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Application of Taguchi Method in the Optimization of the Cutting Forces in Turning Operation of 20MnCr5 Alloy Steel

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Abstract—*In this paper, the Taguchi method is used to optimize the cutting forces in Turning Operation of 20MnCr5 alloy steel using Tungsten Carbide inserts. Three process parameters namely, cutting speed, feed rate, and depth of cut, have been selected for investigation. Experiments were conducted on the basis of Taguchi's L9 orthogonal array. The Signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to optimize the effects of the selected process parameters on Cutting forces. The results reveal that feed rate is the most influencing factor followed by depth of cut and cutting speed. The confirmation experiments validate the results of the findings.*

Keywords*: Taguchi method, Cutting forces, Orthogonal array, Optimization, ANOVA, SNR*

1. INTRODUCTION

The term turning, in the general sense, refers to the generation of any cylindrical surface with a single point cutting tool. More specifically, it is often applied just to the generation of external cylindrical surfaces oriented primarily parallel to the work piece axis[1].

The Relative forces in a turning operation are important in the design of machine tools. The machine tool and its components must be able to withstand these forces without causing significant deflections, vibrations, or chatter during the operation. There are three principal forces during a turning process and these are Cutting or Tangential force, axial or feed force and radial or thrust force[2]. The cutting or tangential force acts downward on the tool tip allowing deflection of the workpiece upward. It supplies the energy required for the cutting operation. The axial or feed **force** acts in the longitudinal direction. It is also called the feed force because it is in the feed direction of the tool. This force tends to push the tool away from the chuck. The **radial or thrust force** acts in the radial direction and tends to push the tool away from the workpiece.

R W Lanjewar, P Saha, U Datta, A J Banarjee, S Jain and S Sen investigate the use of different process parameters for minimum machining forces for selected parameter range[3]. Negrete et.al. [4] optimized the cutting parameters for minimizing cutting power whereas Cayda [5] varied the cutting tool to evaluate the machinability of AISI 4340 steel. Aggarwal and Singh [6] optimized the radial and feed forces in CNC machining of P-20 tool steel material using TiN coated tungsten carbide inserts.

The cutting forces are determined mainly by depth of cut and feed rate, respectively more than that by cutting speed (Nicoletalungu et al., 2012)[6]. The cutting force components are very sensitive even to the very smallest changes in the cutting process; therefore, instead of calculating the cutting forces theoretically, measuring them in process by Dynamometers is preferred (Sanglam, H et al., 2007)[7].

The metal cutting studies focus on the features of tools, work material composition and mechanical properties and all the machine parameter settings that influence the process efficiency and output quality characteristics/responses. A significant improvement in process efficiency can be obtained by process parameter optimization that identifies and determines the regions of critical process control factors leading to desired outputs or responses with acceptable variations ensuring a lower cost of manufacturing. The performance of any machining process is evaluated in terms of machining rate.

The aim of the present work is to study the effect of turning process parameters on the performance characteristics—Cutting forces— while machining 20MnCr5 steel. The main applications of 20MnCr5 are in making gear-boxes, piston, bolts, spindles, camshafts, gears, shafts, etc

2. SELECTION OF PROCESS PARAMETERS

The objective of this work is to obtain optimal settings of turning process parameters to yield optimal Cutting forces. The selection of machining parameters was done based upon review of literature. The process parameters selected are cutting speed, feed and depth of cut.

3. TAGUCHI METHOD

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook [9]. Taguchi introduces his approach for designing products/processes so as to be robust to environmental conditions, designing and developing products/processes so as to be robust to component variation, and minimizing variation around a target value [9].

The method which is based on orthogonal array provides a significantly reduced variance for the experiment, resulting in the optimum setting of the process parameters. Orthogonal array provides a set of well-balanced experiments, with less number of experiment runs. This technique is used for the data analysis and in the prediction of the optimal results. The S/N ratio is the ratio of mean (signal) to the standard deviation (noise). The ratio depends on the characteristics of the product to be optimized. Standard S/N ratios are generally identified as the Smaller-the-better (SB), Nominal-the-best (NB), and Larger-the-better (HB). Signal to noise ratios, the log functions of desired output quality with emphasis on variation, provide a set of well-balanced experiments to accommodate many design factors simultaneously [10]. Liu et. al. [11] applied the Taguchi's parameter design approach to determine an ideal feed rate and desired force combination. Manoj Kumar Sahoo [12] reported the optimization of turning process parameters using Taguchi approach.

With the S/N, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. In this paper, equation (1) is used to calculate S/N ratio for cutting forces. Here, y denotes the measured value of Cutting forces in each trial and n denotes the number of observations in that trial.

$$\eta = -10 \text{ Log10 } (1/n \sum Yi2) \qquad \text{-- (1)}$$

Traditional experimental methods like full factorial experiments are very complicated and difficult to implement; as they require a large number of experiments [12]. To minimize the number of tests, Taguchi developed a particular design of orthogonal arrays to study the entire parameter space with small number of experiments.

4. EXPERIMENT SETUP

Turning has been done on centre lathe using tungsten carbide inserts available at Central Workshop of NIT Kurukshetra. After each experiment run a new carbide insert is used.

