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Experimental Investigation of Turning Operation Process Parameters on Surface Roughness and Material Removal Rate on EN9 Medium Carbon Steel

Dr. Avtar Singh[1]* and Gurdeep Singh[2]
Assistant Professor[1], Student[2]
Yadavindra Department of Engineering, Punjabi University Guru Kashi Campus
Damdama Sahib (Talwandi Sabo)
*Corresponding author Email: avtardhanjal@gmail.com

Abstract - In the present study, the influence of major process parameters of turning operation, viz. spindle speed, tool feed rate and depth of cut have been investigated and optimized on surface roughness and material removal rate (MRR) of EN9 medium carbon steel. The experiments were conducted using an L9 orthogonal array of the Taguchi method, which is an efficient and systematic approach to study the influence of various process parameters on the response parameters. The performance characteristics were analysed using "signal-to-noise ratios" criteria, where the "smaller is better" adopted for surface roughness and the "larger is better" criterion for material removal rate. The experimental results of the study were also analysed using the "main effects plots of means," which revealed that the spindle speed is the significant process parameter for surface roughness, while the tool feed rate and depth of cut largely affect the material removal rate.

Keywords: Turning Operation, surface roughness, material removal rate, orthogonal array, signal to noise ratio

I. BACKGROUND

Medium carbon steel is versatile material commonly used for heavy machines and many more industrial applications. Medium carbon steel has good ability of surface hardening that makes it suitable for manufacturing of shafts, gears, camshafts axles, cutting tools and other wide variety of applications [1]. The medium carbon steel contains the carbon percentage in the range of 0.5-0.6% with limited percentage of other elements such as Si, Mn and Cr and carries tensile strength in the range of 700 – 1000 Pa. Machining processes play an important role in the manufacturing of different parts for various intended applications. There are many machining operations, such as turning, milling, shaping, and drilling etc., available that convert the raw material into a finished

product. The process parameters play an important role in the production of quality products. The less machine time required for the manufacturing of product increase the capacity of plant and efficiency. Aforementioned that medium carbon steel is used for manufacturing of shafts, axles and camshaft etc. So, the turning operation is required to perform for the manufacturing of such type of components. In turning operation, the surface finish and the material removal rate are the important characteristics that need attention of the researchers [2]. The important process parameters of turning operation are spindle speed, tool feed rate and depth of cut which significantly affect the surface roughness and the material removal rate [3–6]. it is suggested by the previous studies that process parameters of turning operation such that spindle speed, tool feed rate and depth of cut significantly affects the surface roughness and the material Removal rate.

This paper presents the experimental investigation in which the effect of process parameters of turning operation namely spindle speed, tool feed rate and the depth of cut on surface roughness and MRR is discussed. This paper organized as follows: In the next section of the paper the methodology used for the study is presented, followed by results and discussion.

II. METHODOLOGY

Medium carbon steel bar of diameter 25.4 mm (approx.) was used in this investigation. The chemical composition of the material is given in the Table 1. The 150 mm long pieces were cut to perform the turning operation. CNC lathe machines of Jobber series available at Centre Tool Room, Ludhiana (Punjab) India was used to perform the turning operation. The lathe machine of Jobber series having horizontal 2-axis and maximum turning diameter 320 mm was used to turn the work piece upto 100 mm long cut as depicted in Fig. 1. The DNMG carbide tool (D-Diamond 55° angle, N-Negative, M-Medium tolerance, G-Double sided) was used for turning operation as shown in Fig 2 and the specifications are listed in the Table 2. During the turning the HP KOOLKUT – 70 grade coolant was used.

