Optimization of Different Machining Parameters of En24 Alloy Steel In CNC Turning by Use of Taguchi Method

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ABSTRACT

The present paper outlines an experimental study to optimize the effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. Five parameters were chosen as process variables: Speed, Feed, Depth of cut, Nose radius, Cutting environment (wet and dry). The experimentation plan is designed using Taguchi's L18 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

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

1. Introduction:

Increasing the productivity and the quality of the machined parts are the main challenges of metal-based industry; there has been increased interest in monitoring all aspects of the machining process. Turning is the most widely used among all the cutting processes. The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts and surface finish is one of the most critical quality measures in mechanical products.[1]

EN24 is a medium-carbon low-alloy steel and finds its typical applications in the manufacturing of automobile and machine tool parts. Properties of EN24 steel, like low specific heat, and tendency to strain-harden and diffuse between tool and work material, give rise to certain problems in its machining such as large cutting forces, high cutting-tool temperatures, poor surface finish and built-up-edge formation. This material is thus difficult to machine.[2] One of the most important parameters in tool geometry is the nose radius. It strengthens the tool point by thinning the chip where it approaches the point of tool and by spreading the chip over larger area of point. It also produces better finish because tool marks are not as deep as formed by sharp tool.[3] 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.

The objective of this experimental investigation is to ascertain the effects of cutting speed, feed rate, depth of cut, nose radius and cutting environment on Material removal rate and surface roughness in CNC turning of EN 24 medium alloy steel. Design of experiment techniques, i.e. Taguchi's technique; have been used to accomplish the objective. L18 orthogonal array used for conducting the experiments.

2. Taguchi technique

It includes both upstream and shop-floor quality engineering. 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.[4] 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.[5] Taguchi's design is a fractional factorial matrix that ensures a balanced comparison of levels of any factor. In this design analysis each factor is evaluated independent of all other factors [3]
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.[6]

3. Experimental detail

3.1 Work material

The work material selected for the study was EN 24 medium alloy steel with high tensile strength, shock resistance, good ductility and resistance to wear. The EN24 alloy steel is required to be heated to a temperature of 900^0C to 950^0 for hardening and followed by quenching in a oil medium. It is then tempered with temperature of 200^0 to 225^0C and obtains a final hardness of 45 to 55 HRC.

TABLE 3.1: Chemical Composition of the Material

Constituent	**C**	**Si**	**Mn**	**Ni**	**Cr**	**Mo**
% composition	0.35 to 0.45	0.1 to 0.30	0.5 to 0.7	1.3 to 1.8	0.9 to 1.4	0.2 to 0.35

3.2 Selection of Cutting Tools and tool holders

The cutting tool selected for machining EN24 alloy steel was TiN coated tungsten carbide inserts. The tungsten carbide inserts used were of ISO coding TNMG 160404, TNMG 160408 and TNMG 160412 and tool holder of ISO coding ETJNL2525M16.The tool geometry of the insert and tool holder is as follows

Insert shape	60° Triangle
Insert clearance angle	00
Cutting edge length	16 mm
Insert thickness	4.76 mm
Nose radius	0.4, 0.8 and 1.2 mm
Shank height	25 mm
Shank width	25 mm
Tool length	150 mm

3.3 Experimental plan and cutting conditions

The experiments were carried out on a CNC turning centre machine (Jyoti DX 200) of Jyoti CNC Automation Pvt. Ltd. Installed at S.K. Engineering works, Udyog Nagar Udhana Surat India. Specimens of Ø32 mm x 220 size were used for the experimentation. The experimental setup is shown in Fig.1.

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 5.1.

Fig3.1: Pictorial View of CNC Turning Machine Tool

TABLE 3.2: Process Parameters and their Levels

Factors	Parameters	Units	Levels		
			L1	L2	L3
A	Cutting environment	-	Wet	Dry	-
B	Cutting speed	m/min	180	220	260
C	Feed rate	mm/rev	0.2	0.25	0.3
D	Depth of cut	mm	1.25	1.5	1.75
E	Nose radius	mm	0.4	0.8	1.2

Surface roughness can generally be described as the geometric features of the surface. Surface roughness measurement is carried out by using a portable stylus-type profilometer (TR 200, India Tools & Instruments Co., Mumbai). 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).

$$MRR\ (mm^3/min) = \frac{[\text{Initial Weight of workpiece (gm)} - \text{Final Weight of workpiece (gm)}]}{\text{Density (gm/mm 3)} \times \text{Machining Time (min)}} \quad \text{----------------------(1)}$$

3.3.1 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. 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.

