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APPLICATION OF TAGUCHI TECHNIQUE FOR THE OPTIMIZATION OF FORCES AND SURFACE FINISH DURING THE MACHINING OF STEEL EN-19 USING AN UNCOATED CARBIDE TOOL INSERT

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ABSTRACT

The objective of this paper is to obtain optimal turning process parameters (cutting speed, feed rate and depth of cut) resulting in an optimal value of feed force, tangential force and surface roughness for machining EN-19 steel with an uncoated carbide tool insert. The effects of the process parameters on the feed force, tangential force and surface roughness have been arrived at using Taguchi's design of experiments approach. The results indicate that the selected process parameters significantly affect the mean and variance of feed force, tangential force and surface roughness. The contributions of parameters from the ANOVA table for measured feed force, the depth of cut (95.18%) has a major contribution than that of cutting speed (2.29%) and feed rate (1.16%). Similarly for a measured tangential force (Fy) the depth of cut (87.4%) has a major contribution than that of feed rate (9.08%) and cutting speed (0.91%). In case of measured Thrust force (Fz), the depth of cut (74.87%) has a major contribution than that of cutting speed (4.7%) and the feed rate (3%). Similarly the surface roughness (Ra) measured on the workpiece, the depth of cut (59.03%) has a major contribution than that of cutting speed (23.97%) and feed rate (9.04%). In all of these cases the interaction effects are not having any major contributions. The predicted optimum feed force, tangential force and the surface roughness are 107.03 N, 144.45 N, and 0.915 µm respectively are very much near the experimentally obtained values.

Keywords: *Cutting Forces, Surface Finish and Carbide Tool*

1. Introduction

In metal cutting industries the major drawback of not running the machine tool to their optimum operating conditions and the operating conditions continue to be chosen solely on the basis of the handbook values or worker's experience. The literature survey has revealed that a very little work has been conducted to obtain the optimal levels of cutting parameters like cutting speed, feed rate and depth of cut, which yields the best machining characteristics. Brewer and Rueda developed various nomograms to assist the selection of optimum conditions [1]. Armarego and Brown used the maxima/minima principle of differential calculus for optimization of machining variables in turning operations [11]. P.G.Petropoulos, used other techniques which have been used to optimize metal cutting conditions, include geometrical programming [2].R.M.Sundaram used the application of goal programming technique in metal cutting operation [3]. Elsayed and Chen determined optimal settings of process parameters of production process using robust design methodology [4]. Hari Singh 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 like Tool geometry, Tool material, hardness of workpiece and cutting parameters like cutting speed, feed rate and depth of cut for both dry cutting and wet cutting operations [5]. Byrne D.M. and Taguchi S, observed that when the quality characteristic of interest is to be maximized or minimized, the loss function may become a half parabola [6]. Hari Singh and Pradeep Kumar, studied on optimization of feed force through setting of optimal value of process parameters namely cutting speed, feed rate and depth of cut in turning of EN-24 steel with TiC Coated Tungsten Carbide inserts. The authors used Taguchi's parameter design and concluded that in the case of feed force the effect of depth of cut and feed rate is more as compared to cutting speed [7]. Sahoo et. al., observed that the optimization of machining parameter combinations

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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 and depth of cut on three different workpiece materials namely Aluminium, Mild steel and Brass. It was concluded that feed rate is 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 influence, while in case of Brass depth of cut was noticed to impose some influence on surface finish. The factorial interactions were responsible for controlling the fractal dimensions of surface profile produced in CNC turning [8]. Motorcu and Sahin have machined the hardened AISI 1040 steel with triangular and square tools in different machining conditions and modeled the surface roughness. They classified the effects of machining parameters on surface roughness as feed rate, depth of cut and cutting speed respectively. They have also stated that the lowest surface roughness is produced with square tools [9].

2. Experimentation

The EN-19 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 – uncoated carbide insert (WIDIA) make, environment – dry cutting.

Insert geometry – TNMG 160404TTS (Uncoated carbide insert)

Tool holder – MTJNR2020K16

Cutting conditions – Dry

Tool overhang – 40 mm

In selecting an appropriate orthogonal array, 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 behaviour 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 [10]. The selected interactions were:

i) between cutting speed and feed (AxB)

ii) between feed and depth of cut (BxC)

iii) between cutting 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.