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Table 1 Composition range of material of EN9

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**
Element (%)	0.50-0.60	0.4 max	0.50-0.80	0.035 max	0.015-0.035	0.30 Max

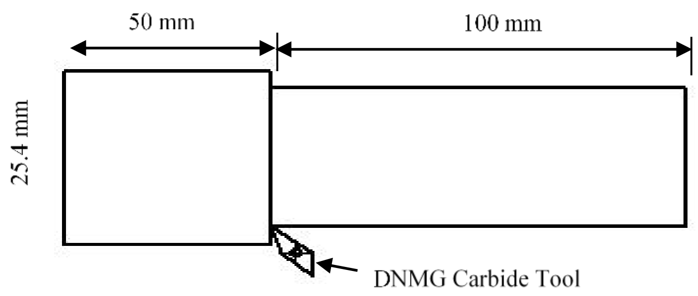

Fig. 1 - Turning Operation

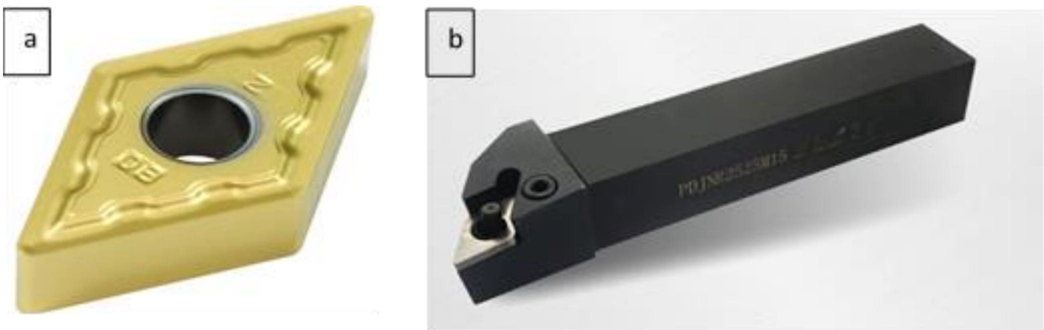

Fig *2* Turning Tool (a) DNMG carbide insert (b) Tool holder

Table 2 DNMG Carbide Tool Specification

Thickness (mm)	6.35 mm
Corner Radius (mm)	0.8 mm
Spindle Edge Length	15.5 mm
Height	12.7 mm
Hole Diameter	5.16mm

A. Selection of Process parameters

In turning operation, the material removal rate (MRR) and Surface Roughness are mainly depending on process parameters, tool geometry and work piece characteristics. The process parameters include spindle speed, tool feed rate and depth of cut. In present study, process variables are taken as inputs whereas tool and work piece characteristics were considered fixed. The experiments were conducted by varying the process parameters of turning operation. The spindle speed was selected in the range of 450-650 RPM, the tool feed rate from 0.05 to 0.15 mm/rev and the depth of cut varies from 0.5 to 1.5 mm as shown in Table 3

The design matrix as shown in Table 4, to perform the experiment was prepared for the selected process parameters using the L9 orthogonal array of Taguchi method using Minitab statistical software version 18. The nine work pieces were machined on CNC lathe machine as per the combinations provided by L9 orthogonal array [4, 6]. Subsequently, the surface roughness (R_a) was measured using Mitutoyo SJ-201 surface roughness tester available in the machining science lab of the mechanical engineering section of Yadavindra department of Engineering, Talwandi Sabo and MRR (mm^3/min) was calculated using the using the equ.1

$$MRR = \pi . D . d . f . N \ \left[\frac{mm^3}{min}\right] \ldots\ldots\ldots\ldots (1)$$

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Where:
D – Diameter of workpiece (mm), d - Depth of cut (mm,) f- Feed (mm/rev), N – Spindle speed (rpm)

Table 3 Process parameters selected for experimentation

Process Parameters	Unit	Levels 1	2	3
Spindle Speed (v)	rpm	450	550	650
Tool feed rate (f)	mm/rev	0.05	0.10	0.15
Depth of Cut (d)	mm	0.5	1.0	1.5

Table 4 Orthogonal array design (L9)

S. No.	Spindle Speed (v) (rpm)	Tool Feed Rate (f) (mm/rev)	Depth of cut (d) (mm)
1	450	0.05	0.5
2	450	0.10	1.0
3	450	0.15	1.5
4	550	0.05	1.0
5	550	0.10	1.5
6	550	0.15	0.5
7	650	0.05	1.5
8	650	0.10	0.5
9	650	0.15	1.0

