Application of Taguchi technique for Analysis of Forces and Surface finish during hard machining of Steel EN-24 using Ceramic tool insert

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Abstract- The objective of this paper is to obtain optimal setting of turning process parameters cutting speed, feed rate and depth of cut resulting in an optimal value of Feed force, Tangential force & Surface roughness while machining hardened EN-24 steel with ceramic tool insert. The effect of the selected process parameters on the feed force, tangential force and surface roughness have been accomplished using Taguchi's design of experiments approach. The results indicate that the selected process parameters significantly affect the mean & variance of feed force, tangential force and surface roughness. The percent contributions of parameters in the ANOVA table for Feed force (F_x) for Depth of cut (86.67%) has a major contribution than that of cutting speed (2.29%) and Feed rate (0.89%). Tangential force (F_y), Depth of Cut (81.47%) has a major contribution than that of Feed rate (15.24%) and Cutting speed (0.96%). Similarly the Surface roughness (R_a), has Depth of cut (58.97%) has a major contribution than that of Cutting speed (24.85%) and Feed rate (13.21%). In all these cases the interactions are not having any major contributions. The predicted optimum Feed force, Tangential force and Surface roughness are-100N, 230N and 0.96 µm. The results have been validated by the confirmation of experiment and found to be with in the range of these values.

Keywords–Cutting force; Feed force; Surface roughnes; coated Ceramic tool and ANOVA.

I. INTRODUCTION

In the recent years, hard machining(HM) of steel parts hardened to about 60 HRC performed by both mixed ceramic and CBN tools became very popular and effective technology replacing successively grinding operations traditionally used. In much mass production manufacturing process, hard machining can be performed in several typical machining operations especially in turning and milling operations.

The metal cutting industries in developing countries continue to suffer from a major drawback of not running the machine tools at their optimum operating conditions. The operating conditions continue to the chosen solely on the basis of the handbook values and or work experience. The literature survey has revealed, a little research has been conducted to obtain the machining characteristics. R.C. Brewer and R. Rueda developed various nomograms to assist the selection of optimum conditions [1].E.J.A. Armarego and R.H. Brown used the maxima/minima principle of differential calculus for optimization of machining variables in turning operations [2]. P.G.Petropoulos used other techniques which have been used to optimize metal cutting conditions include geometrical programming [3]. E.A. Elsayed and Chen determined optimal settings of process parameters of production process using robust design methodology [4]. Harisingh and Pradeep Kumar constructed an Ishikawa cause-effect diagram in order to identify the process parameters that may affect the machining characteristics of turned parts such as cutting tool parameters- Tool geometry and Tool material; workpiece related parameters – metallographic hardness etc., cutting parameters- cutting speed, feed rate and depth of cut, dry cutting and wet cutting [5]. Singh and Kumar studied on optimization of feed force through setting of optimal value of process parameters namely speed, feed and depth of cut in turning of EN-24 steel with TiC coated Tungsten carbide inserts. The authors used Taguchi's parameters design and concluded that the effect of depth of cut and feed variations of feed force affected more as compared to speed [6]. Sahoo et al, studied for optimization of machining parameters combinations emphasizing on fractal characteristics of surface profile generated in CNC turning operation. The authors used L_{27} Taguchi orthogonal array design with machining parameters: cutting speed, feed rate and depth of cut on three different workpiece materials namely Aluminium, Mild steel and Brass. It was concluded that feed rate was more significant in influencing surface finish in all three materials. It was observed that in case of Mild steel and Aluminium feed rate showed some influences while in case of Brass depth of cut was noticed to impose some influences on surface finish. The factorial interactions were responsible for controlling the fractal dimensions of surface profile produced in CNC turning [7]. Motorcu and Sahin have machined the hardened AISI 1040 steel with triangular and square tools in different machining conditions and modeled the surface parameters on surface roughness. They classified the effects of machining and cutting speed respectively. The authors stated that the lowest surface roughness is produced with square tools [8].

In this paper an experimental evaluation was carried out by using coated ceramics inserts, to perform turning operations on hard steel material (EN24 steel) of hardness 50HRC at different cutting conditions for study and coated ceramics tools were used for studying the machining characteristics for the various feed rate, cutting speeds and depth of cut .The forces measured are cutting force and feed force using lathe tool dynamometer and surface roughness was measured using Talysurf Surface Tester.