4.1 Workpiece Material

The work material selected for the study was 20MnCr5 alloy steel which was in the form of bar with a diameter of 35 mm and length of 290 mm. The main applications of 20MnCr5 are in making gear-boxes, piston, bolts, spindles, camshafts, gears, shafts, etc. The Chemical composition of the work material 20MnCr5 alloy steel is given in table 1:

Table 1: Chemical composition of 20MnCr5 steel alloy

ELEMENTS	WEIGHT (%)
Carbon	0.17-0.20
Silicon	Max 0 .4
Manganese	1.1-1.4
Phosphorus	Max 0.025
Sulphur	Max 0.035
Chromium	1.0-1.3

4.2 Process parameters and their levels

The Experimentation consists of turning of 20MnCr5 steel alloy on a centre lathe machine. The process parameters along with their 3 levels are given in table 2.

Table 2

Process parameters	Unit	Level1	Level2	Level3
Speed (s)	rpm	420	550	715
Feed (f)	mm/rev	0.04	0.06	0.08
Depth of cut(d)	mm	0.5	0.7	0.9

5. RESULTS AND ANALYSIS

Taguchi technique [13] is a powerful tool for identification of effect of various process parameters based on orthogonal array (OA) experiments which provides much reduced variance for the experiments with an optimum setting of process control parameters. In this work L9 array was used to carry out the experiment.

The response, Cutting forces, were measured by varying the machining parameters and the corresponding values are shown in table 3. MINITAB version 17 software is used.

Table 3: Experiment Results

Exp. No.	CONTROL PARAMETER LEVELS			Radial force (N)	Feed force (N)	Thrust force (N)
	Speed (s) (rpm)	Feed (f) (mm/rev)	Depth of cut (d) (mm)			
1	420	.04	0.5	2	7	10
2	420	.06	0.7	23	43	41
3	420	.08	0.9	10	79	64
4	550	.04	0.7	5	10	9
5	550	.06	0.9	7	34	32
6	550	.08	0.5	25	37	43
7	715	.04	0.9	5	10	16
8	715	.06	0.5	7	25	23
9	715	.08	0.7	19	57	50

Table4: ResponseforSignaltoNoiseRatio

Level	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	-27.93	-18.83	-24.73
2	-26.05	-28.68	-27.59

3	-26.72	.33.19	-28.39
Delta	1.88	14.37	3.66
Rank	3	1	2

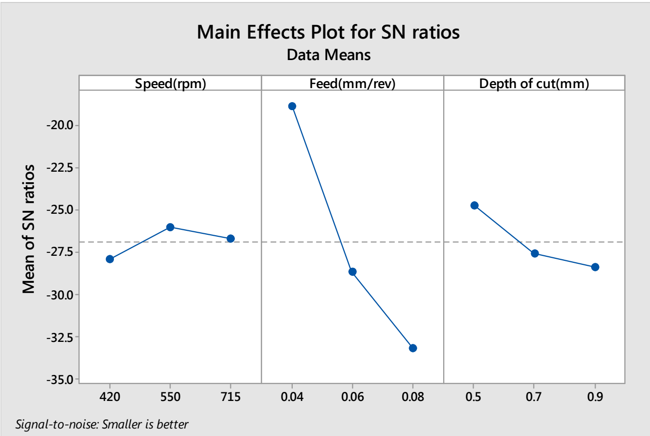

Fig. 1: Effects of process parameters on Cutting forces (SNRdata)

Table 5: Response Table for Means

Level	Speed (rpm)	Feed (mm/rev)	Depth of cut(mm)
1	31.000	08.222	19.889
2	22.444	26.111	28.556
3	23.556	42.667	28.556
Delta	8.556	34.444	08.667
Rank	3	1	2

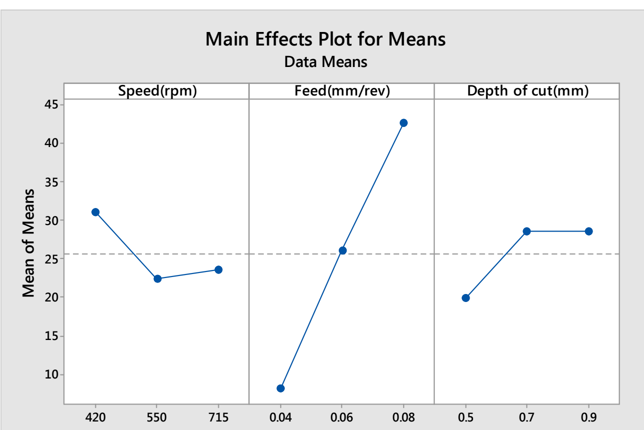

Fig. 2: Effects of process parameters on Cutting force (Mean data)

The Response tables for Signal to Noise ratio and for Means are shown in tables 4 and 5 respectively while the graphs shown in figure 1 and 2 represent the main effects plot for SN ratio and means respectively.

6. CONCLUSION

The following conclusions are drawn from the study:

(a) The optimal setting of process parameters in turning for minimum Cutting forces within the selected range is as follows:
(i) Depth of cut should be 0.5 mm.
(ii) Feed rate should be 0.04 mm/rev.
(iii) Speed should be 550 rpm.

(b) The results reveal that feed rate is the most influencing factor followed by depth of cut and cutting speed.

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