Table 5 Results of experiment study

S. No.	Spindle Speed (v) (rpm)	Tool Feed Rate (f) (mm/rev)	Depth of cut (d) (mm)	Surface roughness (R_a) (µm)	MRR (mm^3/min)
1	450	0.05	0.5	3.027	897.71
2	450	0.10	1.0	2.297	3449.32
3	450	0.15	1.5	2.757	7602.53
4	550	0.05	1.0	1.640	2108.76
5	550	0.10	1.5	2.191	6194.42
6	550	0.15	0.5	2.353	3227.95
7	650	0.05	1.5	1.781	3660.71
8	650	0.10	0.5	1.239	2542.21
9	650	0.15	1.0	1.740	7474.47

III. RESULTS AND DISCUSSION

The results of the surface roughness, MRR and machining time for the experiment performed as per the design matrix listed in the Table 5. It is evident that for different combinations of the process parameters the surface roughness (Ra) varies from 1.238 to 3.027 µm, MRR varies from 897.71 to 7602.53 (mm^3/min).

Signal-to -noise (S/N) ratio criteria is used to determine the best among the selected level of the process parameters for the particular response parameters. Two criteria were used to evaluate the S/N ratio of the process parameters either “Smaller is better” or “larger is better” criteria [7]. The “smaller is better” means the objective to minimize the response and vice versa for “larger is better” criteria

A. Surface roughness

For surface roughness the “small is better” criteria was adopted because lower the surface roughness indicates smoother and better surface finish. The Taguchi analysis suggested that the higher value of S/N ratio indicated the best performance for “smaller is better” criteria. S/N ratio for different process parameters at various levels listed in Table 6. It is evident that S/N ratio increase significantly from -8.550 to -3.895, when the spindle speed varies from 450 to 650 rpm which suggested that increase in spindle speed reduce the surface roughness i.e increase in surface finish of the surface. In the case of tool feed rate the higher value of S/N ratio -5.299 at 0.1 mm/rev (level -2) indicated that minimum surface roughness but further increase in tool feed rate increase the surface roughness of the surface. The similar behaviour was observed in case of depth of cut for surface roughness. The higher delta value indicated the most influential variable for the surface roughness. For Spindle speed the delta value 4.655 which was maximum as compared to the other process parameters, so it was inferred that the spindle speed was the most influential process parameter for surface roughness. Whereas the tool feed rate was the second most influential process parameter followed by the depth of cut.

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Table 6 Signal to Noise Ratio for surface roughness (Smaller is better)

Level	Spindle Speed (rpm)	S/N ratio	Feed (mm/rev)	S/N ratio	Depth of Cut (mm)	S/N ratio
1	450	-8.550	0.05	-6.310	0.5	-6.305
2	550	-6.181	0.1	-5.299	1.0	-5.443
3	650	-3.895	0.15	-7.017	1.5	-6.878
Delta		4.655		1.718		1.435
Rank		**1**		**2**		**3**

