Selection of Optimum Machining Parameters For EN36 Alloy Steel in CNC Turning Using Taguchi Method

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Abstract-In this research work, L18 orthogonal array based Taguchi optimization technique is used to optimize the effect of various cutting parameter for surface roughness and Material Removal Rate (MRR) of EN 36 work material in turning operation. The orthogonal array, the signal to noise ratio and analysis of variance are employed to study the performance characteristics in both dry and wet machining conditions of cylindrical work pieces using Tin coated tungsten carbide cutting tool on CNC lathe. Five machining parameter such as spindle speed, feed rate, depth of cut, nose radius and the cutting environment (wet & dry) are optimized with consideration of surface roughness. Results of this study indicate for optimal cutting parameter, minimum surface roughness (Ra) and maximum material removal rate were obtained and developed model can be used to increase the machine utilization at low production cost in manufacturing environment.

Index Terms - Taguchi method, Surface roughness, MRR, CNC Turning, L18 Orthogonal array

1. INTRODUCTION

NOW a days it is the need of industries to production of the work pieces having high quality, dimensional accuracy, surface finish, high production rate, less wear on the cutting tools and also low cost of machining. Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy [1]. Nirav.M et al.[2] have conducted the experiment the specimen heated with gas flame were machined on a lathe under different cutting conditions of surface temperature, cutting speed and feed rates. Cutting force, feed force and surface roughness were studied under the influence of machining parameter at 200°C,300C,400C,500C and optimum result was achieved by taguchi and it conclude that process parameter do not have same effect for every response. K.Senthil Kumar et al.[3] investigated The effect on surface roughness of machining parameters Material-Duplex Stainless Steel The surface roughness is mainly influenced by the feed rate. With an increase in feed rate, the surface roughness also increases considerably. The cutting speed and the depth of cut are less significant for surface roughness than the feed rate From the ANOVA analysis, the parameter that has the most significant effect on surface roughness is the feed rate. Cutting speed has the next most significant effect, and finally, the depth of cut has the least significant effect on surface roughness. P.Ravindrababu et al.[4] have optimized the burnishing parameters and determination of characteristics in engineering materials (EN8, EN24,EN31) studied reveals that the burnishing depth, increase in micro hardness or increase in magnitude of compressive residual stresses, is higher in case of softer alloy steel EN 31 as compared to the relatively harder EN 8 and EN 24 alloy steels. higher extent of burnishing resulted in different extents of micro structural modification (as reflected by the magnitude of compressive residual stresses) and showed a maximum at intermediate burnishing pass first in EN 8, EN 31 and second in EN 24 steel of the three passes studied in this investigation and Surface roughness is most influenced by burnishing force in c EN 8, by burnishing speed in EN 24 and EN 31. Mahendra Korat et al.[5] have studied the effects of the process parameters viz. coolant condition, cutting speed, feed, depth of cut, nose radius, on response characteristics viz. material removal rate, surface roughness on EN24 material in CNC turning analyze that the nose radius is the most significant factor and cutting environment is most in significant factor for both surface roughness and MRR., ANOVA (S/N Data) results shows that nose radius, depth of cut ,feed rate, cutting speed and coolant condition affects the material removal rate by 40.68 %, 20.96 % , 20.53 % , 14.88 % and0.023 % respectively. Jakhale prashant P. et al.[6] have experimental design was used to obtain optimum cutting condition on high alloy steel by changing operational parameters and insert Geometry in turning process analyze multi- response optimization problem has been solved by obtaining an optimal parametric combination, capable of producing high surface quality turned product in a relatively lesser time. The best settings of control factors (i.e cutting speed, feed rate and depth of cut), they influence the output parameters are determined through experiments. [7] In this study, nose radius has been taken into consideration along with cutting speed, feed rate and depth of cut. The fifth factor taken into consideration is the cutting environment. Machining is done under two different environmental conditions—dry, wet. In this work, L18 orthogonal array based Taguchi optimization technique is used to optimize the effect of machining parameter such as spindle speed, feed rate, depth of cut, nose radius and cutting environment (wet & dry) on Material removal rate(MRR) and surface roughness(SR) in CNC turning of EN 36 carbon alloy steel.

2 TAGUCHI METHOD

A Japanese engineer G. Taguchi developed a methodology, based on the fewer experimental designs and providing a clear understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing [8]. Taguchi introduced his approach, using experimental design for [9]:

- Designing products/processes so as to be robust to environmental conditions;
- Designing and developing products/processes so as to be robust to component variations;
- Minimizing variation around a target value.