TABLE 3.3 L18 Orthogonal Array for present work

	L18(21×34)				
Tria lNo.	**1**	**2**	**3**	**4**	**5**
	A	**B**	**C**	**D**	**E**
1	Wet	180	0.2	1.25	0.4
2	Wet	180	0.25	1.5	0.8
3	Wet	180	0.3	1.75	1.2
4	Wet	220	0.2	1.25	0.8
5	Wet	220	0.25	1.5	1.2
6	Wet	220	0.3	1.75	0.4
7	Wet	260	0.2	1.5	0.4
8	Wet	260	0.25	1.75	0.8
9	Wet	260	0.3	1.25	1.2
10	Dry	180	0.2	1.75	1.2
11	Dry	180	0.25	1.5	0.4
12	Dry	180	0.3	1.25	0.8
13	Dry	220	0.2	1.5	1.2
14	Dry	220	0.25	1.75	0.4
15	Dry	220	0.3	1.25	0.8
16	Dry	260	0.2	1.75	0.8
17	Dry	260	0.25	1.25	1.2
18	Dry	260	0.3	1.5	0.4

Surface roughness being a ‘lower the better’ type of machining quality characteristic, the S/N ratio for this type of response was used and is given below [4]

S/N ratio = -10 Log_{10} $\{(Y_1^2 + Y_2^2 + . . . + Y_N^2)/N\}$ --------(2)

where $Y_1, Y_2, . . ., Y_N$ are the responses of the machining characteristic, for a trial condition repeated n times. The S/N ratios were computed using Eq. 2 for each of the 18 trials and the values are reported in Table 4.1

Material removal rate being a ‘higher the better’ type of machining quality characteristic, the S/N ratio for this type of response was used and is given below [4]

S/N ratio = - 10 Log_{10} $\{(1/Y_1^2 + 1/Y_2^2 + . . . + 1/Y_N^2)/N\}$ ----------------(3)

The S/N ratios were computed using Eq. (3) for each of the 18 trials and the values are reported in Table 4.2

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 (µ m)**		**S/N Ratio**
	R1	**R2**	
1	3.82	3.721	-11.5287
2	2.605	2.63	-8.35783
3	2.466	2.467	-7.84162
4	1.767	1.846	-5.13884
5	1.598	1.536	-3.90308
6	4.92	4.894	-13.8164
7	3.173	3.175	-10.0321
8	2.782	2.768	-8.86529
9	2.621	2.567	-8.27987
10	1.067	1.094	-0.67317
11	6.222	6.022	-15.739
12	3.716	3.623	-11.2928
13	1.054	1.047	-0.42797
14	5.181	5.258	-14.3528
15	3.779	3.701	-11.4579
16	1.843	1.945	-5.55075
17	1.7	1.653	-4.48892
18	3.721	3.798	-11.5031

TABLE 4.2 Experimental Results for material removal rate

Trial No.	**Material Removal Rate mm3/min**		**S/N Ratio**
	R1	**R2**	
1	47434.33	47890.43	93.5632
2	56154.71	55014.52	94.8977
3	64310	63283.78	96.0951
4	44042.43	44321.18	92.9047
5	53310.85	51917.1	94.4197
6	123373.7	111245.4	101.352
7	75128.26	74798.75	97.4969
8	97199.14	92668.67	99.5410
9	58330.8	50421.54	94.6392
10	41276.99	41733.09	92.3616
11	67841.73	62995.9	96.2962
12	58152.66	51653.25	94.7462
13	41254.93	37073.69	91.8207
14	97213.9	93381.1	99.5764
15	73187.77	63150.59	96.6011
16	81388.95	74139.73	97.7873
17	47775.85	45304.68	93.3474
18	120121.9	119627.6	101.574

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

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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	0.288	0.288	0.14	0.09
V	2	4.742	2.371	1.15	1.41
F	2	84.603	42.302	20.51	25.1
doc	2	10.298	5.149	2.50	3.06
NR	2	219.843	109.922	53.29	65.4
Error	8	16.501	2.063		4.91
Total	17	336.276			