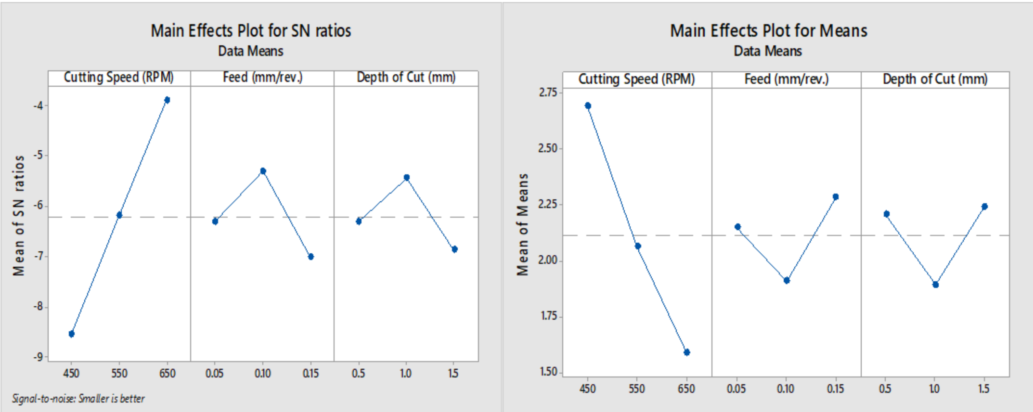

Fig 3 Signal to Noise ratio and plot of means for surface roughness

It is interpreted from the Fig 3 of "Main Effects Plots for Means" that increase in spindle speed the decrease in mean value which suggested that the increase in spindle speed decrease the surface roughness. For tool feed rate the minimum mean value was at the mid-level which showed that increase in tool feed rate decrease the surface roughness means smoother the surface, but further increase in tool feed rate indicated that decreased surface roughness. It is confirmed from the analysis of S/N ratio and the main effects plots of means that in this study the minimum surface roughness achieved at the maximum spindle speed during turning operation [2, 7].

B. Material Removal rate (MRR)

Material removal rate is an important characteristic of machining. The higher the MRR means the minimum time required for machining a component. The higher MRR contributed in the higher production rate, reduced manufacturing time resulting in the increase in manufacturing efficiency. For analysis of S/N ratio of MRR the "larger is better" criteria was adopted because the higher value of S/N ratio represented the significant process parameter for the response parameters. It is clearly depicted from the S/N ratio listed in the Table 7 that tool feed rate at 1.5 mm/rev has 15.088 S/N ration which was higher in comparison to the spindle speed and depth of cut. The values of delta for tool feed rate and depth of cut were 9.542 and 9.186 respectively which indicated that both the process parameters significantly affect the MRR during turning operation while the delta for spindle speed was 3.194 which means that it moderately affects the MRR. The similar observations were interpreted by the graph for S/N ratio and plot of means as shown in Fig. 4. Therefore, it was suggested that increase in tool feed rate and depth of cut increase the MRR and vice versa. So, it was confirmed from the analysis of results that increase in tool feed rate and the depth of cut increase the MRR.

Table 7 Signal to Noise Ratio (Larger is better*)*

Level	Spindle Speed (rpm)	S/N ratio	Feed (mm/rev)	S/N ratio	Depth of Cut (mm)	S/N ratio
1	450	9.088	0.05	5.546	0.5	5.723
2	550	10.831	0.1	11.567	1.0	11.568
3	650	12.282	0.15	15.088	1.5	14.910
Delta		3.194		9.542		9.186
Rank		**3**		**1**		**2**

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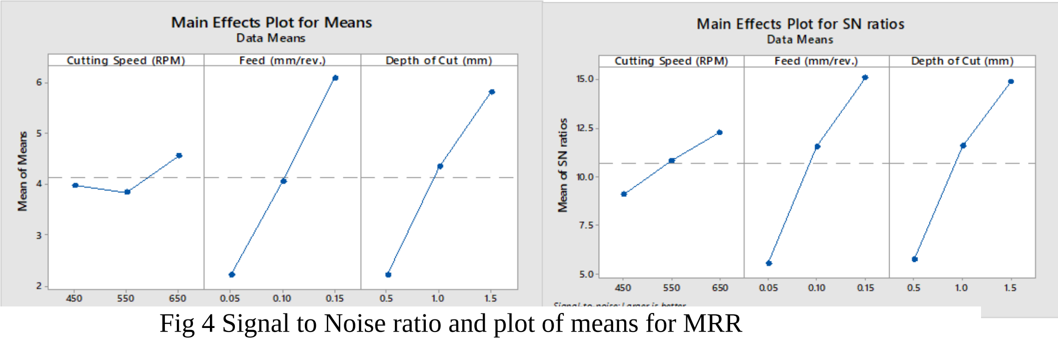

Fig 4 Signal to Noise ratio and plot of means for MRR

IV. CONCLUSION

1. The experimental results of the study indicated that spindle speed, feed and depth of cut significantly affect the surface roughness and material removal rate during the turning operation.
2. Among the selected process parameters, spindle speed observed the most significant process parameter for surface roughness followed by the tool feed rate and depth of cut.
3. For material removal rate tool feed rate and depth of cut were the most dominating process parameters.

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