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Analysis And Prediction Of Feed Force, Tangential Force, Surface Roughness And Flank Wear In Turning With Uncoated Carbide Cutting Tool Using Both Taguchi And Grey Based Taguchi Method

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***Abstract*—The aim of the present study is to investigate the effects of process parameters (cutting speed, feed rate and depth of cut) on performance characteristics (tangential force, feed force, surface roughness and flank wear) in turning of EN-19 steel with uncoated carbide cutting tool. Experiments are designed and conducted based on Taguchi's L_{27} orthogonal array carried out under dry cutting conditions for tangential force, feed force and surface roughness, whereas for the flank wear the experiments are conducted as per L_9 orthogonal array. The responses are feed force, tangential force, surface roughness and flank wear were recorded for each experiment The depth of cut was identified as the most influential process parameters in the responses of both tangential force and feed force. The feed rate was identified as the most influential process parameter on the surface roughness, while the cutting speed has a significant contribution for flank wear. Grey relational analysis is used to optimize the multi-performance characteristics to minimize the tangential force and surface roughness. The feed rate was identified as the most influential process parameter in the responses of both tangential force and surface roughness**

Keywords—Taguchi; Grey based Taguchi; feed force; tangential force; surface roughness; flank wear

I. INTRODUCTION

Turning is a very important machining process in which a single point cutting tool removes unwanted material from the surface of a rotating cylindrical work piece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. Turning is carried on lathe that provides the power to turn the work piece at a given rotational speed and feed to the cutting tool at specified rate and depth of cut. Therefore three cutting parameters namely cutting speed, feed rate and depth of cut need to be optimized in a turning operation. Turning produces three cutting force components namely tangential force (F_Y), which acts in cutting speed direction, feed force (F_X) which acts in the feed rate direction and thrust force (F_Z) which acts in the radial direction and which is normal to the cutting speed. Surface roughness has become the most significant technical requirements and it is an index of product quality. In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. Nowadays, the manufacturing industries specially are focusing their attention on dimensional accuracy and surface finish. In order to obtain optimal cutting parameters to achieve the best possible surface finish, manufacturing industries have resorted to the use of handbook based information and operators' experience. This traditional practice leads to improper surface finish and decrease in the productivity due to sub-optimal use of machining capability. This causes high manufacturing cost and low product quality.

Singh and Kumar [1], studied an optimization of cutting force through setting of optimal value of process parameters namely cutting speed, feed rate and depth of cut while machining EN-24 alloy steel (0.4%C) with TiC coated carbide inserts. The effects of the selected process parameters have been accomplished using Taguchi's parameter design approach and concluded that the effect of depth of cut and feed rate in variation of cutting force were affected more as compared to cutting speed.

Hamdi, Aquici et.al., [2], experimentally studied the heat treated AISI H11 steel when machined with cubic boron nitride which is essentially made of TiCN. Results showed that the cutting force components were influenced principally by the depth of cut and workpiece hardness, on the other hand both feed rate and workpiece hardness have statistical significance on surface roughness.

Singh and Kumar [3], 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 parameter design and concluded that the effect of depth of cut and feed rate in variation of feed force were affected more as compare to speed.

Sahoo et.al. [4], 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: speed, feed and depth of cut on three different work piece materials namely Aluminum. Mild steel and Brass. It was concluded that feed rate was more significant influencing surface finish in all three materials. It was observed that in case of Mild steel and Aluminum feed showed some influences while in case of Brass depth of cut was noticed to impose some influences on surface finish. The factorial interaction was responsible for controlling the fractal dimensions of surface profile produced in CNC turning.

Ali Riza Motorcu [5], studied on surface roughness in the turning of AISI 8660 hardened alloy steels by ceramic based cutting tools was investigated in terms of main cutting parameters such as cutting speed, feed rate, depth of cut in addition to tool's nose radius using a statistical approach. Machining tests were carried out with PVD coated ceramic cutting tools under different conditions. An orthogonal design, signal-to-noise ratio and analysis of variance were employed to find out the effective cutting parameters and nose radius on the surface roughness. The obtained results indicate that the feed rate was found to be dominant factor among controllable factors on the surface roughness followed by depth of cut and tool's nose radius.