II. EXPERIMENTAL DETAILS

The heat treated EN-24 steel is selected as the work material for turning operation. The following process parameters were selected for the present work: cutting speed-(A), feed rate-(B), and depth of cut-(C), Tool material-coated ceramic insert (Kennametal Widia) make.
Insert geometry- MTJNR2020M12.
Tool holder- MTJNR2020K16.
Cutting conditions-Dry
Tool overhang-20 mm
Selection of an orthogonal array (OA):
In selecting an appropriate OA, the prerequisites are:
i) Selection of process parameters and interactions to be evaluated
ii) Selection of number of levels for the selected parameters.
The non-linear behavior of the process parameters if exists, can only be revealed if more than two level of the parameters along with their values at three levels are given in Table 1. It was also decided to study the two factor interaction effects on the cutting force [9]. The selected interactions were:
i) Between cutting speed and feed (AxB)
ii) Between feed and depth of cut (BxC)
iii) Between speed and depth of cut (AxC)
The three parameters each at three levels and three second – order interactions were selected and the total degree of freedom (DOF) required is 18, since a three level parameter has 2 DOF (number of levels – 1) and each second order interaction has 4 DOF (product of DOF of interacting parameters). As per Taguchi's method the total DOF of the selected OA must be greater than or equal to the total DOF required for the experiment. In this paper Taguchi's method approach is used to analyze the cutting forces, surface roughness and optimum cutting conditions for Feed force (F_x), Tangential force (F_y) and surface roughness (R_a) by considering the turning process parameters like cutting speed, feed rate and depth of cut using coated ceramic insert while machining EN-24 steel.

EN-24 steel rods of 60 mm diameter and 300 mm length were machined on HMT Lathe having power 3.5 KW using coated Ceramic inserts having the designation MTJNR2020M12. The workpiece is machined as per the process parameters given in Table 1. The Feed force (F_x) and Tangential force (F_y) were measured for each trial using lathe tool dynamometer and the Surface roughness (R_a) is measured using Talysurf. The results of the experiments for twenty seven trials were reported in Table 2. The Analysis of Variance (ANOVA) for raw data and Signal to Noise ratio are calculated for Feed force (F_x), Tangential force (F_y) and Surface roughness (R_a) and are tabulated in Table 3 to Table 8. The Signal – to – Noise ratio for LB characteristics are calculated using:

$$S/N_{LB} = -10 \log \left(1.\ \frac{1}{r}\sum_{i=1}^{r}\right) \qquad (1)$$

Table 1 shows the details of the process parameters:

Process parameters	Parameters Designation	Levels		
		L1	L2	L3
Cutting speed (m/min)	**A**	**101.78**	**131.94**	**171.53**
Feed (mm/rev)	**B**	**0.086**	**0.102**	**0.125**
Depth of cut (mm)	**C**	**0.4**	**0.6**	**0.8**

A confidence interval for the predicted mean on a confirmation run can be calculated using the following equation

$$CI=\sqrt{F_{\alpha}\left(1,f_{g}\right)\left[\frac{1}{n_{eff}}+\frac{1}{R}\right]\left(V_{g}\right)} \quad (2)$$

Where F_{α} $(1,f_e)$ = F – ratio required for α, α is the risk factor

F_e = error DOF

V_e = error variance

R = Number of repetitions

N= Number of trials

N_{eff} = effective number of replications and is equal to

$$\frac{N}{1 + [\text{Total DOF associated with items used in } \mu \text{ estimate}]}$$

Table 2 shows the details of experimental data of Feed force (Fx), Tangential force (Fy) and Surface Roughness (Ra) for L27 AO