The EN-19 steel rods of 45 mm diameter and length of 300 mm was machined on HMT A28-2487 Lathe using uncoated carbide inserts having the designation TNMG 160404TTS. The workpiece is machined as per the process parameters given in Table 1. The feed force (Fx), tangential force (Fy) and thrust force (F_z) was measured for each trial using lathe tool dynamometer and the surface roughness (Ra) is measured using Talysurf surface tester. For each trial the new insert is used in order to have the uniformity of cutting conditions. The results of the experiments for twenty seven trials were reported in Table 2. The ANOVA results for tangential force is tabulated in Table3, and its Signal to Noise (S/N) ratio is tabulated in Table 4, similarly the ANOVA results for surface roughness is tabulated in Table 5 and its S/N ratio in Table 6 using MINITAB V14.0 software. The Signal – to – Noise ratio for Lower the Better (LB) characteristics are calculated using

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

Table 1: Process Parameters

Process parameters	Parameters Designation	Levels		
		L1	L2	L3
Cutting speed (m/min)	A	11.31	19.1	24.71
Feed (mm/rev)	B	0.125	0.187	0.218
Depth of cut (mm)	C	0.5	1.0	1.5

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

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

Where, $F_{\alpha}(1,f_e)$=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

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

Table 2: Experimental Data for 27 Trials

Sl. No	Fx (N)	Fy (N)	Fz (N)	Ra (μm)	S/N-Fx (db)	S/N-Fy (db)	S/N-Ra (db)
1	130	190	30	1.18	-42.278	-45.575	-1.437
2	200	280	120	1.25	-46.020	-48.943	-1.938
3	300	400	160	1.36	-49.542	-52.041	-2.670
4	110	200	100	1.02	-40.827	-46.020	-0.172
5	200	320	110	1.10	-46.020	-50.103	-0.827
6	300	470	240	1.31	-49.542	-53.442	-2.345
7	110	220	100	1.03	-40.827	-46.848	-0.256
8	240	380	130	1.25	-47.604	-51.595	-1.938
9	330	540	230	1.36	-50.370	-54.647	-2.670
10	160	210	110	1.25	-44.082	-46.444	-1.938
11	230	310	160	1.35	-47.234	-49.827	-2.606
12	330	420	200	1.5	-50.370	-52.465	-3.521
13	130	210	140	1.06	-42.278	-46.444	-0.506
14	230	330	150	1.15	-47.234	-50.370	-1.213
15	330	480	180	1.39	-50.370	-53.624	-2.860
16	140	230	90	1.11	-42.922	-47.234	-0.906
17	260	390	150	1.35	-48.299	-51.821	-2.606
18	360	560	200	1.45	-51.126	-54.963	-3.227
19	130	150	120	1.05	-42.278	-43.521	-0.423
20	200	270	150	1.15	-46.020	-48.627	-1.213
21	310	390	200	1.27	-49.827	-51.821	-2.076
22	110	200	130	0.95	-40.827	-46.020	0.445
23	210	320	160	1.08	-46.444	-50.103	-0.668
24	310	470	220	1.3	-49.827	-53.442	-2.278
25	120	200	110	0.90	-41.583	-46.020	0.915
26	230	360	150	1.06	-47.534	-51.126	-0.506
27	330	530	200	1.2	-50.370	-54.485	-1.583

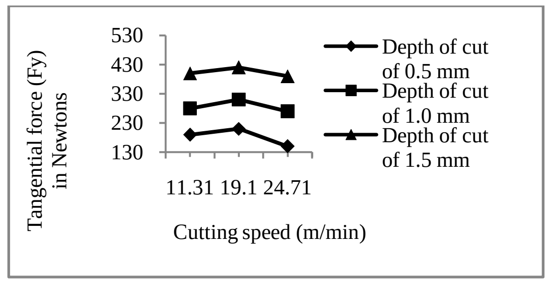

Fig. 1 Variation of Tangential force (Fy) for Different Cutting Speeds and Constant Feed Rate of 0.125 mm/rev

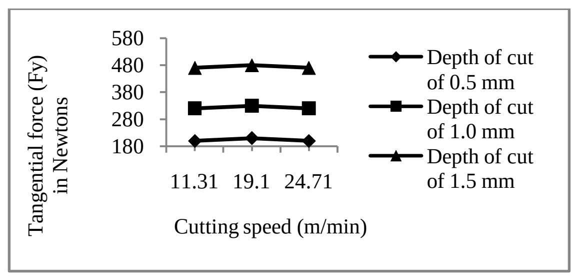

Fig. 2 Variation of Tangential Force (Fy) for Different Cutting Speeds and Constant Feed Rate of 0.187 mm /rev