Y.Sahin and A.R.Motorcu [6], developed a surface roughness model in terms of main cutting parameters such as cutting speed, feed rate and depth of cut using response surface methodology. Machining tests were carried out in turning AISI 1050 hardened steel by cubic boron nitride cutting tools under different conditions. The results indicated that the feed rate was dominant factor on the surface roughness.

Hari singh and Pradeep Kumar [7], adopted the design of experiment based approach to obtain an optimal setting of turning process parameters (cutting speed, feed rate and depth of cut) that may yield optimal tool wear (flank wear and crater wear) to titanium carbide coated carbide inserts while machining En24 steel (0.4%C), a difficult-to-machine material. The effects of the selected process parameters on tool wear and subsequent optimal settings of the parameters have been accomplished using Taguchi's parameter design approach. The results indicated that the selected process parameters affect significantly the tool wear characteristics of TiC coated carbide tool. The predicted optimal values of flank wear width and crater wear depth of coated carbide tool while machining En24 steel are 0.172 mm and 0.244 micron respectively. The results are further confirmed by conducting further experiments. The percent contributions of each parameter to the variation of tool wear characteristics of TiC coated carbide tool are for both flank wear and crater wear depth cutting speed is the most significant contribution compared to depth of cut and feed rate. This paper is aimed at optimizing the feed force, tangential force, surface roughness and flank wear using taguchi technique and also the application of grey based taguchi method in optimizing the multi-responses of tangential force and surface roughness.

II. 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), Environment - Dry cutting

Tool material - uncoated carbide cutting insert (WIDIA) make, Tool overhang - 40 mm, Tool holder - MTJNR 2020K16, Insert geometry - TNMG 160404TTS.

The EN-19 steel rods of 60 mm diameter and length of 500 mm was machined on HMT A28-2847 lathe using uncoated carbide inserts having the designation TNMG 160404TTS. The workpiece is machined as per the process parameters listed in Table 1 using L_{27} orthogonal array. The feed force (F_X) and tangential force (F_Y) was measured for each trial using lathe tool dynamometer and the surface roughness (Ra) is measured using Talysurf surface tester. For each trials the new insert is used in order to have the uniformity of cutting conditions. The results for the experiments for 27 trials were reported in Table 2.

TABLE I. VALUES OF PROCESS PARAMETERS FOR CUTTING FORCE, FEED FORCE AND SURFACE ROUGHNESS

Process parameters	***Level - 1***	***Level - 2***	***Level - 3***
Cutting speed (m/min) - A	101.8	171.5	222.4
Feed rate (mm/rev) - B	0.125	0.187	0.218
Depth of cut (mm) - C	0.5	1.0	1.5

For the evaluation of flank wear (V_b) on uncoated carbide cutting tool insert, the value of process parameters considered for machining on EN-19 steel using L_9 orthogonal array is listed in Table 3. The EN-19 steel rod was machined using uncoated carbide cutting tool insert for the total machining time of 10 minutes for each trial as per the process parameters listed in Table 3. After the machining, the insert is removed from the tool holder and are observed under the Tool Maker's Microscope for the evaluation of flank wear (V_b) and the readings are tabulated in Table 4. The ANOVA results for tangential force is tabulated in Table 5, and its Signal - to - Noise (S/N) ratio is tabulated in Table 6. Similarly the ANOVA results for feed force is tabulated in Table 7, and its Signal - to - Noise (S/N) ratio is tabulated in Table 8, The ANOVA results for surface roughness is tabulated in Table 9, and its Signal - to - Noise (S/N) ratio is tabulated in Table 10 and The ANOVA results for flank wear is tabulated in Table 11, and its Signal - to - Noise (S/N) ratio is tabulated in Table 12.

Grey Based Taguchi Method:

The integrated Grey based Taguchi method combines the algorithm of Taguchi method and grey relational analysis to determine the optimum process parameters for multiple responses.

Taguchi Method:

The concept of the Taguchi method is that the parameter design is performed to reduce the sources of variation on the quality characteristics of product, and reach a target of process robustness.