Sl. No	F_X (N)	F_Y (N)	Ra-µm	S/N-Fx	S/N-Fy	S/N-Ra
1	100	250	1.19	-42.2788	-47.9588	-1.4369
2	170	330	1.25	-46.0206	-50.3702	-1.9400
3	280	440	1.36	-49.5424	-52.8690	-2.6707
4	100	280	1.01	-40.8279	-48.9431	-0.1720
5	180	420	1.10	-46.0206	-52.4649	-0.8278
6	260	520	1.30	-49.5424	-54.3200	-2.3454
7	130	300	1.04	-40.8279	-49.5424	-0.2567
8	190	430	1.25	-47.6042	-52.6693	-1.9382
9	320	560	1.36	-50.3703	-54.9637	-2.6766
10	150	260	1.24	-44.0824	-48.2994	-1.9382
11	200	350	1.36	-47.2346	50.8813	-2.6066
12	280	450	1.5	-50.3703	53.0642	-3.5218
13	150	300	1.07	-42.2789	-49.5424	-0.5061
14	230	430	1.16	-47.2346	-52.6693	-1.2139
15	300	540	1.39	-50.3703	-54.6478	-2.860
16	110	320	1.11	-42.9226	-50.1029	-0.9064
17	190	460	1.35	-48.2995	-53.2551	-2.6066
18	260	600	1.45	-51.1261	-55.5630	-3.2274
19	150	250	1.05	-42.2789	-47.9588	-0.4238
20	200	340	1.15	-46.0206	-50.6295	-1.2146
21	270	430	1.26	-49.8272	-52.6693	-2.0760
22	150	290	0.96	-40.8279	-49.2479	-0.4553
23	240	410	1.08	-46.4344	-52.2556	-0.6685
24	310	510	1.3	-49.8272	-54.1514	-2.2887
25	110	310	0.90	-41.5836	-49.8272	-0.9151
26	130	400	1.07	-47.5346	52.0411	-0.5061
27	260	580	1.2	-50.3703	-55.2685	-1.6362

Table 3 shows ANOVA results for Feed force (Fx)

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	1118.5181	559.2590	24.2542	3.11	4.46	8.65	0.89%
B	2	2696.29	1348.145	58.4670	3.11	4.46	8.65	2.15%
C	2	108318.5	54159.25	2348.806	3.11	4.46	8.65	86.67%
AxB	4	8503.72	2125.93	92.1984	2.81	3.84	7.01	6.8%
BxC	4	1437.06	329.265	14.2797	2.81	3.84	7.01	1.14%
AxC	4	1481.5	370.375	16.0626	2.81	3.84	7.01	1.18%
Error	8	1429.61	178.7012					1.17%
Total	26	124985.18						100.00%

Table 4 shows ANOVA results for Signal to Noise ratio (S/N) for Feed force (Fx)

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	4.2137	2.1068	0.4108	3.11	4.46	8.65	1.60%
B	2	6.2855	2.1427	0.4178	3.11	4.46	8.65	2.39%
C	2	220.1093	110.0546	21.4623	3.11	4.46	8.65	83.78%
AxB	4	19.6553	4.9138	0.9582	2.81	3.84	7.01	7.48%
BxC	4	2.6572	0.6643	0.1295	2.81	3.84	7.01	1.01%
AxC	4	4.6504	1.1626	0.2267	2.81	3.84	7.01	1.77%
Error	8	5.1278	0.6409					1.95%
Total	26	262.6989						100.00%

Table 5 shows ANOVA results for Tangential force (Fy)

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	2540.741	1270.37	1.3830	3.11	4.46	8.65	0.87 %
B	2	43229.6298	21614.8149	23.5322	3.11	4.46	8.65	14.82%
C	2	238096.2966	119048.1483	129.6088	3.11	4.46	8.65	81.66%
AxB	4	3037035	75.9258	0.08266	2.81	3.84	7.01	0.104%
BxC	4	6081.4812	1520.3703	1.6552	2.81	3.84	7.01	2.08%
AxC	4	370.370	95.5925	0.1040	2.81	3.84	7.01	0.12%
Error	8	918.5186	114.8148					0.31%
Total	26	291540.7407						100.00%

Table 6 shows ANOVA results for Signal to Noise ratio (S/N) for Tangential force (Fy)

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	1.1016	0.5538	1.006	3.11	4.46	8.65	0.79%
B	2	18.100	9.05	16.4425	3.11	4.46	8.65	13.07%
C	2	116.1788	58.0894	105.5403	3.11	4.46	8.65	83.55%
AxB	4	1.1369	0.2842	0.5163	2.81	3.84	7.01	0.02%
BxC	4	3.0616	0.7654	1.3906	2.81	3.84	7.01	2.20%
AxC	4	0.0139	0.0347	0.0630	2.81	3.84	7.01	0.09%
Error	8	0.5504	0.0688					0.97%
Total	26	139.0475						100.00%

