Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 11; April-June, 2015 pp. 5-8

http://www.krishisanskriti.org/jmsme.html

Optimization of Material Removal Rate during Dry Turning of EN 354 Alloy Steel Material using Taguchi Methods

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Abstract—*This paper focuses on optimizing turning process parameters for maximizing material removal rate (MRR) using Taguchi's parameter design approach. Experiments were conducted based on Taguchi's L9 orthogonal array. Dry turning experiments are carried out on EN 354 alloy steel bars with tungsten carbide cutting tool. Three cutting parameters— Cutting Speed, Feed rate and Depth of Cut— have been selected for investigation. The signal to noise ratio (SNR) and the analysis of variance(ANOVA) are applied to optimize process parameters for maximizing material removal rate. The confirmation experiment is also conducted at the predicted optimal setting of the process parameters and the average value is found to lie within 95% confidence interval.*

Keywords*: Material Removal Rate (MRR), ANOVA, Taguchi methods, Optimization, Dry Turning, Orthogonal array*

1. INTRODUCTION

Taguchi method is one of the most effective systems of off-line quality control where the quality is in-built at the product design stage instead of controlling it at the manufacturing stage or through the inspection of final products (Ross, 1996). 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 [1].

Akhyar et al. [2] used Taguchi method for optimization of cutting parameters in turning Ti-6%Al-4%V extra low interstitial with coated and uncoated cementedcarbide tools under dry cutting condition and highcutting speed. Kaladhar et. al. [3] investigated theeffect of turning process parameters on surface roughness of AISI 202 austenitic steel. It was revealed that the feed is themost significant parameter influencing surface roughness.

Negrete et.al. [4] optimized the cutting parameters for minimizing cuttingpower whereas Cayda [5] varied the cutting tool to evaluate the machinability of AISI 4340 steel.Mustafa Gunay and Emre Yucel [6]usedTaguchi technique for determining optimum surfaceroughness in turning of high-alloy white cast iron on CNC lathe using ceramic and cubic boron nitride (CBN)cutting tools.Dave et. al. [7] studied the effect ofmachining conditions on MRR and surface roughnessduring CNC turning of different grade of EN materials using TiN-coated cutting tools.Aggarwal and Singh [8] optimized the radial and feedforces in CNC machining of P-20 tool steel material using TiNcoated tungsten carbide inserts.Liu et. al. [9] applied the Taguchi's parameter design approach to determine an ideal feed rate and desired force combination; the experimental results indicated that surface roughness decreases with a slower feed rate and larger grinding force.

Themetal cutting studies focus on the features of tools, workmaterial composition and mechanical properties and all the machine parameter settings that influence the process efficiency and output qualitycharacteristics/responses. A significant improvement inprocess efficiency can be obtained by process parameteroptimization that identifies and determines the regionsof critical process control factors leading to desiredoutputs or responses with acceptable variations ensuringa lower cost of manufacturing. The performance of any machining process is evaluatedin terms of machining rate.

2. SELECTION OF PROCESS PARAMETERS

The objective of this work is to obtain optimalsettings of turning process parameters to yieldoptimal material removal rate (MRR). The selection of machining parameters was done based upon review of literature.The process parametersselected are cutting speed, feed and depth of cut.

3. TAGUCHI METHOD

Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The method is based on orthogonal arrays which provide a reduced variance and set of well-balanced experiments. Taguchi recommends the use of the loss function to measure the performance characteristicdeviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the performancecharacteristic in the analysis of the S/N ratio, that is, the lower-the-better, the higher-the-better, and the nominal-the-better. 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].

Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, 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 usedto calculate S/N ratio for material removal rate. Here, y denotes the measured value of MRR in each trial and n denotes the number of observations in that trial.

$$SNR(larger\ the\ better) = -10\log\frac{1}{n}\sum\frac{1}{y^2} \quad (1)$$

Traditional experimental methods like full factorial experiments are verycomplicated and difficult to implement; as they require a large number of experiments [11]. To minimize the number of tests, Taguchi developed aparticular design of orthogonal arrays to study the entireparameter space with small number of experiments.

4. EXPERIMENT SETUP

Turning hasbeen done on centre latheusing tungsten carbide insertsavailable 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 En354 steel. It is used in the manufacturing of forged gears, camshaft, and other heavy-duty machinery components.Chemical composition of the work material EN354 (SAE/AISI 4320) alloy steel is given in table 1:

Table 1: Chemical Composition of EN 354 alloy steel

Elements	Carbon	Silicon	Manganese	Sulphur	Phosphorus	Chromium	Molybdenum	Nickel
Range (in %)	0.20	0.35	0.50-1.00	0.04	0.04	0.75-1.25	0.10-0.20	1.50 - 2.00

4.2Process parameters and their levels

Experiment consists of dry turning of EN 354 steel alloy on a centre lathe machine. The process parameters along with their 3 levelsare given in table 2.

Table 2

Process Parameters	Unit	Level1	Level2	Level3
Speed (s)	Rpm	550	715	930
Feed (f)	mm/rev	0.05	0.07	0.10
Depth of cut (d)	Mm	0.4	0.6	0.8

5. RESULTS AND ANALYSIS

Taguchi technique [12] 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, material removal rate, was measured by varying the machining parameters and the corresponding values are shown in table 3. MINITAB version 17 software was used for analysis of variance (ANOVA).