A loss function is defined to calculate the deviation between the experimental value and the desired value. The value of the loss function is further transformed into an S/N ratio. Usually, there are three categories of performance characteristics in the analysis of the S/N ratio, i.e., Lower-the-better, higher-the-better and nominal-the-best. The S/N ratio η_{ij} for the i^{th} performance characteristic in the j^{th} experiment can be expressed as:

$$\eta_{ij} = -10*\log(L_{ij})$$

The loss function L_{ij} for higher-the-better performance characteristic can be expressed as

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n}\frac{1}{y_{ijk}^2}$$

L_{ij} = loss function of the i^{th} process response in the j^{th} experiment, k - number of tests

y_{ijk} = experimental value of the i^{th} performance characteristic in the j^{th} experiment at the k^{th} tests.

For Lower-the-better performance characteristic, the loss function L_{ij} can be expressed

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} y_{ijk}^2$$

For nominal-is-best performance characteristics, the S/N ratio can be expresses as:

$$\eta_{ij} = 10*\log\left[\frac{\bar{y}^2}{\sigma}\right]$$

The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category to the performance characteristic, a larger S/N ratio corresponds to a better performance characteristic. This S/N ratio value can be considered for the optimization of single response problems. However optimization of multi-response cannot be straightforward as in the optimization of a single response. The higher S/N ratio for one response may correspond to the lower S/N ratio for another response. To overcome the limitation combined approaches are proposed by researches. In this, grey based Taguchi method is adopted to optimize the multi-response.

The Signal – to – Noise ratio for tangential force, feed force, surface roughness and flank wear are calculated using Lower the Better(LB) characteristics

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

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

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

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

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

Grey Relational Analysis:

The grey relational analysis based on the grey system theory can be used to solve the complicated interrelationships among the multiple responses effectively. In a grey system some information and some information is unknown. Data pre-processing is the first stage in grey analysis since the range and unit in one data sequence may differ from the others. Data pre-processing is a means of transferring the original sequence to a comparable sequence. Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for this analysis.

Experimental data y_{ij} is normalized as Z_{ij} ($0 \le Z_{ij} \le 1$) for the i^{th} performance characteristics in the j^{th} experiment can be expressed as:

For S/N ratio with Larger-the-better condition

$$Z_{ij} = \frac{yij - \min(yij, i = 1,2,3,....n)}{\max(yij, i = 1,2,...n) - \min(yij, i = 1,2,....n)} \qquad (3)$$

For S/N ratio with smaller the better

$$Z_{ij} = \frac{\max(yij, i = 1,2,3,....n) - yij}{\max(yij, i = 1,2,...n) - \min(yij, i = 1,2,....n)}$$

According to Deng, larger normalized results correspond to better performance and the best normalized result should be equal to one. Then, the grey relational co-efficients are calculated to express the relationship between the ideal (best) and the actual experimental results.

Grey Relation grade

The grey relational co-efficient

$$\gamma_{ij} = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{oi}(k) + \xi\Delta_{max}} \qquad (4)$$

where

a) j=1,2,…n; k=1,2,…m, n is the number of experimental data items and m is the number of responses.
b) $y_0(k)$ is the reference sequence ($y_0(k) = 1$, k=1,2,…m); $y_j(k)$ is the specific comparison sequence.
c) $\Delta_{oj} = \left\| x_0^*(k) - x_i^*(k) \right\|$

d) $\Delta_{min} = \min_{\forall jei} \min_{\forall k} \left\| x_0^*(k) - x_i^*(k) \right\|$

e) $\Delta_{max} = \max_{\forall jei} \max_{\forall k} \left\| x_0^*(k) - x_i^*(k) \right\|$

f) ξ is the distinguishing co-efficient which is defined in the range 0≤ξ≤1 (the value may adjusted based on the practical needs of the system) = 0.5.

The grey relational grade $\overline{\gamma_{ij}}$ is expressed as

$$\overline{\gamma_{ij}} = \frac{1}{k} \sum_{i=1}^{m} \gamma_{ij} \qquad (6)$$

Where $\overline{\gamma_j}$ the grey relational grade for the j^{th} experiment and k is the number of performance characteristics. The grey relational grade shows the correlation between the performance sequence and the comparability sequence. The evaluated grey relational grade varies from 0 to 1 and equals 1 if these two sequences are identically coincident. The higher grey relational grade implies the better quality; on the basis of grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

The experimental values of both cutting force and surface roughness using uncoated carbide cutting tool with cutting speeds of 101.8 m/min, 171.5 m/min, 222.4 m/min at different feed rates of 0.125 mm/rev, 0.187 mm/rev, 0.218 mm/rev and at different depth of cuts of 0.5 mm, 1.0 mm and 1.5 mm respectively have been presented in Table 2.