The philosophy of Taguchi is applicable widely. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (*S*/*N*) ratio *η*. usually; there are three categories of the performance characteristic in the analysis of the *S*/*N* ratio, that is, the lower-the-better, the higher-the-better, and the nominal the-better. The *S*/*N* ratio for each level of process parameters is computed based on the *S*/*N* analysis Regardless of the category of the performance characteristic the larger *S*/*N* ratio corresponds to the better performance characteristic Therefore, the optimal level of the process parameters is the level with the highest *S*/*N* ratio *η*. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the *S*/*N* and ANOVA analyses, the optimal combination of the process parameters can be predicted.

In this paper, the cutting parameter design by the Taguchi method is adopted to obtain optimal machining performance in turning operation.

Nominal is the best:

$$S/N_T = 10\log(\frac{\bar{y}}{s_y^2}) \quad (1)$$

Larger –is-the better (maximize):

$$S/N_L = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

Smaller-is-the better (minimize):

$$S/N_s = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right) \quad (3)$$

Where y, is the average of observed data, S_y^2 is the variance of y, n is the number of observations and y is the observed data. The goal of this research was to produce minimum surface roughness (R_a) in a turning operation. Smaller R_a values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study [9]. The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps:

- Identify the performance characteristics and select process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
- Conduct the experiments based on the arrangement of the orthogonal array.

- Calculate the total loss function and the *S/N* ratio.
- Analyze the experimental results using the *S/N* ratio and ANOVA.
- Select the optimal levels of process parameters.
- Verify the optimal process parameters through the confirmation experiment.

3 EXPERIMENTAL DETAIL

3.1 Work Material

EN 36 Steel is a low carbon and high alloy content alloy steel .Characteristics of steel are toughness arising from the use of nickel .It is widely used for components with large cross section, requiring high toughness and Score strength such as gears, crane shafts and heavy-duty gear shafts in aircraft and truck construction and mechanical engineering.

TABLE II
Physical properties of EN36 steel

Density (g/cm^3)	Coefficient of thermal expansion	Modulus of Elasticity (KN/mm^2)
15.7	11.6×10^{-6}	669-696

TABLE III
Major constituents of EN36 steel (%)

C	Ni	Cr	Si	Mn	S	P	Mb
0.7	3.2	1.050	0.25	0.42	0.01	0.012	0.140

3.2 EXPERIMENTAL SETUP & CUTTING CONDITIONS

In this study, cylindrical work pieces of EN 36 alloy steel having diameter of Φ 40 mm and length of 220 mm used. The experiments were carried out on a MCL 10 CNC Lathe were used for the experimentation. The experiments were conducted under environmental condition (dry-wet) machining condition TiN coated tungsten carbide inserts with tool holder of ISO coding ETJNL2525M16. For the present experimental work the five process parameters four at three levels and one parameter at two levels have been decided. It is desirable to have two minimum levels of process parameters to reflect the true behavior of output parameters of study. The process parameters are renamed as factors and they are given in the adjacent column. The levels of the individual process parameters/factors are given in Table 5

TABLE V
Details of process parameters for EN36 steel

F	Parameters	Level 1	Level 2	Level 3
A	Cutting Environment	Wet	Dry	-
B	Spindle Speed(rpm)	250	350	500
C	Feed(mm/rev)	0.5	0.62	0.75
D	Depth Of Cut(mm)	1.0	1.5	1.75
E	Nose Radius(mm)	0.5	0.8	1.4

Surface roughness can generally be described as the geometric features of the surface. Surface roughness measurement is carried out by using Mitutoyo SJ-301 surface roughness tester. This instrument is a portable, self-contained instrument for the measurement of surface texture. The parameter evaluations are microprocessor based. The measurement results are displayed on a screen. 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. Initial and final weights of work piece were noted. Machining time was also recorded. Following equations were used to calculate the response Material Removal Rate (MRR).

MRR = [Initial Weight of workpiece (gm) − Final Weight of workpiece (gm)] Density (gm /mm^3) × Machining Time (min)

As per Taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degrees of freedom (DOF) and for two level process parameter one degree of freedom. This gives a total of 9 DOF for five process parameters selected in this work. For such kind of situation Taguchi L18 orthogonal array is used as shown in Table 3.3.

