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Multi Response Optimization of Machining Responses in Turning Process of AISI D2 Tool Steel using WPM Approach

Parvinder Singh[1*], A. S. Channi[2]

[1]M. Tech. Scholar, Department of Mechanical Engineering, Yamuna Institute of Engineering & Technology, Yamuna Nagar, Haryana, INDIA, E-mail Id: *psparvinder85@gmail.com**

[2]Assistant Professor, Department of Mechanical Engineering, Yamuna Institute of Engineering & Technology, Yamuna Nagar, Haryana, INDIA, E-mail Id: *aschanni@yamuna.edu.in*

Abstract: *AISI D2* tool steel material is a highly demanding material which covers a broad range of industrial applications. In this research article, turning operation performed on AISI D2 tool steel by employing Taguchi's DOE approach in form of L9 orthogonal array in order to design the experiments. The various process responses such as; thrust force, surface roughness, and material removal rate have been analyzed by using Analysis of Variance. Different process variables investigated are; spindle speed, feed rate, and depth of cut. Multi response optimization has also been attempted to optimize the considered process responses simultaneously using weighted product method. Feed rate and depth of cut have been observed to be most significant for considered process characteristics.

Keywords: Feed rate; Material removal rate; Spindle speed; Taguchi; Turning operation

I. INTRODUCTION

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters.

The optimization of process parameters for turning EN24 steel bars, using spindle speed, depth of cut and feed rate as controlled factors and feed force as response variable through the Taguchi approach were reported [1]. An experimental investigation were conducted using steel work piece, spindle speed, work piece length and cutting tool material control parameters and surface roughness as response parameter [2]. Results show that the effect of spindle speed on the surface roughness is most significant, the effect of cutting tool material is less significant and especially, small work piece length result in better surface roughness. An attempt is made to review the optimizing machining parameters in turning process reported an optimal setting of process parameters [3]. Various conventional techniques employed for optimization include geometric programming, geometric plus liner programming, goal programming, dynamic programming etc. The latest technique for optimization includes fuzzy logic, scatter search technique, genetic algorithm, and Taguchi technique and response surface methodology.

Taguchi method has been applied to find the optimum process parameters for end milling while hard machining of hardened steel [4]. L18, array, S/N ratio and ANOVA are applied to study performance characteristics of machining parameters with the consideration of surface furnishing and tool life. in this study we fine that cutting speed is most influencing parameters.

Experimental investigation has also been carried out for turning process of AISI O1 tool steel [5]. Results reported WSN method of multi response optimization provided with best optimum solution to the problem investigated. Number of investigators have been explored the utility of multi attribute decision making approaches for the purpose of process optimization in broad range of engineering applications [6-11, 12].

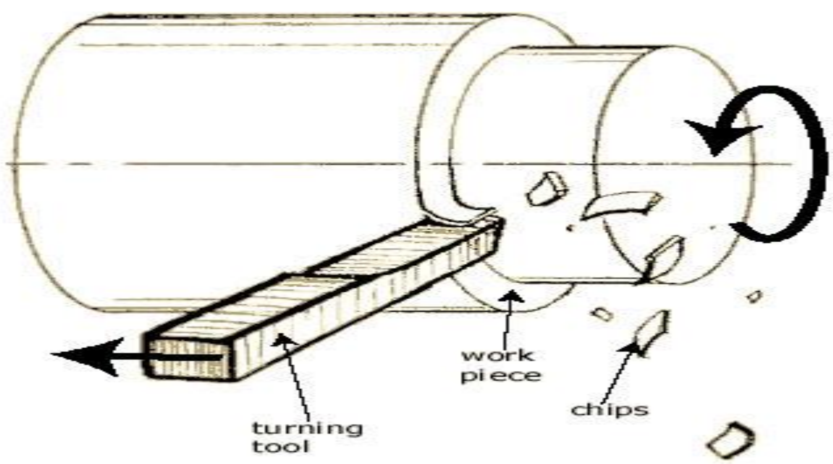

Figure 1: Process of turning operation.

II. EXPERIMENTATION

Hindustan machine tool (HMT) lathe machine was used for this experimentation. The size and the shape of work piece were selected based on the availability from the supplier. Also the work piece was design was finalized keeping in the view the capabilities of the lathe machine to ensure the better performance in machining the work piece.

Figure 2: Set up of work piece on HMT lathe

The following parameters were selected for the study based on the availability of these parameters.