From Table 20, The S/N ratio of both cutting force and surface roughness are determined by considering Lower-the-Better characteristic (refer equation 1). The normalized values of S/N ratios are determined by considering the Larger-the-Better characteristic (refer equation 3) because larger normalized results correspond to better performance and the best normalized should be equal to one. The grey relational co-efficient are determined to express the relationship between the ideal (best) and the actual experimental results (refer equation 4). The grey relational grade shows the correlation between the reference sequence and the comparability sequence. The evaluated grey relational grade varies from 0 to 1 and equals 1, if these two sequences are identically coincident. The higher grey relational grade implies the better product quality.

TABLE II. EXPERIMENTAL VALUES OF CUTTING FORCE, FEED FORCE AND SURFACE ROUGHNESS

Sl. No.	**(A)**	**(B)**	**(C)**	**F_Y (N)**	**F_X (N)**	**R_a (μm)**
1	101.8	0.125	0.5	270	120	2.29
2			1.0	490	220	2.21
3			1.5	620	320	2.30
4		0.187	0.5	360	140	4.57
5			1.0	650	250	4.36
6			1.5	870	340	5.32
7		0.218	0.5	400	150	6.88
8			1.0	700	270	6.96
9			1.5	1000	360	8.14
10	171.5	0.125	0.5	300	140	1.75
11			1.0	520	240	1.96
12			1.5	650	340	2.12
13		0.187	0.5	380	150	4.20
14			1.0	670	260	4.00
15			1.5	900	370	5.00
16		0.218	0.5	420	160	5.92
17			1.0	740	280	6.14
18			1.5	1050	390	6.94
19	222.4	0.125	0.5	380	170	2.10
20			1.0	590	330	2.30
21			1.5	720	390	2.51
22		0.187	0.5	450	180	4.41
23			1.0	750	340	4.33
24			1.5	970	410	5.36
25		0.218	0.5	490	190	6.47
26			1.0	810	360	7.27
27			1.5	1120	460	8.02

TABLE III. VALUES OF PROCESS PARAMETERS FOR EVALUATION OF FLANK WEAR (V_B)

Process parameters	***Level-1***	***Level-2***	***Level-3***
Cutting speed (m/min)- A	101.8	171.5	222.4
Feed rate (mm/rev) - B	0.125	0.187	0.218
Depth of cut (mm) - C	1.0	1.0	1.0

TABLE IV. EXPERIMENTAL VALUES OF FLANK WEAR (V_B)

No.	***A***	***B***	***C***	***Flank wear V_b (mm)***
1	101.8	0.125	1.0	0.20
2	101.8	0.187	1.0	0.26
3	101.8	0.218	1.0	0.15
4	171.5	0.125	1.0	0.22
5	171.5	0.187	1.0	0.35
6	171.5	0.218	1.0	0.32
7	222.4	0.125	1.0	0.40
8	222.4	0.187	1.0	0.48
9	222.4	0.218	1.0	0.36

TABLE V. ANOVA FOR TANGENTIAL FORCE (F_Y) USING UNCOATED CARBIDE CUTTING TOOL

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	49696.30	24848.15	8.35	3.49	3.3
B	2	276318.52	138159.26	46.44	3.49	18.5
C	2	1104585.19	552292.59	185.66	3.49	74.1
Error	20	59496.30	2974.81			4.1
Total	26	1490096.30				100

TABLE VI. ANOVA FOR TANGENTIAL FORCE (F_Y) USING SIGNAL -TO-NOISE RATIO

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	11.51	5.75	38.33	3.49	3.8
B	2	51.68	25.84	172.27	3.49	17.0
C	2	238.21	119.10	794.00	3.49	78.2
Error	20	3.07	0.15			1.0
Total	26	304.47				100