Table 3: Experiment Results and SNR

Exp. No.	CONTROL PARAMETER LEVELS			MRR (mm3/min)	SNR
	Speed (s) (rpm)	Feed (f) (mm/rev)	Depth of cut (d) (mm)		
1	550	0.05	0.4	1253.09	61.9596
2	550	0.07	0.6	2476.27	67.8760
3	550	0.10	0.8	4612.53	73.2788
4	715	0.05	0.6	1786.55	65.0403
5	715	0.07	0.8	3225.01	70.1706
6	715	0.10	0.4	2473.37	67.8658
7	930	0.05	0.8	4354.24	72.7782
8	930	0.07	0.4	1332.49	62.4933
9	930	0.10	0.6	6349.71	76.0551

Table 4: ResponseforSignaltoNoiseRatio

Level	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	67.70	66.59	64.11
2	67.69	66.85	69.66
3	70.44	72.40	72.08
DELTA	2.75	5.81	7.97
RANK	3	2	1

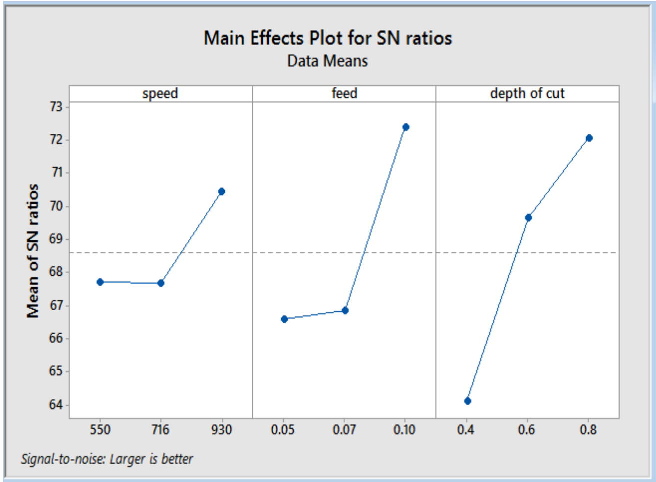

Fig. 1: Effects of process parameters on MRR (SNRdata)

Table 5: Response Table for Means

Level	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)
1	2781	2465	1686
2	2495	2345	3538
3	4012	4479	4064
Delta	1517	2134	2378
Rank	3	2	1

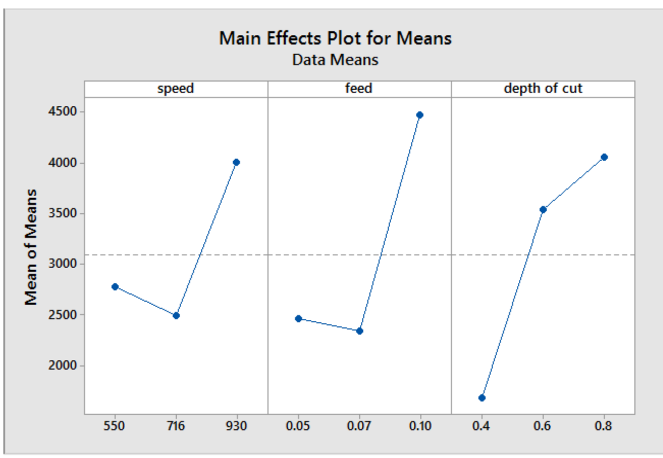

Fig. 2: Effects of process parameters on MRR (Mean data)

Table 6: ANOVA for MRR

Source	DF	Adj SS	Adj MS	F-Value	P-value
Speed	2	3900036	1950018	2.44	0.291
Feed	2	8623971	4311985	5.40	0.156
Depth of cut	2	9357061	4678530	5.86	0.146
Error	2	1597914	798957		
Total	8	23478981			
S= 893.844, R-sq=93.19%, R-sq (adj) = 72.78%					

6. ESTIMATION OF OPTIMUM VALUE OF MRR

The optimum value of material removal Rate (MRR) is predicted at the optimal levels of significant variables which have been selected as speed (s1), feed (f3)and depth of cut (d3).

The estimated mean of the response characteristic can be computed for material removal rate:

$$\mu_{MRR} = \overline{s3} + \overline{f3} + \overline{d3} - 2\mu \quad (3)$$

$$= 4012 + 4479 + 4064 - \ 2 \times 2953.69$$

$$= 6641.62 \ mm^3/\text{min}$$

Where μ = overall mean of MRR

$\overline{s3}$, $\overline{f3}$ and $\overline{d3}$ are taken from table 5.

For MRR, 95 % confidence interval of confirmation experiment[1] is calculated as:

$$CI = \sqrt{f_{0.5}(1, f_e) V_e \left[\frac{1}{N_{eff}}\right]} \quad (4)$$

$$= \pm 3391.78$$

Where, *fe*=2, is taken from ANOVA table 6,

$f_{0.5}$(1, 2)= 18.512 (taken from F- distribution table)

N_{eff}=N/(1+TotalDF associated in mean estimation)

= 9/(1+6)

=1.2857

V_e= Error of Adj MS= 798957

So the Confidence Interval is:

$3249.84 < \mu_{MRR} (mm^3/\text{min}) < 10033.4$

7. CONFIRMATION EXPERIMENT

In order to validate the results obtained, two confirmation experiments were conducted at optimal level of the process variables. The average value of the characteristics was obtained and compared with the predicted value. The average value of MRR was obtained 7013.56 mm^3/minwhich is within the 95% of confidence interval of response characteristic. It is to be pointed out that this optimal value is within the limit of process variables.

8. Conclusion

The following conclusions are drawn from the study:

(a) The optimal setting of process parameters in turning for maximum MRR within the selected range is as follows:

i) Depth of cut should be 0.8mm.

ii)Feed rate should be 0.1mm/rev.

iii) Speed should be 930 rpm.

(b) The predicted optimal range (95% CI) of the material removal rate is:

CI: 3249.84< μ_{MRR} ($mm^3/\min$) <10033.4

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