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Effect of Machining Parameters on Cutting Forces during Turning of Mild Steel on High Speed Lathe by using Taguchi Orthogonal Array

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ABSTRACT

Although many investigations have been carried out on turning of mild steel, but the present work deals with analysis of the parameters affecting the tool forces induced during the turning process of mild steel on high speed lathe i.e. at higher speeds the investigation is carried out and the influencing parameters have been analyzed .Design of experiments was implemented for the analysis of the influence of turning parameters such as cutting speed, feed rate and depth of cut on the tool force. The results of the machining experiments were used to characterize the main factors affecting the tool force by the Analysis of Variance (ANOVA) method. The depth of cut was found to be the most significant parameter influencing the tool force in the turning process followed by feed rate and a minor effect of speed. Also the mathematical regression equation for the model was developed to find out the predicted tool force for the said model and the same was compared with the actual experimental results. The comparative results indicated that the experimentally obtained results almost coincide with the predicted results.

Keywords: Mild Steel, Dry turning, High Speed, optimization, Cutting Force, Taguchi Method, L9.

1. INTRODUCTION

Turning of mild steel using HSS is one of the major machining operations carried out in manufacturing industries and workshops. The analysis of the forces involved in these turning operations plays an important role as it directly influences the power consumption associated with the machine on which turning operation is carried out. The machinability of materials are often expressed in terms of the ease with which the tool can operate on a material and the forces so involved have a greater influence on the durability of the tool .In the current discussion the effect of cutting parameters on the forces so involved i.e. Thrust force (F_y),Feed force(F_x) and Cutting force (F_z) are being analyzed using Taguchi's L9 Orthogonal Array optimization methodology.

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The study on MDN250 steel using coated ceramic tool by Lalwani et al. also conveys the significance of considering cutting force [1]. MDN 250 steel has many practical implementations in the field of defense and research; hence, the results and the conclusions drawn here will prove to be helpful in the selection of optimum manufacturing conditions, which will contribute for better productivity [2, 3].Apart from the parameter cutting force,Honet et al. reviewed the heat generation and heat dissipation in high speed metal turning on coated materials and also briefly reviewed some temperature measurement techniques in metal cutting [4] .

Al though enough research has been made when it comes to the context of mild steel , but the accuracy of the reading and the means by which the results are acquired are in question [5]. Hence in various machinability researches different types of optimization techniques are implemented in order to achieve more accurate results. R. Kumar et al. used regression analysis and ANOVA in order to study the cutting force and temperature in machining Ti-6Al-4V alloy [6].

2. DESIGN OF EXPERIMENTS

Designs of experiments are considered as very useful strategy for deriving clear and accurate conclusions from the experimental observations. In this phase of experimentation a design of experimentation technique viz Taguchi's L9 orthogonal array has been used for studying the influence of 3 process parameters (cutting speed, feed and depth of cut) on 3 different responses (Thrust force (F_y),Feed force(F_x) and Cutting force (F_z)) during machining of mild steel. Experiments were performed at three different levels. Nine experiments were performed .

2.1 Parameters

In this investigation, for implementation of the concept of Design of Experiments; Speed, Feed and Depth of Cut are taken as input parameters and their levels are shown in table 1. Thrust force (F_y), Feedforce (F_x) and Cutting force (F_z) being the output parameters.

Table.1 cutting parameters and their levels

Condition	Speed(RPM)	Feed(mm/rev)	Depth of Cut(mm)
High(+1)	525	0.690	1.5
Medium(0)	315	0.380	1.0
Low(-1)	269	0.094	0.5

2.2 Taguchi's L9 Orthogonal Array

Traditional experimental design procedures are too complicated and not easy to use. Also a large number of experimental works need to be carried out when the number of process parameters increase. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [7].