TABLE VII. ANOVA FOR FEED FORCE (F_X) USING UNCOATED CARBIDE CUTTING TOOL

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	26340.74	13170.37	61.31	3.49	10.2
B	2	6807.41	3403.70	15.84	3.49	2.6
C	2	219696.30	109848.15	511.37	3.49	85.4
Error	20	4296.30	214.81			1.8
Total	26	257140.74				100

TABLE VIII. ANOVA FOR FEED FORCE (F_X) USING SIGNAL - TO - NOISE RATIO

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	27.24	13.62	123.82	3.49	8.7
B	2	7.47	3.73	33.91	3.49	2.4
C	2	276.37	138.19	1256.27	3.49	88.2
Error	20	2.24	0.11			0.7
Total	26	313.32				100

TABLE IX. ANOVA FOR SURFACE ROUGHNESS (R_A) USING UNCOATED CARBIDE CUTTING TOOL

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	1.76	0.88	9.46	3.49	1.6
B	2	103.69	51.85	557.53	3.49	93.7
C	2	3.32	1.66	17.85	3.49	3.0
Error	20	1.87	0.093			1.7
Total	26	110.64				100

TABLE X. ANOVA FOR SURFACE ROUGHNESS (R_A) USING SIGNAL - TO - NOISE RATIO

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	7.07	3.54	22.12	3.49	1.4
B	2	474.97	237.48	1484.25	3.49	95.9
C	2	10.06	5.03	31.44	3.49	2.0
Error	20	3.29	0.16			0.7
Total	26	495.39				100

TABLE XI. ANOVA FOR FLANK WEAR (V_B) USING UNCOATED CARBIDE CUTTING TOOL

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	0.066422	0.033211	23.537208	19.0	74.4
B	2	0.015622	0.007811	5.535790	19.0	17.5
C	2	0.004355	0.002178	1.543586	19.0	4.9
Error	2	0.002823	0.001411			3.2
Total	8	0.089222				100

TABLE XII. ANOVA FOR FLANK WEAR (V_B) USING SIGNAL - TO - NOISE RATIO

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal=MSS/MSS$_E$***	***Ftab 95% CI***	***P=(SS/SS$_T$)*100***
A	2	59.91	29.96	8.49	19.0	71.6
B	2	14.14	7.07	2.00	19.0	16.9
C	2	2.56	1.28	0.36	19.0	3.1
Error	2	7.07	3.53			8.4
Total	8	83.68				100

TABLE XIII. MEAN VALUES OF TANGENTIAL FORCE (F_Y) ON VARIOUS PROCESS PARAMETERS

$\overline{A_1}$	595.6	$\overline{B_1}$	504.4	$\overline{C_1}$	383.3
$\overline{A_2}$	625.6	$\overline{B_2}$	666.7	$\overline{C_2}$	657.8
$\overline{A_3}$	697.8	$\overline{B_3}$	747.8	$\overline{C_3}$	877.8

TABLE XIV. MEAN VALUES OF FEED FORCE (F_X) ON VARIOUSPROCESS PARAMETERS

$\overline{A_1}$	241.1	$\overline{B_1}$	252.2	$\overline{C_1}$	155.6
$\overline{A_2}$	258.9	$\overline{B_2}$	271.1	$\overline{C_2}$	283.3
$\overline{A_3}$	314.4	$\overline{B_3}$	291.1	$\overline{C_3}$	375.6

TABLE XV. MEAN VALUES OF SURFACE ROUGHNESS (R_A) ON VARIOUS PROCESS PARAMETERS

$\overline{A_1}$	4.78	$\overline{B_1}$	2.17	$\overline{C_1}$	4.29
$\overline{A_2}$	4.23	$\overline{B_2}$	4.62	$\overline{C_2}$	4.39
$\overline{A_3}$	4.75	$\overline{B_3}$	6.97	$\overline{C_3}$	5.08

TABLE XVI. MEAN VALUES OF FLANK WEAR (V_B) ON VARIOUS PROESS PARAMETERS

$\overline{A_1}$	0.203	$\overline{B_1}$	0.273	$\overline{C_1}$	0.333
$\overline{A_2}$	0.297	$\overline{B_2}$	0.363	$\overline{C_2}$	0.280
$\overline{A_3}$	0.413	$\overline{B_3}$	0.277	$\overline{C_3}$	0.300

III RESULT AND DISCUSSION

Table 5 indicates that for tangential force, depth of cut has a significant contribution (74.1%) compared to feed rate (18.5%) and cutting speed (3.3%). The S/N ratio also exhibits similar trend and these are tabulated in Table 6.