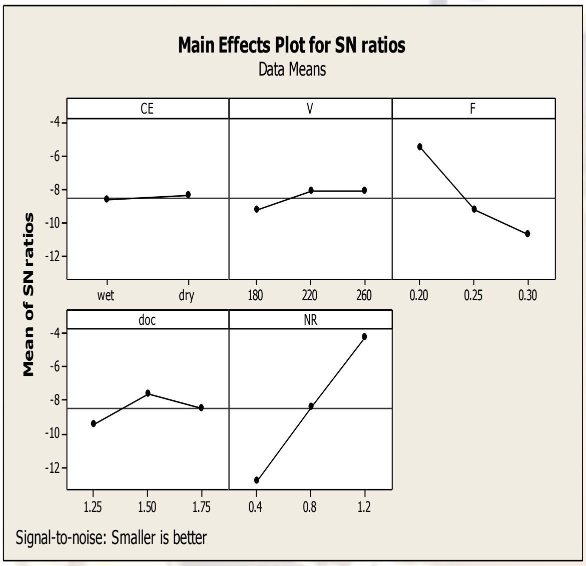

Fig 4.1: Effects of Process Parameters on Surface Roughness

TABLE 4.4Response Table for Surface Roughness

Level	CE	V	F	doc	NR
1	2.853	3.288	2.129	3.285	4.492
2	3.135	3.048	3.330	2.640	2.750
3		2.645	3.523	3.057	1.739
Delta	0.282	0.642	1.393	0.645	2.753
Rank	5	4	2	3	1

The ranks indicate the relative importance of each factor to the response. The ranks and the delta values for various parameters show that nose radius has the greatest effect on surface roughness and is followed by feed, depth of cut, cutting speed and coolant condition in that order. As surface roughness is the “lower the better” type quality characteristic, from Figure 5.3, it can be seen that the first level of coolant condition (A1), third level of cutting speed (B3), first level of feed (C1), second level of depth of cut (D2), and third level of nose radius (E3) result in minimum value of surface roughness.

4.2 Analysis of Variance for MRR

TABLE 4.5 ANOVA for MRR

Source	DF	SS	MS	F	%P
CE	1	0.035	0.0354	0.06	0.023
V	2	22.513	11.2565	20.50	14.88
F	2	31.072	15.5359	28.29	20.53
doc	2	31.718	15.8590	28.88	20.96
NR	2	61.546	30.7730	56.04	40.68
Error	8	4.393	0.5491		2.90
Total	17	151.28			

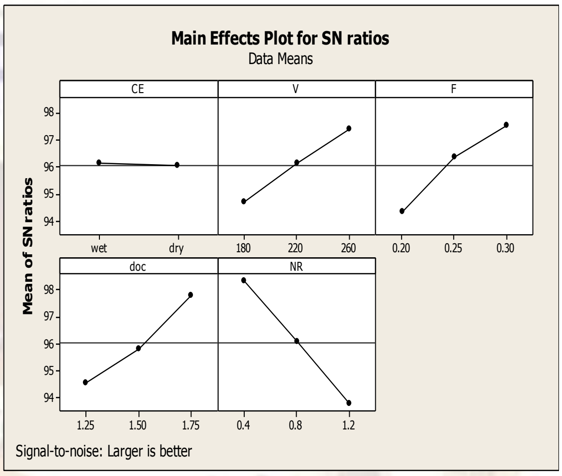

Fig 4.2: Effects of Process Parameters on MRR

TABLE 4.6 Response Table for MRR

Level	CE	V	F	doc	NR
1	67269	54812	54207	54391	86754
2	67626	69456	68398	66184	65923
3		78075	79738	81768	81768
Delta	357	23264	25531	27376	37088
Rank	5	4	3	2	1

The ranks and the delta values show that nose radius have the greatest effect on material removal rate and is followed by depth of cut, feed rate and cutting speed 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 cutting speed (B3), third level of feed (C3), third level of depth of cut (D3) and first level of nose radius provide maximum value of MRR.

4.3 Confirmation 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 CI_{CE} 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	A1B3C3 D3E1	123812 mm3/ min	114756< μ_{MRR} <132867	125852mm^3/ min
SR	A1B3C1 D2E3	0.434 µm	0 < μ_{SR} < 1.052	0.4840 µm

Conclusion

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 En24 material in CNC turning. Based on the results obtained, the following conclusions can be drawn:

1 Analysis of Variance suggests the nose radius is the most significant factor and cutting environment is most in significant factor for both surface roughness and MRR.

2 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.

3 ANOVA (S/N Data) results shows that nose radius, feed rate, depth of cut, cutting speed and coolant condition affects the surface roughness by 65.38 %, 25.15 % , 3.06 % , 1.41 % and 0.09 % 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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