Influence of Machining Parameters while Turning of EN19 Steel under Dry Conditions

B.B. Ashok Kumar*, Ch. Maheswara Rao, B. Naga Raju
Assistant Professor, Department of Mechanical Engineering, ANITS, VSP-531162, A.P., India
Assistant Professor, Department of Mechanical Engineering, ANITS, VSP-531162, A.P., India
Professor, Department of Mechanical Engineering, ANITS, VSP-531162, A.P., India
ashokanitsmech@gmail.com

Abstract

The present work is to find the effect of turning process parameters on the multiple performance characteristics during dry turning of EN19 a medium carbon steel. A series of experiments were performed on CNC turret lathe as per taguchi's standard L9 orthogonal array (OA). Three controlled parameters of speed, feed and depth of cut are taken as the input variables. The output measures of Material Removal Rate (MRR), Surface Roughness characteristics (R_a, R_q and R_z) are optimized concurrently using taguchi based Utility method. From the optimization results, the optimal combination of process parameters is obtained at 250 m/min of speed, 0.1 mm/rev of feed and 0.6 mm of depth of cut respectively.

Key Words: Material Removal Rate (MRR), Surface Roughness characteristics (R_a, R_q and R_z), Utility Method and ANOVA.

1. Introduction

In manufacturing industries, the enhancement in productivity and quality can be achieved through well organized/designed experiments only. From past years one such important approach followed by the researchers is that Taguchi's Robust Design. M. Taguchi's parametric design covers the entire parametric space with a reduced number of experiments. Kaladhar, et al. has analyzed the effect of process parameters on Material Removal Rate and Surface Roughness Characteristics. They used AISI 304 As the work piece and L16 orthogonal array has been employed for the experiments. Finally, they found that feed and depth of cut are the significant parameters for MRR and R_a respectively. A Mahamani et.al., have studied the influence of machining parameters on cutting force and surface roughness while hard turning of AA2219-TiB2/ZrB2 in-situ metal composites with uncoated tungsten carbide tool. They employed Taguchi's L27 orthogonal array for the experiments and Regression analysis for the optimization. The results concluded that the feed rate has strongest effect on both Cutting force and Surface Roughness. Harish Kumar, et al., has done the experiments to find the effect of speed, feed and depth of cut on the responses while turning of MS1010 using HSS tool. From the results of ANOVA they found that speed is the most influencing factor for surface roughness. Taguchi method uses two main concepts namely Signal-to-Noise (S/N) ratio and orthogonal array (OA). S/N ratio measures quality with emphasis on variation and OA accommodates many design factors simultaneously. Taguchi method offers the quality of product is measured by quality characteristics such as: Nominal-the-Better, Smaller-the-Better and Larger-the-Better. Feng and Wang, develops an empirical model for the prediction of surface roughness. They analyzed the effect of material, feed rate, cutting tool point angle, depth of cut, spindle speed and cutting time on the surface roughness. The major problem encountered with taguchi method is that it can solve only the problem with single responses. To overcome this, Taguchi based Utility method has been employed. Singh & Kumar, conducted experiments to optimize the multiple responses while turning of EN24 steel using tungsten carbide tool having titanium carbide coating. For solving this they used Taguchi design of experiments and Utility concept. In the present work taguchi based utility method is employed to optimize the multiple performance characteristics.

2. Experimentation

In the present work a medium carbon steel EN19 has been selected as the work piece. It is regularly used for bolts, nuts, in riffle barrels, shafts, gears, spindles and axles, etc. The chemical composition and mechanical properties of EN19 steel are given in the tables 1 and 2. Taguchi's standard L9 orthogonal Array (OA) has been employed for conducting the experiments with selected three process parameters at three different levels. The process parameters selected with their levels and the L9 OA design is given in the tables 3 and 4.

Table 1. Chemical Composition of EN19 Steel

C	Si	Mn	Cr	Mo	S	P
0.36-0.44	0.1-0.35	0.7-1	0.9-1.20	0.25-0.35	0.035	0.040 max

Table 2. Mechanical Properties of EN8 Steel

Density (gm/cm3)	Tensile Strength (N/mm2)	Yield Strength (N/mm2)	Elongation (%)	IZOD (J)	Hardness (BHN)
7.7	850-1000	680	13	50	248-302

Table 3. Process Parameters and Their Levels

	I	II	III
Speed, m/min	100	175	250
Feed, mm/rev	0.1	0.15	0.2
Doc, mm	0.4	0.6	0.8

Table 4. Standard L9 OA

S.No.	V	F	D
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3. Methodology

Utility may be defined as the effectiveness/fitness of a product or a process in reference to the levels of expectations to the customers. In general, the performance evaluation of any manufacturing process depends on the number of output characteristics that are involved. Therefore, it is essential to estimate an overall utility of a product/process by considering the relative contribution of all the quality characteristics. Utility theory provides a methodological framework for the evaluation of alternative attributes provides to the decision maker. It follows the utility maximization principle, according to which the best choice is the one that provides the highest satisfaction to the decision maker.

