Optimization of Machining Parameters for Turned Parts through Taguchi's Method

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Abstract— The objective of the study is to achieve minimum requirement of radial force during machining of turned parts. This analysis presents the influence of process parameters (nose radius, cutting speed, feed rate and depth of cut) on the radial force as a response variable. For experimentation, an L_{18} Orthogonal Array (OA) of Taguchi design of experiment is used. EN-16 steel alloy is used as work material because this material has a wide range of applications in automotive industries etc. Carbide cutting inserts are used during experimentations. Furthermore, the analysis of variance (ANOVA) is also applied to find out the most considerable factor. The entire analysis work is carried out using Minitab-16 software. The optimal setting of parameters is: 3rd level of cutting speed, 1st level of feed rate and 1st level of depth of cut. Depth of cut is most significant factor and nose radius is insignificant factor. Finally confirmation experiments are done to verify the optimal results.

Key words: ANOVA, Minitab 16, Orthogonal Array (OA), Taguchi's Method, Radial force, Turning Operation

Nomenclature:

r	nose radius
v	cutting speed
f	feed rate (mm/rev.)
d	depth of cut (mm)
SS	sum of square
MS	mean square
DF	degree of freedom
F	fisher ratio
ANOVA	Analysis of variance
C.I.	confidence interval
Ve	variance of error term
Fe	error DF
R	number of repetitions
N	number of experiments

I. INTRODUCTION

Today, the goal of manufacturing industries is to make the products in low cost and high quality. But manufacturing industries face the problem of unavailability of optimal setting of machining parameter so; there is an enormous requirement to setting up the parameters for higher efficiency of the manufacturing industries. Performance characteristics of the experiments are highly influenced by machining parameters (nose radius, cutting speed, feed rate, depth of cut) so optimization study of turning is necessary to minimize the cutting force and for improving the quality of products. Optimization study also helps to in improving the tool life. In this study, Taguchi's approach is used to optimize machining parameters. Taguchi provides off line approach which can be used to improve the quality of product at a low cost. Taguchi's design of experiment is a fast and efficient method to find out the effect of parameters on the responses. Experiments have been performed based on standard L_{18} Orthogonal Array (OA). The selection of orthogonal array depends on (1) selection of process parameters and interactions to be estimated and (2) number of levels of selected parameters.

II. THEORETICAL ANALYSIS

A. *Mechanism of Cutting*

Work piece which is to be machined is clamped in the chuck and tool is clamped in the tool post. Tool is stationary and spindle of the lathe machine is rotated. As the tool makes contact with the work piece, it exerts a pressure on it, resulting in the compression of the metal near the tool tip. So, due to compression near the tool tip on the work piece, machining of work piece take place. During, machining of the bar various force acting on the bar as shown in fig. 2.

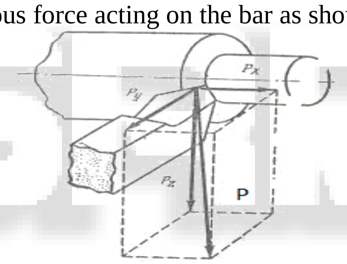

Fig. 2. Resolution of cutting forces

B. *Taguchi's Approach*

Taguchi's approach is used to obtain the optimum level of control parameters. This approach provides the facility of not performing many experiments because Orthogonal Array (OA) has a limited set of well-balanced experiments. Taguchi's Signal-to-noise ratio (S/N), is a log functions of desired response, perform as objective functions for optimization, helps in data study and predict the optimal result. According to Taguchi's method, the total degree of freedom of the selected orthogonal array must be greater than or equal to the total degree of freedom required for the experiment. Taguchi recommends the use of raw data and loss function to measure the deviation between the experimental value and the desired value which is further transformed into signal-to-noise ratio (S/N). Fundamentally, there are three types of categories in the evaluation of signal-to-noise ratio i.e. nominal-the-better (NB), higher-the-better (HB) and lower-the-better (LB).The aim of this investigation is to minimize the radial force. So lower-the-better characteristics is used to calculate the signal-to-noise ratio. The S/N ratio for this type of quality

Characteristic are calculated by this equation:

$$(S/N)\ ratio = -\frac{\log_{10}(Y_1^2 + Y_2^2 + Y_3^3 + \cdots \dots \dots \dots \dots + Y_n^2)}{n}$$

III. Experimental Parameters And Design

This investigation is carried out with four factors such as, Nose radius, cutting speed, feed rate, and depth of cut. Nose radius has two level and other three factors have three levels and radial force and are response variable in this study. Eighteen experiments runs based on the L_{18} Orthogonal Array are performed.