1. **Spindle speed**
2. **Feed rate**
3. **Depth of cut**

Table I. Various factors and their levels

S. No.	***Factor***	***Levels***	***Level 1***	***Level 2***	***Level 3***	***Unit***
A	Speed	3	500	350	200	rpm
B	Feed rate	3	.2	.1	.05	mm/rev
C	Depth of cut	3	1.2	.8	.4	mm

Taguchi's L9 orthogonal array has been used for designing the experimentation. The whole experimentation replicated twice and the mean value of responses has been provided here.

Table II. Control log for experiment

Experiment no.	***Spindle speed (A)***	***Feed rate (B)***	***Depth of cut (C)***
1	500	0.2	1.2
2	500	0.1	0.8
3	500	0.05	0.4
4	350	0.2	0.8
5	350	0.1	0.4
6	350	0.05	1.2
7	200	0.2	0.4
8	200	0.1	1.2
9	200	0.05	0.8

The level of the each factor during each trial is more conveniently expressed by means experimenters log sheet. In the present study, three response variables has been selected (thrust force, surface roughness and MRR). The detail of these response variables are given below.

Table III. Response variables & their units

S. No.	Response name	Unit	Response type
1	Thrust force	Kg.	Continuous
2	Surface roughness	µm.	Continuous
3	MRR	mm^3/ sec.	Continuous

The material removal rate (MRR) in the turning operation is the volume of material removed per unit time

$$MRR = \frac{\pi\,(Do - Di)L}{4T} \qquad (1)$$

Where; D_o = Original Dia in mm; D_i = Final dia in mm; L = length of work piece in mm; T = Time in second.

Table IV. L9 OA Experimental Design with process responses

S. No.	Spindle Speed (A)	Feed Rate (B)	Depth of Cut (C)	Thrust Force	Surface Roughness	Material Removal Rate
1	500	0.2	1.2	138.67	4.61	99.12
2	500	0.1	0.8	23.34	2.77	7.42
3	500	0.05	0.4	9.67	2.11	3.92
4	350	0.2	0.8	33.34	3.65	16.39
5	350	0.1	0.4	25.34	2.07	10.46
6	350	0.05	1.2	31.67	1.33	25.41
7	200	0.2	0.4	24.34	3.02	5.74
8	200	0.1	1.2	85.34	3.32	29.72
9	200	0.05	0.8	26.67	2.67	2.39

III. MULTI-RESPONSE OPTIMIZATION USING WPM (WEIGHTED PRODUCT METHOD)

In this method, the combined index of an alternative is calculated. The major steps are as follows;

- The determination of the objective and identification of relevant evaluation attributes.
- Perform the normalization of the raw data. The attributes can be beneficial or non-beneficial. The normalized values expression for the case of higher-is-better (i.e. beneficial attribute) is given as;

$$m_{ab}=(m_{ab})_K/(m_{ab})_L \qquad (2)$$

where $(m_{ab})_K$ is the measure of the attribute for the K-th alternative, and $(m_{ab})_L$ is the measure of the attribute for the L-th alternative that has the highest measure of the attribute out of all alternative considered and for the case of lower-is-better (i.e. non-beneficial attribute) it is given as;

$$m_{ab}=(m_{ab})_L/(m_{ab})_K \qquad (3)$$

Step 3: The overall or composite performance score of an alternative can be express as;

$$P_a = \prod_{b=1}^{p} [(m_{ab})_{normal}]^{wy} \quad (4)$$

Table V. Normalized matrix for each process response

S. No.	*Spindle Speed (A)*	*Feed Rate (B)*	*Depth of Cut (C)*	**Thrust Force**	**Surface Roughness**	**Material Removal Rate**
1	500	0.2	1.2	0.069734	0.288503	1
2	500	0.1	0.8	0.41431	0.480144	0.074859
3	500	0.05	0.4	1	0.630332	0.039548
4	350	0.2	0.8	0.290042	0.364384	0.165355
5	350	0.1	0.4	0.38161	0.642512	0.105529
6	350	0.05	1.2	0.305336	1	0.256356
7	200	0.2	0.4	0.397288	0.440397	0.05791
8	200	0.1	1.2	0.113311	0.400602	0.299839
9	200	0.05	0.8	0.36258	0.498127	0.024112

The weights have been decided as 0.33 for all the process characteristics such as; thrust force (TF), surface roughness (SR), and material removal rate (MRR).

Table VI. Weighted normalized and Combined index matrix

S. No.	Thrust Force	Surface Roughness	Material Removal Rate	Combined Index
1	0.415276	0.663513	1	0.27554
2	0.747683	0.784969	0.425109	0.24950
3	1	0.858732	0.344391	0.29574
4	0.664679	0.716662	0.552176	0.26303
5	0.72767	0.864173	0.476115	0.29940
6	0.676047	1	0.638143	**0.43141**
7	0.737403	0.762902	0.390578	0.21973
8	0.487428	0.739427	0.672006	0.24220
9	0.715489	0.794552	0.292508	**0.16629**

The optimized parametric setting for WPM combined index (higher is better) is; **A2 B2 C1** and ANOVA analysis is also presented above.