Table 7 indicates that for feed force, depth of cut has a significant contribution (85.4%) compared to cutting speed (10.2%) and feed rate (2.6%). The S/N ratio also exhibits similar trend and these are tabulated in Table 8.

Table 9 indicates that for surface roughness, feed rate has a significant contribution (93.7%) compared to depth of cut (3.0%) and cutting speed (1.6%). The S/N ratio also exhibits similar trend and these are tabulated in Table 10.

Table 11 indicates that for flank wear, cutting speed has a significant contribution (74.4%) compared to feed rate (17.5%) and depth of cut (4.9%). The S/N ratio also exhibits similar trend and these are tabulated in Table 12.

Estimating the optimal tangential force, feed force, surface roughness and flank wear:

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 13.

The significant parameters with optimal levels are selected as A_1, B_1 and C_1. The estimated mean of the response characteristics can be computed as

$\mu_{TF} = \overline{A_1} + \overline{B_1} + \overline{C_1} - 2 * \overline{T_{TF}} = 595.6 + 504.4 + 383.3 - 2*639.63 = 204$ N

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

$$CI = \sqrt{4.35 * 2974.81\left[\frac{1}{3.86} + 1\right]} = \pm 127.64$$

$\mu_{TF} + CI = 204 + 127.64 = 332$ N, $\mu_{TF} - CI = 204 - 127.64 = 76$ N,

$(\mu_{TF} – CI) < \mu_{TF} < (\mu_{TF} + CI)$, $332 < \mu_{TF} < 76$

The experimentally determined value of tangential force (F_Y) is found to be 270 N. This result is within the predicted optimal tangential force for 95% confidence interval.

Similarly the optimal feed force, surface roughness and flank wear are predicted at the selected optimal setting of process parameters. The mean values of feed force, surface roughness and flank wear for various cutting speed, feed rate and depth of cut are shown in Table 14, Table 15 and Table 16 respectively.

The Table 17 shows the optimal values of various responses of tangential force, feed force, surface roughness and flank wear. The confirmation of experiment is carried out after conducting the trials by selecting the various optimal process parameters of cutting speed, feed rate and depth of cut for various responses of tangential force, feed force, surface roughness and flank wear respectively and the experimental values measured are all found to be within the predicted range.

From Table 18, ANOVA for grey relational grade, the feed rate is having most significant factor 66.7%, depth of cut 26.5%, cutting speed 2.6% and the error is 4.2% respectively. The average value of multi-response cutting force and surface roughness ($\overline{T}$) is determined from Table 20 i.e., 0.5228. The mean value of the individual process parameters of multi-response of cutting force and surface roughness are tabulated in Table 21.

From Table 21, in order to determine the estimated mean of the response characteristics (μ) of multi-response cutting force and surface roughness on individual process parameter is larger the better characteristic is considered i.e., $A_2B_1C_1$.

The estimated mean of the response characteristic and co-efficient of $\overline{T}$ in the equation is one less than the number of items added to estimate the mean and the mean value (μ) is 0.8311. Once the optimal level of the process parameters has been determined, the final step is to predict and verify the improvement of the responses using the optimal level of process parameters. From Table 19, the initial designated levels of parameters are determined by considering the least value of absolute difference between the mean value of grey relational grade and the individual grey relational grade of each experimental run which are tabulated in the 9th column of Table 20 i.e., (0.0048, experimental run of 22nd row, A_3,B_2 and C_1 the grey relational grade is 0.5180) for which the cutting force (F_Y) is 450 N and surface roughness is 4.41 μm as tabulated in Table 2. The predicted optimal process parameters A_2, B_1 and C_1 i.e., for cutting speed of 171.5 m/min, feed rate of 0.125 mm/rev and depth of cut of 0.5 mm when machining is performed by using uncoated carbide cutting tool on EN-19 material both the cutting force (F_Y) and surface roughness (R_a) measured are 320 N and 1.75 μm respectively for which the taguchi based grey relational grade obtained is 0.9354 , the largest value in all the experimental results which are tabulated in Table 20. It is clearly shown that the multi-responses in turning process are together improved by using this method.

