the work pieces has been repeated three times and average of three measurements of surface roughness parameter values has been recorded.

Ra value of surface roughness is measured by this instrument. Initial and final weights of work piece were noted. Machining time was also recorded. Following equation is used for MRR calculation.

MRR= x F x rpm
Where D1= Diameter of workpiece before cutting
D2= Diameter of workpiece after cutting

VI. Selection of Orthogonal Arrays and Experimental Design

The DOF is defined as the number of comparisons between machining parameters that need to be made to determine, which level is better and specifically how much better it is. According to Taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degrees of freedom (DOF) and for three level process parameter have two degree of freedom. It gives a total of 6 DOF for three process parameters selected in this work. For this kind of calculation Taguchi L9 orthogonal array is used as shown in below Table 2.

Run	DOC	Feed	Cutting speed
	A	B	C
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 3: The basic Taguchi L9 Orthogonal array

VII. Orthogonal Array for Experimental Result

Cutting speed	feed	doc	Surface Roughness
66	0.05	0.15	0.9
66	0.06	0.2	1.25
66	0.07	0.25	0.82
70	0.05	0.2	1.69
70	0.06	0.25	1.17
70	0.07	0.15	1.62
75	0.05	0.25	0.9
75	0.06	0.15	0.65
75	0.07	0.2	0.9

Table 4: Experimental Results for Surface Roughness

DOC	FEED	Cutting speed	MRR
0.25	0.05	66	0.105
0.25	0.06	70	0.112
0.25	0.07	75	0.162
0.2	0.05	70	0.112
0.2	0.06	75	0.138
0.2	0.07	66	0.138
0.15	0.05	75	0.118
0.15	0.06	66	0.127
0.15	0.07	70	0.156

Table 5: Experimental Results for MRR

VIII. Data Analysis and Discussion

The experiments were conducted to study the effect of process parameters over the output response variables. The experimental results for the surface roughness and material removal rate are given in Table 4 and Table 5 respectively. The values of S/N ratio are obtained for the surface roughness and MRR. In the present study all the designs, plots and analysis have been carried out using Minitab-16 statistical software.

Cutting speed	Feed	Doc	Surface Roughness	S/N Ratio	MEAN
66	0.05	0.15	0.9	0.91515	0.9
66	0.06	0.2	1.25	-1.9382	1.25
66	0.07	0.25	0.82	1.723723	0.82
70	0.05	0.2	1.69	-4.55773	1.69
70	0.06	0.25	1.17	-1.36372	1.17
70	0.07	0.15	1.62	-4.1903	1.62
75	0.05	0.25	0.9	0.91515	0.9
75	0.06	0.15	0.65	3.741733	0.65
75	0.07	0.2	0.9	0.91515	0.9

Table 6: Experimental Results for Surface Roughness

DOC	FEED	Cutting speed	MRR	S/N	MEAN
0.25	0.05	66	0.105	-19.5762	0.105
0.25	0.06	70	0.112	-19.0156	0.112
0.25	0.07	75	0.162	-15.8097	0.162
0.2	0.05	70	0.112	-19.0156	0.112
0.2	0.06	75	0.138	-17.2024	0.138
0.2	0.07	66	0.138	-17.2024	0.138
0.15	0.05	75	0.118	-18.5624	0.118
0.15	0.06	66	0.127	-17.9239	0.127
0.15	0.07	70	0.156	-16.1375	0.156

Table 7: Experimental Results for MRR

The effect of different process parameters on surface roughness and MRR are calculated and plotted as the process parameters changes from one level to another. The average value of S/N ratios has been calculated to find out the effects of different parameters and as well as their levels. The use of both ANOVA technique and S/N ratio approach makes it easy to analyze the results and hence, make it fast to reach on the conclusion.

A. Analysis Of Variance For Surface Roughness:

Source	DF	SS	MS	F	%P
V	2	4.742	2.371	1.15	65.2
F	2	84.603	42.302	20.51	4.13
doc	2	10.298	5.149	2.50	25.06
Error	8	16.501	2.063		4.91
Total	17	336.276			

Table 8: ANOVA for surface roughness

Table 8 shows the result of the analysis of variance (ANOVA) for surface roughness height Ra. The analysis of variance was carried out for a 95% confidence level. The experiments were conducted to study the effect of process parameters over the output response characteristics with the process parameters. The experimental results for the surface roughness are given in Table 8 Experiment was simply repeated two times for obtaining S/N values. In the present study all the designs, plots and analysis have been carried out using Minitab 16 statistical software.