Level of experimental factors	Nose Radius (mm)	Cutting Speed (rpm)	Feed Rate (mm/rev)	Depth of Cut (mm)
1	0.2	420	0.04	0.3
2	0.4	490	0.08	0.5
3	-------	540	0.12	0.7

Table 1: Experimental Factors And Factor Levels

A. Selected Orthogonal Array

S.NO.	Nose Radius(r) (mm)	Cutting Speed (v) (rpm)	FEED RATE (f) (mm/rev.)	DEPTH OF CUT (d) (mm)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Table 2: The Basic Taguchi's L18 Orthogonal Array

B. Experiments and Results

Eighteen experiments are performed with different Cutting conditions to find out the optimal cutting parameters setting.

Work piece	EN- 16 Steel
Work piece Composition	C = 0.30 to 0.40%, Si = 0.10 to 0.35%, Mn = 1.30 to 1.80%, Mo = 0.20 to 0.35%, S = 0.05% and P = 0.05%
Environment	Wet Cutting
Size (mm)	Diameter = 26 mm and length =600 mm
Machine Tool	HMT Lathe Machine

Table 3: Experimental Details

S. no.	Radial force (kg) R_1	Radial force (kg) R_2	Radial force (kg) R_3	Radial force (kg) Mean Value	S/N Ratio
1	2	2	2	2	-6.020
2	5	3	4	4	-12.218
3	8	4	6	6	-15.873
4	2	2	2	2	-6.020
5	6	7	4	6	-15.642
6	7	5	9	7	-17.132
7	6	5	4	5	-14.093
8	4	4	4	4	-12.041
9	4	4	4	4	-12.041
10	8	10	6	8	-18.239
11	5	7	6	6	-15.642
12	11	7	9	9	-19.225
13	5	6	7	6	-15.642
14	9	11	7	9	-19.225
15	6	7	8	7	-16.960
16	8	7	9	8	-18.106
17	5	4	6	5	-14.093
18	7	5	6	6	-15.642

Table 4: Experimental Results And Corresponding S/N Ratio

Average Radial Force ($\bar{T}_{TF}$) = 5.776

C. Analysis Procedure and Discussion

The experiments are performed to find out the influence of nose radius, cutting speed, feed rate, and depth of cut on the radial force. The following graphs and tables indicate the effects of parameter on the response. From fig. 4, it can be noticed that radial Force is minimum at the 1^{st} level of nose radius, 3^{rd} level of cutting speed, and 1^{st} level of feed rate and depth of cut. Effect of machining parameters can be seen in table 6 when nose radius is increased from 0.2 mm to 0.4 mm, radial force increases from 4.444 kg to 7.111 kg. When cutting speed is increased from 420 rpm to 490 rpm then radial force increases from 5.833 kg to 6.167 kg. But as cutting speed is increase from 420 rpm to 540 rpm then cutting force decreases from6.167 kg to 5.533 kg. As feed rate is increase from 0.04 mm/rev. to 0.08 mm/rev. then radial force increases from 5.167 kg to 5.667 kg. and when feed rate is increase from 0.08 mm/rev. to 0.12 mm/rev. then radial force increases from 5.667 kg to 6.500 kg. When depth of cut is increase from 0.3 mm to 0.5 mm, radial force increases from 4.333 kg to 6.000 kg and when depth of cut is increase from 0.5mm to 0.7 mm, radial force increases from 6.000 kg to 7.000 kg.

Level	Nose Radius	Cutting Speed	Feed Rate	Depth of cut
1	-12.34	-14.54	-13.02	-11.80
2	-16.98	-15.10	-14.81	-15.41
3	----	-14.34	-16.15	-16.77
Rank	2	3	4	1

Table 5: Response Table for S/N Ratio of Radial Force.

Level	Nose Radius	Cutting Speed	Feed	Depth of cut
1	4.444	4.833	5.167	4.333
2	7.111	6.167	5.667	6.000
3	-----	5.333	6.500	7.000
Delta	2.667	0.833	1.333	2.667
Rank	2	4	3	1

Table 6: Response Table for Means of Radial Force

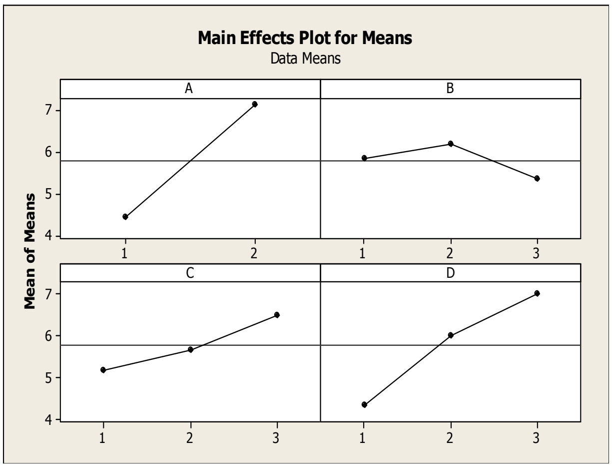

Fig. 4: Radial Force Main Effects Plot for Means

D. Analysis of Variance (ANOVA)

The percentage contribution of selected process parameters on the selected performance characteristic can be estimated by performing analysis of variance test.