Table 7 shows ANOVA results for Surface roughness (Ra)

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	0.151667	0.075833	199.560526	3.11	4.46	8.65	23.97 %
B	2	0.057222	0.028361	75.292105	3.11	4.46	8.65	9.04%
C	2	0.373489	0.186744	491.431578	3.11	4.46	8.65	59.03%
AxB	4	0.023111	0.005777	15.202631	2.81	3.84	7.01	3.65%
BxC	4	0.022889	0.005722	15.057894	2.81	3.84	7.01	3.62%
AxC	4	0.001244	0.000311	0.818421	2.81	3.84	7.01	0.20%
Error	8	0.003045	0.000380					0.49%
Total	26	0.632667						100.00%

Table 8 shows results for the Signal to Noise ratio (S/N) for Surface roughness (R_a)

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= $(SS/SS_T)*100$
					90%	95%	99%	
A	2	8.05240	4.0262	276.4867	3.11	4.46	8.65	23.64 %
B	2	3.1762	1.5881	109.0578	3.11	4.46	8.65	9.34%
C	2	19.9643	9.98215	685.4930	3.11	4.46	8.65	58.61%
AxB	4	1.1861	0.29652	20.3629	2.81	3.84	7.01	3.48%
BxC	4	1.4732	0.3683	25.2918	2.81	3.84	7.01	4.32%
AxC	4	0.0940	0.0235	1.6137	2.81	3.84	7.01	0.28%
Error	8	0.1165	0.01456					0.35%
Total	26	34.0627						100.00%

III. RESULT AND DISCUSSIONS

From Table 3, the ANOVA for Feed force (F_x), for confidence level of 90%, 95% and 99%, it is observed that depth of cut has a major percent contribution (86.67%) compared to the feed rate (2.15%) and cutting speed (0.89%). The Signal to Noise ratio for Feed force (F_x) also exhibits similar trend and these are tabulated in Table 4. However there is no much major contribution from the interactions (AxB), (BxC), (AxC) and error respectively. From Table 5,Tangential force (F_y) for confidence level of 90%, 95%, and 99% it is observed that the depth of cut has a major percent contribution (81.66%) compared to feed rate (14.82%) and cutting speed (0.87%). The Signal to Noise ratio for Tangential force (F_y) also exhibits similar trend and these are tabulated in Table 6. However there is no much major contribution from the interactions (AxB), (BxC), (AxC) and error respectively.

From the Table 7, the ANOVA for Surface roughness (R_a) for confidence level of 90%, 95% and 99%, it is observed that depth of cut has a major percent contribution (59.03%), compared to cutting speed (23.97%) and feed rate (9.04%). The Signal to Noise ratio forSurface roughness (R_a) also exhibits similar trend and these are tabulated in Table 8. However there is no much significant contribution from the interactions (AxB), (BxC), (AxC) and error respectively. The values of Ftab confidence level of 90%, 95% and 99% for Fx, $F_y$and R_a remain same because it depends on the DOF of the factor selected and the DOF of error.

Estimating the optimal Feed force, Tangential force and Surface roughness:

Table 9 Shows the mean values of Tangential force (F_y) for various cutting speed, feed rate and depth of cut.

Cutting speed	F_y (N)	Feed rate (mm/rev)	F_y (N)	Depth of cut (mm)	F_y (N)
101.78 (A_1)	392.22	0.086 (B_1)	344.44	0.4 (C_1)	284.44
131.94 (A_2)	412.22	0.102 (B_2)	411.11	0.6 (C_2)	396.66
171.53 (A_3)	391.11	0.125 (B_3)	440	0.8 (C_3)	514.44