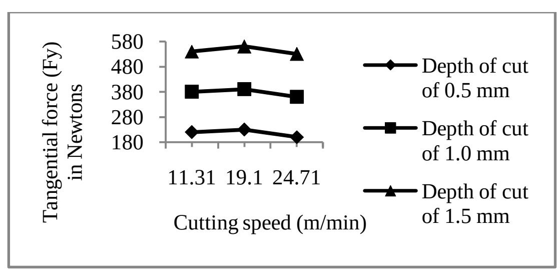

Fig. 3 Variation of Tangential Force (Fy) for Different Cutting Speeds and Constant Feed Rate of 0.218 mm /rev

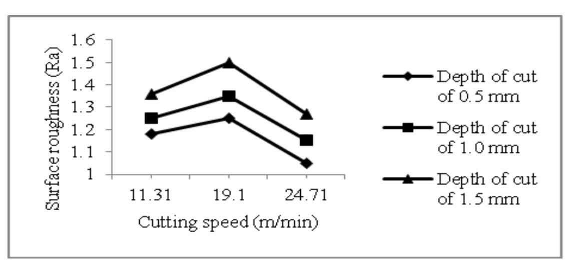

Fig. 4 Variation of Surface Roughness (Ra) for Different Cutting Speeds and Constant Feed Rate of 0.125 mm /rev

Table 3: The ANOVA Results for Tangential Force

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	3489	1744.5	52.466165	3.11	4.46	8.65	0.91%
B	2	34689	17344.5	521.639097	3.11	4.46	8.65	9.08%
C	2	333889	166944.5	5020.887218	3.11	4.46	8.65	87.4%
AxB	4	889	222.25	6.684210	2.81	3.84	7.01	0.23%
BxC	4	8689	2172.25	65.330827	2.81	3.84	7.01	2.27%
AxC	4	156	39	1.172932	2.81	3.84	7.01	0.04%
Error	8	266	33.25					0.07%
Total	26	382067						100.00%

Table 4: The ANOVA Results of Signal – to – Noise (S/N) Ratio for Tangential Force

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	3.58	1.79	17.357575	3.11	4.46	8.65	1.28%
B	2	21.1	10.55	102.303030	3.11	4.46	8.65	7.57%
C	2	249.764	124.882	1210.97697	3.11	4.46	8.65	89.60%
AxB	4	1.351	0.33775	3.275151	2.81	3.84	7.01	0.48%
BxC	4	1.092	0.273	2.647272	2.81	3.84	7.01	0.39%
AxC	4	1.065	0.26625	2.581818	2.81	3.84	7.01	0.38%
Error	8	0.825	0.103125					0.30%
Total	26	278.777						100.00%

Table 5: The ANOVA Results for Surface Roughness

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	0.028611	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 6: The ANOVA Results of Signal – to – Noise (S/N) Ratio for Surface Roughness

Factor	DOF	SS	MSS	Fcal	Ftab confidence level			P= (SS/SS_T)* 100
					90%	95%	99%	
A	2	8.0524	4.0262	276.486746	3.11	4.46	8.65	23.64%
B	2	3.1762	1.5881	109.057821	3.11	4.46	8.65	9.32%
C	2	19.9643	9.98215	685.493064	3.11	4.46	8.65	58.61%
AxB	4	1.1861	0.296525	20.362930	2.81	3.84	7.01	3.48%
BxC	4	1.4732	0.3683	25.291855	2.81	3.84	7.01	4.32%
AxC	4	0.0940	0.0235	1.613789	2.81	3.84	7.01	0.28%
Error	8	0.1165	0.014562					0.35%
Total	26	34.0627						100.00%

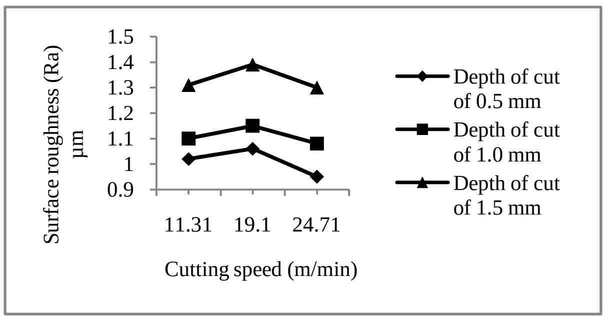

Fig. 5 Variation of Surface Roughness (Ra) for Different Cutting Speeds and Constant Feed Rate of 0.187 mm /rev