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P	%Con.
A	1	96.000	96.000	96.000	47.31	0.000	34.61
B	2	6.333	6.333	3.167	1.56	0.221	2.28
C	2	16.333	16.333	8.167	4.03	0.024	5.89
D	2	65.333	65.333	32.667	16.10	0.000	23.56
Error	10	93.333	93.333	2.029			
Total	17	277.333					

Table 7: Analysis Of Variance for Means

Individual contribution of all the selected process parameter can be found out by ANOVA table for Means (table 7). The percentage contributions in affecting variation in radial force are: nose radius (34.61%), cutting speed (2.28%), feed rate (5.89%), depth of cut (23.56%).

IV. ESTIMATING OPTIMAL RADIAL FORCE

The experiments are performed to find out the influence of process parameters on the radial force. From this investigation, it is noticed that 1^{st} level of nose radius, 1^{st} level of feed rate and 1^{st} depth of cut are the optimal levels of parameters.

The estimated mean of the response characteristic can be calculated as:

$$\mu_{TF} = \bar{T}_{TF} + (\bar{A}_1 - \bar{T}_{TF}) + (\bar{C}_1 - \bar{T}_{TF}) + (\bar{D}_1 - \bar{T}_{TF})$$

Where,

$\bar{T}_{FF}$ = 5.776; Overall mean of radial force

$\bar{A}_1$ = 4.444 kg; Average value of Radial Force at the first level of cutting speed

$\bar{C}_1$= 5.167 kg; Average value of Radial Force at the first level of feed rate

$\bar{D}_1$= 5.776 kg; Average value of Radial Force at the first level of depth of cut

Hence,

μ_{TF} = 2.392

A confidence interval for the predicted mean on a confirmation run can be calculated as using the following equation:

$$C.I. = \sqrt{Fa(1, fe)Ve\left[\frac{1}{neff} + \frac{1}{R}\right]}$$

Where,

V_e = 2.029; Variance of error term

f_e = 46; Error DOF

R = 3 number of repetitions for confirmation experiments

Effective number of replications (n_{eff}) is calculated using equation given below:

$$n_{eff} = \frac{N}{1+[Total\ DOF\ associated\ in\ the\ estimate\ of\ the\ mean]}$$

Where,

N = (3x18) = 54; Total number of experiments

Total DOF associated with the estimation of mean

= (1+2+2+2) = 7

Therefore, n_{eff} = 54/8 = 6.75

Tabulated F-ratio at 95% confidence level (α= 0.05): $F_{0.05(1,46)}$ = 4.0157

So,

CI_{CE} = ±1.988

The predicted mean of radial force is: μ_{TF} = 2.392

The confidence interval of the predicted optimal radial force is:

$[\mu_{TF} - CI] < \mu_{TF} < [\mu_{TF} + CI]$

$0.404 < \mu_{TF}$ (kg) < 4.38

The optimal values of process variables at their selected levels are as follows:

r_1 =540 rpm

f_1 = 0.04 mm/ rev

d_1 = 0.3 mm

V. Confirmation Experiment

This investigation recommends the optimal level of parameters on which three confirmations experiment have been performed. The mean value of radial force was found to be 2.392 kg. This result is in the C.I. of the predicted optimum radial force.

VI. Conclusions

(1) The optimal setting of process parameter is: 1st level of nose radius, 1st level of feed rate and 1st level of depth of cut.
(2) The percentage contributions of nose radius, cutting speed, feed rate, depth of cut in affecting variation in radial force while machining EN-16 steel alloy with carbide inserts are: depth of cut (23.56%), feed (5.89%), cutting speed (2.28%) and nose radius (34.61%).
(3) Nose radius has a large influence on radial force followed by depth of cut, feed rate, cutting speed.
(4) From ANOVA table 7, it is noticed that cutting speed is insignificant factor.
(5) The predicted optimal range of the radial force is:

CI: $0.404 < \mu_{TF}$ (kg) < 4.38

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