3.3.1 SELECTION OF ORTHOGONAL ARRAYS AND EXPERIMENTAL DESIGN

TABLE 3.3 L18 Orthogonal Array for resent work

Trial No.	L18(21×34)				
	1	2	3	4	5
	A	B	C	D	E
1	Wet	250	0.5	1.0	0.5
2	Wet	250	0.75	1.5	0.8
3	Wet	250	0.62	1.75	1.4
4	Wet	350	0.5	1.0	0.5
5	Wet	350	0.75	1.5	0.8
6	Wet	350	0.62	1.75	1.4
7	Wet	500	0.5	1.5	0.5
8	Wet	500	0.75	1.75	0.8
9	Wet	500	0.62	1.0	1.4
10	Dry	250	0.5	1.75	0.5
11	Dry	250	0.75	1.5	0.8
12	Dry	250	0.62	1.75	1.4
13	Dry	350	0.5	1.0	0.5
14	Dry	350	0.75	1.5	0.8
15	Dry	350	0.62	1.75	1.4
16	Dry	500	0.5	1.0	0.5
17	Dry	500	0.75	1.5	0.8
18	Dry	500	0.62	1.75	1.4

4 ANALYSIS AND DISCUSSION

The experiments were conducted to study the effect of process parameters over the output response characteristics with the process parameters as given in Table 3.3. The experimental results for the surface roughness and material removal rate are given in Table 4.1 and Table 4.2 respectively. 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 statistical software.

TABLE 4.1 Experimental Results for Surface Roughness

Trial No.	Surface Roughness(μm)		S/N Ratio
	R1	R2	
1	3.40	3.45	-9.2157
2	6.17	6.25	-14.8715
3	4.56	4.85	-12.1988
4	2.69	2.75	-8.7730
5	4.17	4.25	-14.0179
6	2.84	2.89	-8.5745
7	2.76	2.75	-7.9281
8	3.39	3.45	-11.6239
9	2.12	2.18	-9.2611
10	3.89	3.95	-12.5720
11	3.07	3.18	-13.3961
12	4.89	4.65	-13.0942
13	3.71	3.55	-11.6884
14	4.59	4.45	-12.2026
15	3.55	3.45	-10.2507
16	2.63	2.52	-9.2944
17	7.01	7.10	-12.8892
18	2.87	2.82	-9.4058

TABLE 4.2 Experimental Results for material removal rate

Trial No.	Material Removal Rate(mm^3/min)		S/N Ratio
	R1	R2	
1	45532.15	45805.89	90.730
2	85287.84	87642.41	97.789
3	42328.64	43399.63	96.744
4	63668.92	65306.12	96.495
5	47818.29	49049.66	96.432
6	98863.07	101317.12	94.915
7	45532.15	46647.23	98.810
8	239520.95	245398.77	104.010
9	198019.80	203045.68	105.540
10	34149.11	34985.42	90.850
11	34115.13	35056.96	91.032
12	98765.43	101265.82	98.968
13	79586.15	81632.65	93.188
14	23909.14	24524.83	90.794
15	59317.84	60790.27	99.446
16	91064.31	93294.46	100.766
17	138869.11	140227.87	101.419
18	141442.71	145032.63	101.762

The effect of different process parameters on material removal rate and roughness 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. [7]

4.1 Analysis Of Variance for Surface Roughness

TABLE 4.3 ANOVA for Surface Roughness

Source	DF	SS	MS	F	%P
CE	1	3.854	3.854	0.64	0.447
SS	2	19.238	9.619	1.60	0.261
F	2	36.408	18.204	3.02	0.105
doc	2	4.440	2.220	0.37	0.703
NR	2	11.978	5.989	0.99	0.412
Error	8	48.223	6.028		
Total	17	124.141			

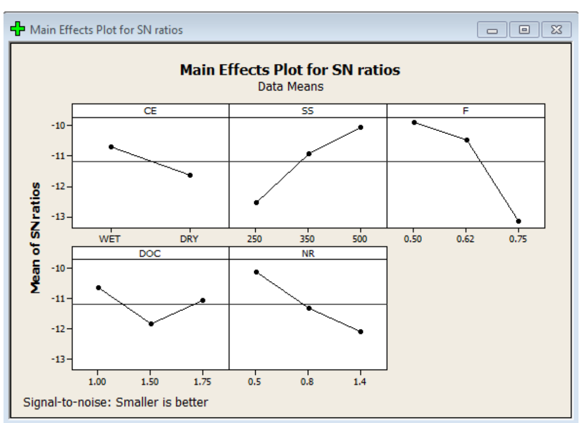

Fig 4.1: Effects of Process Parameters on Surface Roughness

TABLE 4.4Response Table for Surface Roughness

Level	CE	SS	F	Doc	NR
1	3.607	4.359	3.171	3.663	3.256
2	3.993	3.574	3.473	4.070	3.866
3		3.467	4.757	3.668	4.278
Delta	0.387	0.892	1.586	0.407	1.023
Rank	5	3	1	4	2