TABLE XVII. OPTIMAL VALUES OF VARIOUS RESPONSES AND THE CONFIRMATION EXPERIMENTAL VALUES

No.	***Description***	***μ***	***± CI***	***μ + CI***	***μ - CI***	***Experimental value***	***Optimal process parameters***
1	Tangential force	204 N	127.64	332 N	76 N	270 N	A_1 - B_1 - C_1
2	Feed force	106 N	34.3	140 N	72 N	120 N	A_1 - B_1 - C_1
3	Surface roughness	1.518 μm	0.714	2.232 μm	0.804 μm	1.75 μm	A_2 - B_1 - C_1
4	Flank wear	0.148 mm	0.216	0.364 mm	0.068 mm	0.20 mm	A_1 - B_1 - C_2

TABLE XVIII. ANOVA FOR GREY RELATIONAL GRADE

Factor	***DOF***	***SS***	***MSS = SS/DOF***	***Fcal = MSS/SS$_E$***	***Ftab 95% CI***	***%P = (SS/SS$_T$)*100***
A	2	0.017018	0.008509	6.331101	3.49	2.6
B	2	0.429063	0.214531	159.621652	3.49	66.7
C	2	0.170438	0.085219	63.406994	3.49	26.5
Error	20	0.026886	0.001344			4.2
Total	26	0.643405				100

TABLE XIX. COMPARISON RESULTS OF INITIAL AND OPTIMAL TURNING RESPONSES

Initial turning parameters		***Optimal turning parameters***	
		Prediction	***Experiment***
Levels	A_3 - B_2 - C_1	A_2 - B_1 - C_1	A_2 - B_1 - C_1
Cutting force (N)	450		320
Surface roughness (R_a) μm	4.41		1.75
Taguchi based grey relational grade	0.5180	0.8228	0.9354
Improvement of Taguchi based grey Relational grade	-------	0.3048	0.4174

TABLE XX. S/N RATIOS AND GREY RELATIONAL CO-EFFICIENT OF RESPONSES AND GREY RELATIONAL GRADE OF CUTTING FORCE AND SURFACE ROUGHNESS USING UNCOATED CARIBDE CUTTING TOOL.

Exp. No.	***S/N ratios (η_{ij})***		***Normalized values of S/N ratios (Z_{ij})***		***Grey Relational Coefficient (γ_{ij})***		***Grey relational grade***	$\overline{T}-\gamma_{ij}$
	F_Y	R_a	F_Y	R_a	F_Y	R_a		
1	-48.6273	-7.1967	1.0000	0.8250	1.0000	0.7407	0.8704	0.3476
2	-53.8039	-6.8878	0.5811	0.8482	0.5441	0.7671	0.6556	0.1328
3	-55.8478	-7.2345	0.4157	0.8222	0.4611	0.7377	0.5994	0.0766
4	-51.1261	-13.1983	0.7978	0.3755	0.7120	0.4446	0.5783	0.0555
5	-56.2583	-12.7897	0.3825	0.4062	0.4474	0.4571	0.4522	0.0706
6	-58.7904	-14.5182	0.1775	0.2767	0.3781	0.4087	0.3934	0.1294
7	-52.0412	-16.7518	0.7237	0.1094	0.6441	0.3596	0.5018	0.0210
8	-56.9020	-16.8522	0.3304	0.1019	0.4275	0.3576	0.3925	0.1303
9	-60.0000	-18.2125	0.0797	0.0000	0.3520	0.3333	0.3426	0.1802
10	-49.5424	-4.8608	0.9259	1.0000	0.8709	1.0000	0.9354	0.4126
11	-54.3200	-5.8451	0.5393	0.9263	0.5205	0.8715	0.6960	0.1732
12	-56.2583	-6.5267	0.3825	0.8752	0.4474	0.8003	0.6238	0.1010
13	-51.5957	-12.4650	0.7598	0.4305	0.6755	0.4675	0.5715	0.0487
14	-56.5215	-12.0412	0.3612	0.4622	0.4391	0.4818	0.4605	0.0623
15	-59.0849	-13.9794	0.1537	0.3170	0.3714	0.4226	0.3970	0.1258
16	-52.4650	-15.4464	0.6894	0.2072	0.6168	0.3867	0.5018	0.0210
17	-57.3846	-15.7634	0.2913	0.1834	0.4137	0.3798	0.3967	0.1261
18	-60.4238	-16.8272	0.0454	0.1037	0.3437	0.3581	0.3509	0.1719
19	-51.5957	-6.4444	0.7598	0.8814	0.6755	0.8083	0.7419	0.2191
20	-55.4170	-7.2346	0.4505	0.8222	0.4764	0.7377	0.6070	0.0842
21	-57.1466	-7.9935	0.3106	0.7654	0.4204	0.6806	0.5505	0.0277
22	-53.0643	-12.8888	0.6409	0.3987	0.5820	0.4540	0.5180	0.0048
23	-57.5012	-12.7298	0.2819	0.4106	0.4105	0.4590	0.4348	0.0880
24	-59.7354	-14.5833	0.1011	0.2718	0.3574	0.4071	0.3823	0.1405
25	-53.8039	-16.2181	0.5811	0.1494	0.5441	0.3702	0.4572	0.0656
26	-58.1697	-17.2307	0.2277	0.0735	0.3930	0.3505	0.3718	0.1510
27	-60.9844	-18.0835	0.0000	0.0097	0.3333	0.3355	0.3344	0.1884
						$\overline{T}$	0.5228	