Taguchi methods [8] have been widely utilized in engineering analysis and comprise a plan of experiments with the objective of acquiring data in a controlled way, in order to obtain information about the behavior of a given process. The greatest advantage of this method is the minimization of effort in conducting experiments; saving experimental time, reducing the cost, and discovering significant factors quickly. Taguchi's robust design method is a powerful tool for the designing of experiments. In addition to the S/N ratio, a statistical analysis of variance (ANOVA) can be employed to

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indicate the impact of process parameters on tool force values. The steps applied for Taguchi optimization in this study are as follows:

- Selection of noise and control factors
- Selecting Taguchi orthogonal array
- Conduct Experiments
- Tool Force measurement
- Analyze results; (Signal-to-noise ratio)
- Predict optimum performance
- Confirmation experiment

3. MATERIAL AND METHODS

The experiment was carried out on a high speed lathe (MGL-54) which enables to operate at higher speeds for machining and production of jobs. For force measurement, the high speed lathe is connected to a lathe tool dynamometer (as shown in Figure-1) which is capable of logging all tool force Values in every second to the software installed on the computer.

Figure.1 High Speed Lathe Machine (MGL-54)

Work piece: Work piece of standard dimensions was used for machining [9-11]: work piece diameter: 40mm, work piece length: 300mm (approx.)

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4. EXPERIMENTATION

The mild steel was subjected to turning operation which was carried out on High Speed Lathe Machine (MGL-54) and HSS was used for the turning purpose .As the work piece was long it was subjected to facing and center drilling operation at the free end supported by the tailstock. Without such support, the force of the tool on the work piece would have caused it to bend away from the tool, producing distorted results. Work piece was inserted in the 4-jaw chuck and was tightened in the jaws until they just started to grip the work piece. The work piece was then rotated to ensure that it well fits at its seat. Work piece was kept as parallel as possible with the center line of the lathe. The HSS tool was tightly clamped in the tool holder. The angle of the tool holder was properly adjusted so that the tool remained approximately perpendicular to the side of the work piece. The turning was carried out on 9 different sections of the work piece. For each section, all the three parameters, viz. cutting speed, depth of cut and feed rate, were varied as shown in Table 1. and the respective tool forces were being logged by a 3-axis digital data acquisition capable lathe tool dynamometer.

5. RESULTS AND DISCUSSION

Table 2 shows experimental design matrix and tool force value for mild steel. S/N ratio is calculated using lower the better characteristics and shown in Table 2.

Table.2. Experimental Result

Exp No	INPUT PARAMETERS			OUTPUT PARAMETERS				S/N Ratio	Resultant Force in Kgf (Predicted)
				Force					
	Speed	Feed	Depth of Cut	Cutting Force(Fz)in Kgf	Feed Force(Fx) in Kgf	Thrust Force(Fy) in Kgf	Resultant Force in Kgf (Actual)		
1	269	.094	.5	4.9	17.1	11.9	21	-26.4444	23.49
2	269	0.380	1.0	31.6	93.4	63.1	117	-41.3637	80.61
3	269	0.690	1.5	51.9	110.6	82.7	148	-43.4052	174.82
4	315	0.094	1.0	28.5	46.2	42	68	-36.6502	58.36
5	315	0.380	1.5	14.9	103.3	92	139	-42.8603	138.55
6	315	0.690	0.5	11.8	31.3	23.7	41	-32.2557	58.44
7	525	0.094	1.5	24.8	64.4	57	89	-38.9878	109.04
8	525	0.380	0.5	10.6	25.2	16.8	32	-30.103	38.48
9	525	0.690	1.0	48.1	111.4	82.9	147	-43.3463	109.15

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Responses for Signal to Noise Ratios of Smaller is better characteristics is shown in Table 3. Significance of machining parameters (difference between max. and min. values) indicates that depth of cut is significantly contributing towards the machining performance as difference gives higher values. Plot for S/N ratio shown in Figure 2 explains that there is less variation for change in cutting speed where as there is significant variation for change in depth of cut followed by feed rate.