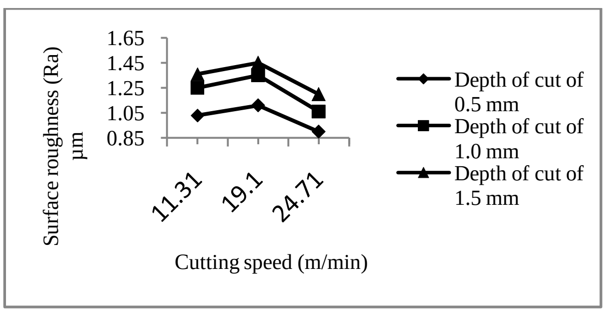

Fig. 6 Variation of Surface Roughness (Ra) for Different Cutting Speeds and Constant Feed Rate of 0.218 mm /rev

3. Results and Discussion

It is observed from the fig.1, 2 and 3 that as the cutting speed is increased from 11.31 m/min to 19.1 m/min the Tangential force increases for all the three different feed rates while for further increase in cutting speed from 19.1 to 24.71 m/min there is a decrease in Tangential force for feed rates of 0.125 mm/rev, 0.187 mm/rev and 0.218 mm/rev for a constant depth of cut of 0.5 mm, 1.0 and 1.5 mm respectively.

It is observed from the fig. 4, 5 and 6 that as the cutting speed is increased from 11.31 m/min to 19.1 m/min the surface roughness (R_a) increases for all the three different feed rates while further increase in cutting speed from 19.1 to 24.71 m/min there is a decrease in surface roughness (Ra) for a feed rates f 0.125 mm/rev 0.187 mm/rev and 0.218 mm/rev for a constant depth of cut of 0.5 and 1.0 mm respectively.

Table 3 indicates that the depth of cut has a significant contribution (87.4%), compared to feed rate (9.08%) and cutting speed (0.91%). However, there is no much significant contribution from the interactions (AxB), (BxC), (AxC) and error respectively. The S/N ratio for tangential force (Fy) also exhibits similar trends and these are tabulated in Table 4. Comparing the F-tabulated values for 90%, 95% and 99% confidence level it is observed that 90% has 3.11, 95% has 4.46 and99% has 8.65. The F-tab confidence level for F_y, and R_a the values remains same, as it depends on the DOF of factors and the DOF of error.

Table 5 indicates that the depth of cut has a significant contribution (59.03%), compared to cutting speed (23.97%) and feed rate (9.04%). However there is no much significant contribution from the interactions (AxB), (BxC), (AxC) and error respectively. The S/N ratio for surface roughness (Ra) for L27 also exhibits similar trends and these are tabulated in Table 6. Comparing the F-tab values for 90%, 95% and 99% confidence level it is observed that 90% has 3.11, 95% has 4.46 and 99% has 8.65. The F-tab of confidence level for Fx, Fy, and Ra the values remains same, as it depends on the DOF of factors and the DOF of error.

3.1 Estimating the optimal tangential force, surface roughness and feed force

The optimal tangential force (μ_{TF}) is predicted at the selected optimal setting of process parameters. The mean values of tangential force for various cutting speed, feed rate and depth of cut are shown in Table 7. The significant parameters with optimal levels are selected as A_3, B_1 and C_1. The interaction effect is not being considered in estimating mean and confidence interval around estimated mean due to poor additivity between parameters and interaction.

Table 7: The Mean Values of Tangential Force for Various Cutting Speed, Feed Rates and Depth of Cut

Cutting speed (m/min)	F_Y (N)	Feed Rate (mm/rev)	F_Y (N)	Depth of cut (mm)	F_Y (N)
11.31 (A1)	333.33	0.125 (B1)	291.11	0.5 (C1)	201.1
19.1 (A2)	348.88	0.187 (B2)	333.33	1.0 (C2)	328.88
24.71 (A3)	321.11	0.218 (B3)	378.88	1.5 (C3)	473.33

The estimated mean of the response characteristics can be computed as

$$\mu_{TF} = \bar{A}_3 + \bar{B}_1 + \bar{C}_1 - 2\bar{T}_{TF}$$

$$\mu_{TF} = 321.11 + 291.11 + 201.11 - 2*334.44 = 144.45$$

Similarly a confidence interval for the predicted mean on a confirmation run can be calculated using the equation 2.