TABLE XXI. MEAN VALUES OF RESPONSES FOR OVERALL GREY RELATIOAL GRADE

$\overline{A_1}$	0.5318	$\overline{B_1}$	0.6978	$\overline{C_1}$	0.6307
$\overline{A_2}$	0.5482	$\overline{B_2}$	0.4653	$\overline{C_2}$	0.4963
$\overline{A_3}$	0.4886	$\overline{B_3}$	0.4055	$\overline{C_3}$	0.4416

IV CONCLUSION

1. The depth of cut has a significant percent contribution for both tangential force and feed force.
2. The feed rate has a significant percent contribution for surface roughness while cutting speed has a significant percent contribution for flank wear.
3. The tangential force (F_Y) obtained is 270 N. By using the Taguchi technique for setting the optimal process parameters for tangential force (F_Y) are cutting speed (101.8 m/min), feed rate (0.125 mm/rev) and depth of cut (0.5 mm) for 95% confidence interval it lies between 76 N to 332 N and hence the tangential force obtained is also lies within this range.
4. The feed force (F_X) obtained is 120 N. By using the Taguchi technique for setting the optimal process parameters for feed force (F_X) are cutting speed (101.8 m/min), feed rate (0.125 mm/rev) and depth of cut (0.5 mm) for 95% confidence interval it lies between 72 N to 140 N and hence the feed force obtained is also lies within this range.
5. The surface roughness (R_a) obtained is 1.75 µm. By using the Taguchi technique for

setting the optimal process parameters for surface roughness (R_a) are cutting speed (171.5 m/min), feed rate (0.125 mm/rev) and depth of cut (0.5 mm) for 95% confidence interval it lies between 0.804 μm to 2.232 μm and hence the surface roughness obtained is also lies within this range.

6. The flank wear (V_b) obtained is 0.20 mm. By using the Taguchi technique for setting the optimal process parameters for flank wear (V_b) are cutting speed (101.8 m/min), feed rate (0.125 mm/rev) and depth of cut (1.0 mm) for 95% confidence interval it lies between 0.068 mm to 0.364 mm and hence the flank wear obtained is also lies within this range.
7. The highest grey relational grade of 0.9354 was observed for the experimental run number 10 shown in response Table 20 of the average grey relational grade, which indicates that the optimal combination of control factors and their levels are 171.5 m/min, feed rate of 0.125 mm/rev and depth of cut of 0.5 mm.
8. During the experimental investigation, it is observed from the table of ANOVA that the feed rate is the most influential control factor among the three turning process parameters for minimization of tangential force and surface roughness when simultaneously considered.

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