Table.3 Effects of Cutting parameters on cutting force

Level	Speed (inRPM)	Feed (mm/Rev)	Depth of Cut(mm)
1	-37.07	-34.03	-29.60
2	-37.26	-38.11	-40.45
3	-37.48	-39.67	-41.75
Delta	0.41	5.64	12.15
Rank	3	2	1

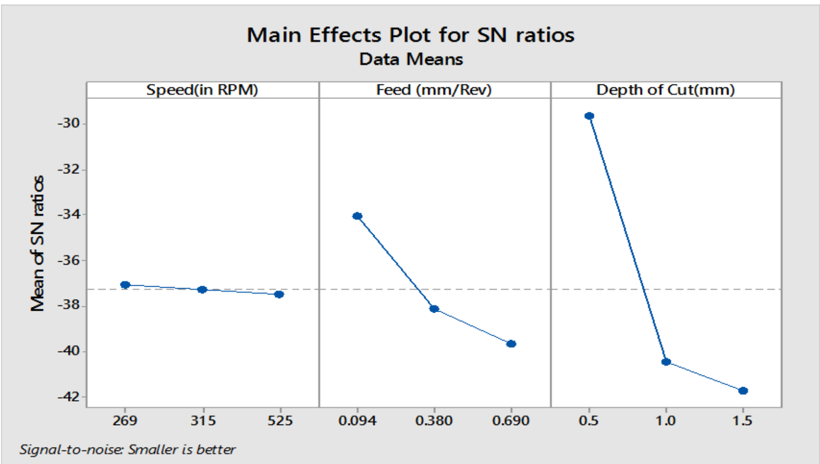

Fig.2 Main effects plot for cutting force

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As Taguchi method cannot determine effect of individual parameters on entire process, hence the percentage contribution of individual parameters can be well determined using ANOVA. ANOVA module of MINITAB software was employed to investigate effect of process parameters (cutting speed, Feed rate and Depth of Cut).

Table.4 Results of ANOVA for cutting force

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
Speed(in RPM)	2	0.2213	0.1106	0.21	0.829	0.32%
Feed (mm/Rev)	2	12.5532	6.2766	11.73	0.079	18.17%
Depth of Cut(mm)	2	55.2057	27.6028	51.57	0.019	79.94%
Error	2	1.0706	0.5353			
Total	8	69.0507				

Table 4 shows Analysis of variance for S/N ratio. F value (51.57) of parameter indicates that depth of cut is significantly contributing towards tool force whereas F value (0.21) of parameter indicates that cutting speed is contributing less towards tool force which is also clearly indicated by contribution percentage. Table 5 shows the model summary of the response.

Table.5 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.731629	98.45%	93.80%	68.60%

Mathematical model of the response was developed using regression analysis module of MINITAB Software and the developed regression equation which gives predicted results of the model is given by:

$$R.F^{0.5} = 1.60 + 0.00006\ \text{Speed (RPM)} + 4.69\ \text{Feed (mm/Rev)} + 5.58\ \text{Depth of Cut (mm)}$$

Using the above regression equation predicted tool force values were computed which is indicated by ‘Resultant tool force in Kgf (predicted)’ in table 2 and it was compared with the actually obtained experimental values. Figure-3 shows the graphical comparison between predicted model and actual model.

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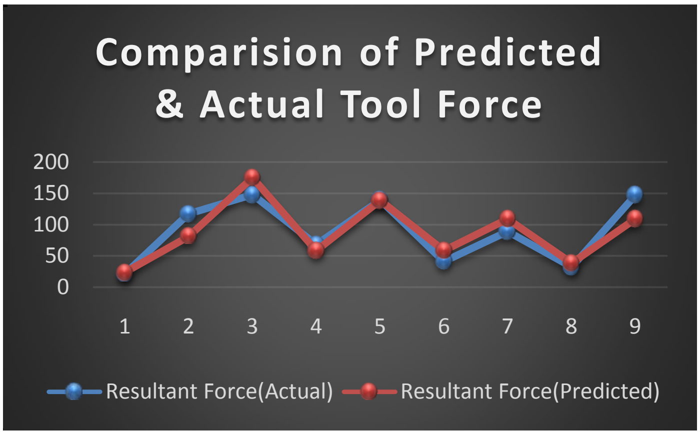

Fig.3 Comparison graph between Predicted and Actual Cutting force

6. CONCLUSION

Taguchi method of experimental design has been applied for optimizing the process parameters for turning mild steel using L9 orthogonal array. Results obtained from Taguchi method closely matched with ANOVA. Best parameters found for lesser tool force are: Cutting Speed (269 RPM), Feed (0.094 mm/rev) and Depth of Cut (0.5mm) for machining on a high speed lathe and the result indicated by prediction model of regression equation was found to be almost confirming with the actual values obtained from experimental analysis.

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