According to the utility theory, if X_i is the measure of effectiveness of an attribute i and there are n attributes evaluating the outcome space, then the overall utility function can be expressed as

$$U(X_1, X_2, \dots \dots \dots, X_n) = f\left(U_1(X_1),\ U_2(X_2) \dots \dots \dots, U_n(X_n)\right)$$

Here, $U_i(X_i)$ is the utility of the i^{th} attribute.

The overall utility function is the sum of individual utilities if the attributes are independent and is given as

$$U(X_1, X_2 \dots \dots \dots X_n) = \sum_{i=1}^{n} U_i(X_i)$$

The overall utility function after assigning weights to the attributes can be expressed as

$$U(X_1, X_2 \dots \dots \dots X_n) = \sum_{i=1}^{n} W_i U_i(X_i)$$

The preference number can be expressed on the logarithmic scale as follows

$$P_i = A * \log\left(\frac{X_i}{X_i'}\right) \dots\dots\dots\dots\dots\dots\dots \text{Eq.(1)}$$

Here, X_i is the value of any quality characteristic or attribute i, $X_i^{'}$ is just acceptable value of quality characteristic or attribute i and A is a constant.

The value of A can be found by the condition that if $X_i = X^*$ (where X^* is the optimal value), then $P_i = 9$.

$$A = \frac{9}{\log \frac{X^*}{X_i'}}$$

The overall utility can be expressed as

$$U = \sum_{i=1}^{n} W_i P_i \dots\dots\dots\dots\dots\dots\dots\dots \text{Eq.(2)}$$

subjected to $\sum_{i=1}^{n} W_i = 1$

Overall utility index that has been computed is now treated as a single objective function for the optimization. The best alternative is one with highest overall utility value.

4. Results and Discussions

The experimental results of performance characteristics; Material Removal Rate (MRR), Surface Roughness characteristics (R_a, R_q and R_z) were measured and mentioned in the table 5.

Table 5. Experimental Results

S.No.	MRR, Cm^3/min	R_a, µm	R_q, µm	R_z, µm
1	4	4.03	4.86	13.71
2	9	5.12	5.38	15.06
3	16	6.57	7.85	21.27
4	10.5	3.93	4.15	12.84
5	21	4.83	5.8	15.8
6	14	5.87	6.34	19.57
7	20	3.21	4..24	13.31
8	15	3.96	4.74	14.36
9	30	5.91	6.96	18.36

Taguchi based utility method first involves in the preparation of preference numbers on the logarithmic scale. Based on these preference numbers of the quality characteristics, the overall utility can be calculated. The individual preference number models for MRR, R_a, R_q and R_z are given in the equations 3, 4, 5 and 6 respectively. The results based on the equations are given in the table 6.

$P_{MRR} = 10.2857 \log (X_i/4)$…………..Eq.(3)

$P_{Ra} = -28.9389 \log (X_i/6.57)$………..Eq.(4)

$P_{Rq} = -32.5144 \log (X_i/7.85)$………..Eq.(5)

$P_{Rz} = -41.0583 \log (X_i/21.27)$………Eq.(6)

Table 6. Preference Numbers of Responses

S.No.	MRR	R_a	R_q	R_z
1	0.0000	6.1426	6.7706	7.8311
2	3.6224	3.1339	5.3352	6.1564
3	6.1926	0.0000	0.0000	0.0000
4	4.3110	6.4584	9.0007	9.0001
5	7.4073	3.8668	4.2737	5.3011
6	5.5961	1.4159	3.0167	1.4854
7	7.1894	9.0017	8.6977	8.3590
8	5.9043	6.3628	7.1236	7.0051
9	9.0006	1.3305	1.6992	2.6234

Now, the overall utility (U_i) index values can be computed from the individual preference values of responses. Here, the weights for the performance characteristics are assumed as equal i.e. 0.25 each. Finally, the values of overall utility index values were calculated and given in the table 8. The overall utility values are analyzed and the optimal condition has been obtained using the taguchi's Higher-the-Better performance characteristic.

Table7. Overall Utility Values

S.No.	U_i	S/N of U_i
1	5.1861	14.2968
2	4.5620	13.1831
3	1.5482	3.7965
4	7.1925	17.1376
5	5.2122	14.3404
6	2.8785	9.1833
7	8.3120	18.3941
8	6.5990	16.3896
9	3.6634	11.2777

Taguchi mean values of the overall utility index are given in the table 8. The main effect plot shown in the figure 1 indicating that the feed is the main effecting parameter and followed by speed and depth of cut. The optimal combination of process parameters which maximizes the overall utility index values are obtained at speed of 250 m/min, feed of 0.1 mm/rev and depth of cut of 0.6 mm respectively.