The optimal Tangential force (F_y) is predicted at the selected optimal setting of process parameters. The significant parameters with optimal levels are selected from the Table 9 as $A_3B_1C_1$.
The estimated mean of the response characteristics can be computed as
μ_{TF}=A3+B1+C1-2T_{TF}
μ_{TF}=391.11+344.44+284.44-2*398.5185=222.9
Similarly a confidence interval for the predicted mean on a confirmation run can be calculated using equation 2.
V_e =error of Variance = 114.8148 from Table 5.
The 90% confidence interval of the predicted optimal Tangential force is
α= 0.10 (90% confidence level)
$F_{0.1}$ (1, 8) = 3.46 (Tabulated)
Confidence Interval (CI) = ± 15.3
$(\mu_{TF}\text{-CI}) < \mu_{TF} < (\mu_{TF}\text{+CI})$
207.6< 222.9< 238.2
The 95% confidence interval of the predicted optimal Tangential force is
α= 0.05 (95% confidence level)
$F_{0.05}$ (1, 8) = 5.32 (Tabulated)
C I = ± 19.0255
$(\mu_{TF}\text{-CI}) < \mu_{TF} < (\mu_{TF}\text{+CI})$
203.9< 222.9< 241.9
The 99% confidence interval of the predicted optimal Tangential force is
α= 0.01 (99% confidence level)
$F_{0.01}$ (1, 8) = 11.3 (Tabulated)
C I = ±27.7
$(\mu_{TF}\text{-CI}) < \mu_{TF} < (\mu_{TF}\text{+CI})$
195.2< 222.9<250.6

Table 11 Shows the details of the optimal values for Feed force (FX), Tangential force (FY) and Surface roughness (Ra).

Sl. No.	Description	Optimal process	90%				95%				99%				Confirmation Experiment
			CI ±	μ - CI	μ+ CI	μ	CI±	μ - CI	μ+ CI	μ	CI±	μ - CI	μ+ CI	μ	
1	F_X	$A_3B_1C_1$	27.9	79.5	135.3	107.4	34.60	72.80	142.0	107.4	50.4	56.98	157.8	107.4	100 N
2	F_Y	$A_3B_1C_1$	15.3	207.6	238.2	222.9	19.02	203.92	241.9	222.9	27.7	195.2	250.6	222.9	230 N
3	R_a	$A_3B_2C_1$	0.04	0.87	0.95	0.91	0.05	0.86	0.96	0.91	0.07	0.84	0.98	0.915	0.96 μm

The confirmation experiment was conducted at the optimal setting of turning process parameters recommended by the investigation. The results are within the predicted range and these are tabulated in Table no. 11

IV.CONCLUSION

- The depth of cut is having a significant percent contribution in feed force (F_x), Tangential force (F_y) and Surface roughness (R_a).
- From the ANOVA table for Feed force, Tangential force & Surface Roughness for 90%, 95% and 99% confidence level, there is no change in percent contribution except for the F-tabulated values. As the confidence level increases the F-tabulated values also increases.

- From the Table 11 the confirmation of experiment after conducting the trials. The Feed force (F_x) obtained is 100 N. By using Taguchi technique for setting the optimal process parameters for Feed force (F_x) are cutting speed (171.53 m/min), feed rate (0.086 mm/rev) and depth of cut (0.4 mm) for 90% confidence interval, it lies between 79.5 to 135.3, 95% confidence interval it lies between 72.80 to 142.0 and 99% confidence interval it lies between 56.98 to 157.8 and hence the Feed force obtain is also lies within the above range.

- From the Table 9, the confirmation of experiment after conducting the trials. The Tangential force (F_y) obtained is 230 N. By using Taguchi technique for setting the optimal process parameters for Tangential force (F_y) are cutting speed (171.53 m/min), Feed rate (0.086 mm/rev) and Depth of cut (0.4 mm) for 90% confidence interval, it lies between 207.6 to 238.2, 95% confidence interval it lies between 203.92 to 241.9 and 99% confidence interval it lies between 195.2 to 250.6 and hence the Tangential force obtain is also lies within the above range.
- From the confirmation of experiment after conducting the trials. The Surface roughness (Ra) obtained is 0.96µm. by using Taguchi technique for setting the optimal process parameters for Surface roughness (R_a) are cutting speed (171.53 m/min), feed rate (0.102 mm/rev) and depth of cut (0.086 mm) for 90% confidence interval it lies between 0.87 to 0.9556, 95% confidence interval it lies between 0.86 to 0.96 and 99% confidence interval it lies between 0.98 and hence the Surface roughness obtained is also lies within the range which is shown in Table 11.

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