LEVEL	cutting speed	Feed	Depth of cut
L1	0.2336	-0.9091	0.1555
L2	-3.3706	0.1466	-1.8603
L3	1.8573	0.5171	0.4251
Max-Min	5.2279	1.0557	2.2853
Rank	1	3	2

Table 9: Response Table for Signal to Noise Ratios (lower the better)

B. Plot Of Average Response Curves:

Since we are looking for the mean and variance of the surface roughness values to be as small as possible, the ideal S/N effects should be as large as possible. This can be shown graphically as well; Fig.5 shows plots of the response and S/N ratio effects.

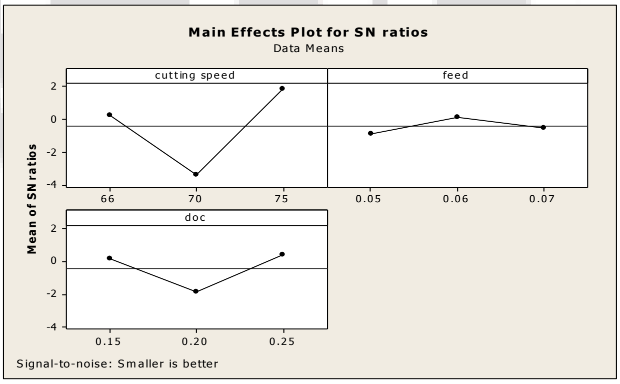

Fig. 5: Effects of Process Parameters on Surface Roughness

The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that cutting speed has the greatest effect on surface roughness then depth of cut and feed has least effect on surface roughness.

C. Analysis Of Variance (Anova) For Mrr:

Source	DF	SS	MS	F	%P
V	2	22.513	11.2565	20.50	30.88
F	2	31.072	15.5359	28.29	40.53
doc	2	31.718	15.8590	28.88	23.96
Error	8	4.319	0.5491		4.67
Total	14	89.622			

Table 10: ANOVA for MRR

LEVEL	cutting speed	Feed	Depth of cut
L1	-17.54	-19.05	--18.23
L2	-17.81	-18.05	-18.06
L3	-18.13	-16.38	-17.19

Max-Min	0.59	2.67	1.04
Rank	3	1	2

Table 11: Response Table for Signal to Noise Ratios (Larger is better)

D. *Plot Of Average Response Curves:*

Since we are looking for the mean and variance of the surface roughness values to be as small as possible, the ideal S/N effects should be as large as possible. This can be shown graphically as well. Figure shows plots of the response and S/N ratio effects

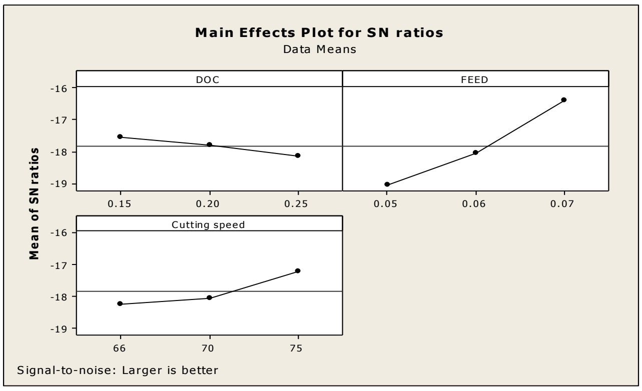

Fig. 6: Effects of Process Parameters on MRR

The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that Feed has the greatest effect on surface roughness then depth of cut and cutting speed has least effect on surface roughness.

IX. RESULT AND CONCLUSION

The present study can be concluded in the following steps:

1) Analysis of Variance suggests the cutting speed is the most significant factor for surface roughness and feed is most significant factor for MRR.
2) ANOVA (S/N Data) results shows cutting speed, Feed and DOC affects the Surface roughness by 65.2%, 25.1%, 4.06 % respectively.
3) ANOVA (S/N Data) results shows cutting speed, Feed and DOC affects the MRR by 30.88%, 40.55%, 23.96 % respectively.

X. SCOPE FOR FUTURE WORK

The results obtain by this method will be useful to other research for similar type of study and may be eye opening for further research on tool vibration, power consumption, temperature effects. There is also scope for considering more factors levels, interactions to optimize a selected set of parameters. A comparison between different optimization techniques can also be studied to check which optimization technique is better.

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