Table 8. Response Table for Means of Overall Utility

Level	V	F	D
1	3.765	6.897	4.888
2	5.094	5.458	5.139
3	6.191	2.697	5.024
Delta	2.426	4.200	0.251
Rank	2	1	3

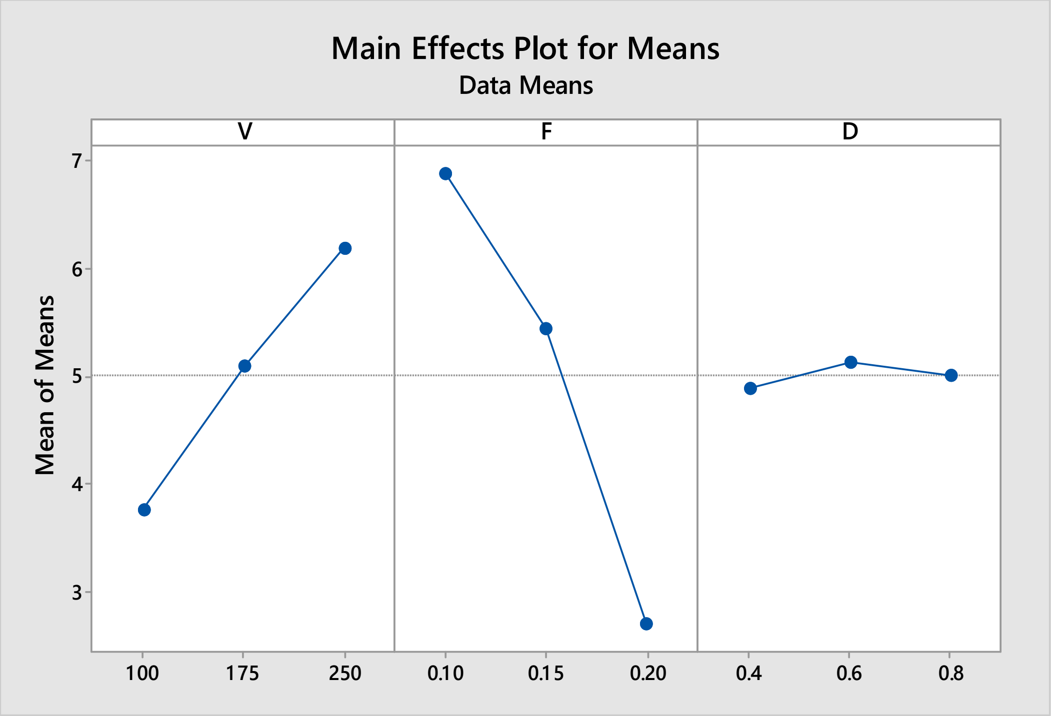

Figure 1. Main Effect Plot for Means of Utility

The ANOVA is used to find the influence of the cutting parameters at $\alpha = 0.05$ (95% of confidence level) on the multi-response. Table 9 shows the ANOVA results of multi-responses and from the results it is found that the feed is the most influencing parameter (74.27%) and followed by the cutting speed (24.06 %) and depth of cut (0.25 %) respectively.

Table 9. ANOVA Results for U_i

Source	DF	Seq SS	Adj MS	F	P	Contribution
Speed (v)	2	8.8553	4.4277	17.09	0.055	0.2406
Feed (f)	2	27.3358	13.6679	52.77	0.019	0.7427
Depth of cut (d)	2	0.0951	0.0475	0.18	0.845	0.0025
Error	2	0.5181	0.2590			0.0140
Total	8	36.8043				100.00

$S = 0.508947$, $R^2 = 98.59\%$, $R^2(\text{adj}) = 94.37\%$

Optimal design for overall Utility (U_i)

For the overall Utility value (U_i), feed and speed are the most significant factors at f1 and v3 levels.

$\mu_{A1B3} = A1 + B3 - T$

Where, $A1 = 6.897$, $B3 = 6.191$

$T = 5.0171$

$\mu_{A1B3} = A1 + B3 - T$

$= 6.897 + 6.191 - 5.0171 = 8.0709$

$$CI = \sqrt{\frac{(F_{95\%,1,doferror} \times V_{error})}{(n_{eff})}}$$

Where, $\eta_{eff} = \frac{N}{(1+dof)}$; where, N is total number of experiments, dof is degree of freedom.

$\eta_{eff} = \frac{9}{(1+2+2)} = 1.8$

$V_{error} = 0.2590$

$F_{95\%,1,2} = 18.5128$ (From standard F-table at $\alpha = 0.05$)

$$CI = \sqrt{\frac{(18.5128 * 0.2590)}{1.8}} = 1.6320$$

The predicted optimal range $= \mu_{A1B3} - CI \leq \mu_{A1B3} \leq \mu_{A1B3} + CI$

$= 8.0709 - 1.6320 \leq \mu_{A3B3} \leq 8.0709 + 1.6320$

$= 6.4389 \leq \mu_{A3B3} \leq 9.7029$

5. Conclusions

The optimal combination of process parameters which maximizes the overall utility index values are obtained at

Speed: level-3, 250 m/min,
Feed: level-1, 0.1 mm/rev and
Depth of cut: level-2, 0.6 mm.

- ANOVA results concluded that feed has the high influence and depth of cut has low influence on the overall utility index.
- The model prepared is best fit and accurate for the prediction of overall utility index.

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