V_e = error variance = 33.25 from Table 3.

The 90% confidence interval of the predicted optimal Tangential force is

$F_{0.1}(1, 8) = 3.46$ (Tabulated), CI = ± 12.036
$(\mu_{TF} – CI) < \mu_{TF} < (\mu_{TF} + CI)$, $132.414 < \mu_{TF} < 156.486$

The 95% confidence interval of the predicted optimal Tangential force is

$F_{0.05}(1,8) = 5.32$ (Tabulated), CI = ± 14.92
$(\mu_{TF} – CI) < \mu_{TF} < (\mu_{TF} + CI)$, $129.53 < \mu_{TF} < 159.37$

The 99% confidence interval of the predicted optimal feed force is

$F_{0.01}(1, 8) = 11.3$ (Tabulated), CI = ± 21.751
$(\mu_{TF} – CI) < \mu_{TF} < (\mu_{TF} + CI)$, $122.699 < \mu_{TF} < 166.201$

The experimentally determined value of tangential force (F_Y) is found to be 150N. This result is within the predicted optimal tangential force for all 90%, 95% and 99% confidence interval.
The estimated mean of the response characteristics for surface roughness can be computed as

$\mu_{Ra} = \bar{A}_3 + \bar{B}_2 + \bar{C}_1 - 2\bar{T}_{Ra}$

$\mu_{Ra} = 1.106 + 1.15 + 1.061 – 2*1.200 = 0.915$

The 90% confidence interval of the predicted optimal Surface roughness is

$(\mu_{Ra} – CI) < \mu_{Ra} < (\mu_{Ra} + CI)$, $0.8744 < \mu_{Ra} < 0.9556$
For 95% confidence interval, $0.865 < \mu_{Ra} < 0.965$
For 99% confidence interval, $0.8415 < \mu_{Ra} < 0.9885$

The experimentally determined value of Surface roughness (R_a) is found to be 0.95 µm. This result is within the predicted optimal surface roughness for all 90%, 95% and 99% confidence interval.
Similarly the predicted optimal feed force for 90%, 95% and 99% confidence interval are as follows
For 90% confidence interval

$(\mu_{Fx} – CI) < \mu_{Fx} < (\mu_{Fx} + CI)$, $97.608 < \mu_{Fx} < 116.452$
For 95% confidence interval, $95.35 < \mu_{Fx} < 118.70$
For 99% confidence interval, $90.00 < \mu_{Fx} < 124.05$

The experimentally determined value of feed force (F_x) is found to be 110 N. This result is within the predicted optimal feed force for all 90%, 95% and 99% confidence interval.

4. Conclusion

i. The depth of cut has a significant contribution in feed force (F_x), Tangential force (F_y) and surface roughness (R_a).
ii. There is no change in percent contribution except for the F-tab values. As the confidence level increases the F- tab values are also increases.
iii. The feed force (F_x) obtained is 110 N. By using the Taguchi technique for setting the optimal process parameters for feed force (F_x) are cutting speed (11.31 m/min), feed rate (0.187 mm/rev) and depth of cut (0.5 mm) for 90% confidence interval it lies between 97.608 to 116.452 for 95% confidence interval it lies between 95.35 to 118.7 and for 99% confidence interval it lies between 90 to 124.05 and hence the feed force obtained is also lies within this range.
iv. The tangential force (F_y) obtained is 150 N. By using the Taguchi technique for setting the optimal process parameters for tangential force (F_y) are cutting speed (24.71 m/min), feed rate (0.125 mm/rev) and depth of cut (0.5 mm) for 90% confidence interval it lies between 132.414 to 156.486 for 95% confidence interval it lies between 129.53 to 159.37 and for 99% confidence interval it lies between 122.699 to 166.201 and hence the tangential force obtained is also lies within this range.
v. The surface roughness (R_a) obtained is 0.95µm. By using the Taguchi technique for setting the optimal process parameters for surface roughness (R_a) are cutting speed (24.71 m/min), feed rate (0.187 mm/rev) and depth of cut (0.5 mm) for 90% confidence interval it lies between 0.8744 to 0.9556, for 95% confidence interval it lies between 0.865 to 0.965 and for 99% confidence interval it lies between 0.8415 to 0.9885.

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