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 and is followed by nose radius, spindle speed, depth of cut and environmental condition in that order. As surface roughness is the "lower the better" type quality characteristic, from Figure 4.1 it can be seen that the first level of coolant condition (A1), third level of spindle speed (B3), first level of feed (C1), first level of depth of cut (D1) and first level of nose radius (E1) result in minimum value of surface roughness.

4.2 Analysis of Variance for MRR

Source	DF	SS	MS	F	%P
CE	1	9.727	9.727	0.49	0.503
SS	2	213.550	106.775	5.40	0.033
F	2	59.426	29.713	1.50	0.279
doc	2	7.058	3.529	0.18	0.840
NR	2	72.394	36.197	1.83	0.222
Error	8	158.201	19.775		
Total	17	520.355			

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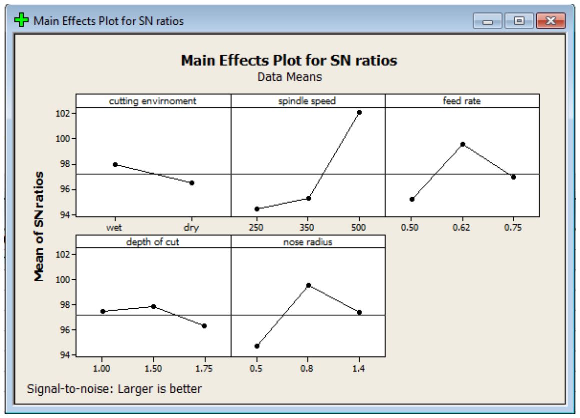

Fig 4.2: Effects of Process Parameters on MRR

TABLE 4.6 Response Table for MRR

Level	CE	SS	F	Doc	NR
1	97455	57365	60605	90813	65648
2	78782	62982	107799	84142	107610
3		144008	95952	89400	91097
Delta	18672	86643	47195	6671	41962
Rank	4	1	2	5	3

The ranks and the delta values show that spindle speed have the greatest effect on material removal rate and is followed by feed, nose radius, depth of cut and environmental condition in that order. As MRR is the "higher the better" type quality characteristic, it can be seen from Figure 5.1 that the first level of coolant condition (A1), third level of Spindle speed (B3), second level of feed (C2), first level of depth of cut (D1) and first level of nose radius(E1) provide maximum value of MRR.

4.3 Confirmation of Experiment

In order to validate the results obtained two confirmation experiments were conducted for each of the response characteristics (MRR, SR) at optimal levels of the process variables. The average values of the characteristics were obtained and compared with the predicted values. The results are given in Table 4.7. The values of MRR and Surface roughness obtained through confirmation experiments are within the 95% of CICE of respective response characteristic. It is to be pointed out that these optimal Values are within the specified range of process variables

TABLE 4.7 Predicted Optimal Values, Confidence Intervals and Results of Confirmation Experiments

Response	Optimal Set of Parameter	Predicted Optimal Value	Predicted Intervals	Actual Value
MRR	A1B3C2D1E2	183092 mm3/ min	114756< μMRR <132867	184051 mm3/m in
SR	A1B3C1 D1E1	1.9625 μm	0 < μSR < 1.052	1.4 μ m

5 CONCLUSIONS

The effects of the process parameters viz. coolant condition, cutting speed, feed, depth of cut, nose radius, on response characteristics viz. material removal rate, surface roughness, were studied on EN36 material in CNC turning. Based on the results obtained, the following conclusions can be drawn:

1 Analysis of Variance suggests the depth of cut is the most significant factor for both surface roughness and MRR and Feed is most in significant factor for surface roughness and spindle speed for MRR.

2 ANOVA (S/N Data) results shows that spindle speed, feed, nose radius, coolant condition, and depth of cut affects the material removal rate by 0.033 %, 0.279 % , 0.222 % , 0.503 % and0.0.840% respectively.

3 ANOVA (S/N Data) results shows that feed, nose radius, spindle speed, depth of cut and coolant condition affects the surface roughness by 0.105 %, 0.412 %, 0.261 %, 0.703 % and 0.447 % respectively.

4 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 (only in dry condition).

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