IV. RESULTS & DISCUSSION

The entire machining process has been found to be significantly get affected with the depth of cut and feed rate of the tool.

In multi-response optimization for turning process of AISI D2 tool steel, **A2 B2 C1** observed as optimal parametric setting of process variables. This suggests that; Spindle speed of 350 rpm, feed rate of 0.1 mm/rev., and depth of cut of 1.2 mm provided with optimum solution to the present investigated problem when consider all the process responses of interests simultaneously.

The mean effect plots and ANOVA analysis have been represented below.

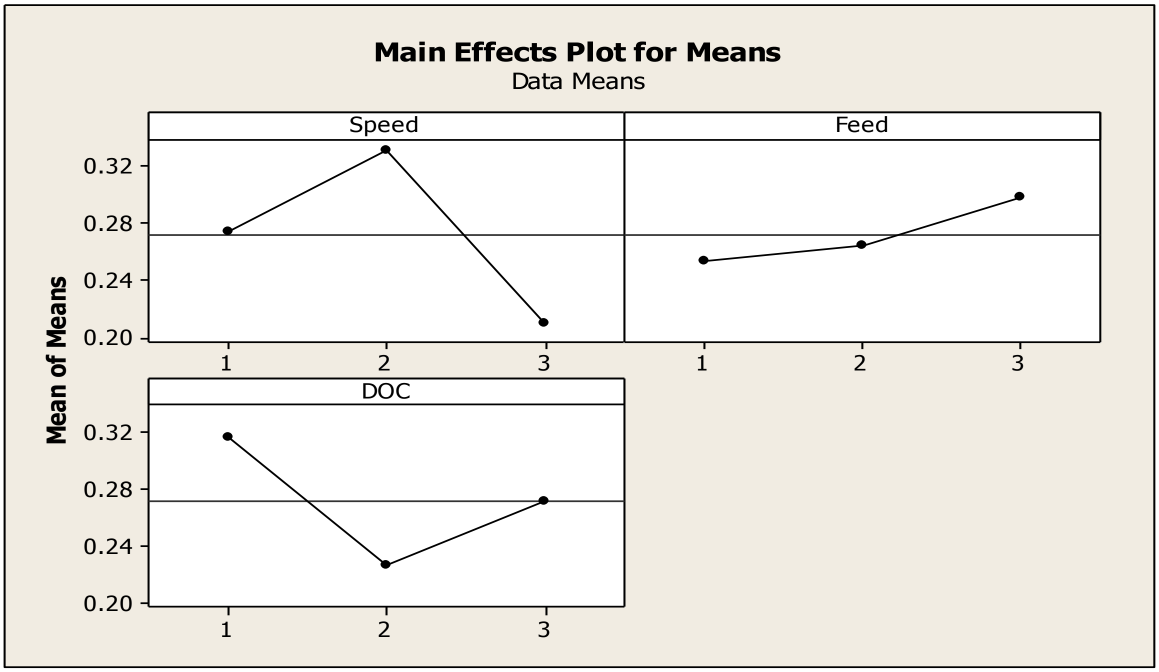

Figure 3: Mean effects plot for WPM combined index.

Table VII. ANOVA results for WPM combined index

Source	***DF***	***Seq SS***	***Adj SS***	***Adj MS***	***F***	***P***	***%contribution***
Speed	2	0.022301	0.022301	0.011151	5.16	0.162	
Feed	2	0.003313	0.003313	0.001656	0.77	0.566	
DOC	2	0.012181	0.012181	0.006090	2.82	0.262	
Error	2	0.004324	0.004324	0.002162			
Total	8	0.042119					

S = 0.0464974 R-Sq = 89.73% R-Sq(adj) = 58.94%

V. CONCLUSIONS

Present study used weighted product method for the multi response optimization in turning process of *AISI D2* tool steel. Following conclusions can be made from present experimentation based research work;

1. Taguchi's L9 orthogonal array enables the proper combination of process variables to be used in experimentation in a most effective manner.
2. Analysis of Variance of process responses provides the significance of considered parameters and results revealed that depth of cut and feed rate effects the process mostly.
3. In multi-response optimization for turning process of AISI D2 tool steel, **A2 B2 C1** observed as optimal parametric setting of process variables. This suggests that; Spindle speed of 350 rpm, feed rate of 0.1 mm/rev., and depth of cut of 1.2 mm provided with optimum solution to the present investigated problem when consider all the process responses of interests simultaneously.

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