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Optimization of Cutting force in Turning AISI 1040 Steel: Using Taguchi Orthogonal Array and Genetic Algorithm

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Abstract

Turning is the well-known material removal process that removes the unwanted material from the outer diameter of the rotating cylindrical work piece. The cutting tool is moved parallel to the axis of rotation. In the turning process, a cutting force is generated by the cutting tool as it machines the work piece and it has the great effect on the machinability. The objective of this paper is to select an optimal combination of process parameters (Spindle Speed, Feed rate and Depth of cut) turning operation, resulting is an optimal value of cutting force. Taguchi orthogonal array and genetic algorithm is used for designing a high quality system. Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. In this paper Taguchi orthogonal array method and genetic algorithm is used to find the best combination of the machining parameters which gives optimal cutting force. Taguchi orthogonal array has been designed with three levels of these cutting parameters by using Minitab 16 software. Analysis of variance (ANOVA) is also conducted to determine the performance of experimental measurements and the effects of different parameters. For optimal value of cutting force, a correlation is established between cutting speed, Feed and depth of cut by regression analysis. Finally compare these results with the experimental result.

Keywords: Turning, Taguchi orthogonal array, ANOVA, Linear Regression, Genetic Algorithm.

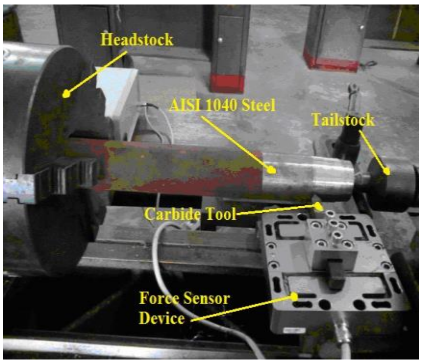
1. Introduction

Turning is a form of machining or a material removal process which is used to create rotational parts by cutting away unwanted material. Turning is the most widely used among all the cutting processes. The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts , The cost of machining amounts to more than 20% of the value of manufactured products in industrialized countries. Cutting force of turned components has greater influence on the quality of the product. Cutting force in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time and tool nose radius. Many studies have been made using Taguchi Method to optimize the turning parameter. Tarng. Y.S , S.C. Juang and C.H. Chang [1] proposes the use of grey-based Taguchi methods for the optimization of the Submerged Arc Welding (SAW) process parameters in hard facing with considerations of multiple weld qualities. They found that a grey relational analysis of the S/N ratios can convert the optimization of the multiple performance characteristics into the optimization of a single performance characteristic called the grey relational grade. Vijayan. P and V. P. Arunachalam [2] reported research in their work Taguchi‗s off-line quality control method applied for determines the optimal process parameters which maximize the mechanical properties of squeeze cast LM24 aluminum alloy. For this purpose, concepts like orthogonal array, S/N ratio and ANOVA were employed. Nihat Tosun Cogun and Gul Tosun [3] investigated the effect and optimization of machining parameters on the kerf (cutting width) and material removal rate (MRR) in wire electrical discharge machining (WEDM) operations. The experimental studies were conducted under varying pulse duration, open circuit voltage, wire speed and dielectric flushing pressure. The settings of machining parameters were determined by using Taguchi experimental design method. The level of importance of the machining parameters on the cutting kerf and MRR was determined by using analysis of variance (ANOVA). The optimum machining parameter combination was obtained by using the analysis of signal-to-noise (S/N) ratio. The variation of kerf and MRR with machining parameters is mathematically modeled by using regression analysis method. Sahoo. P. [4] used Response Surface Methodology (RSM) to develop a predictive

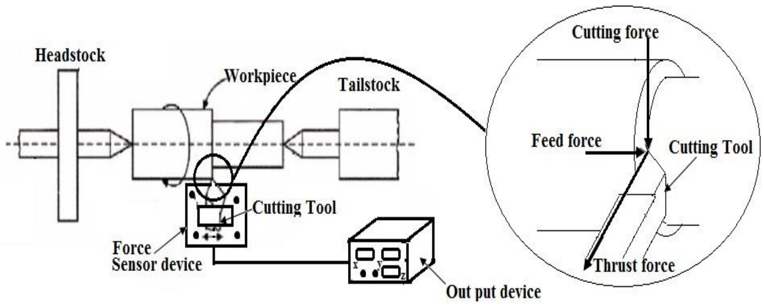
model of surface roughness in terms of machining parameters in turning based on experimental results and then used Genetic algorithm (GA) to optimize the machining parameter that results minimum surface roughness.
Saha [5] used genetic algorithm (GA) to obtain the optimum cutting parameters by minimizing the unit production cost for a given amount of material removal for the multi-pass face milling process. The cutting parameters optimized were: cutting speed, feed and depth of cut. Hasan Oktem ,Tuncay Erzurumlu and Mustafa C [6] developed a Taguchi optimization method for low surface roughness in terms of process parameters when milling the mold surfaces of 7075-T6 aluminum. Considering the process parameters of feed, cutting speed, axial and radial depth of cut, and machining tolerance, they performed a series of milling experiments to measure the roughness data. Regression analysis was performed to identify whether the experimental measurements represent a fitness characteristic for the optimization process. It is therefore imperative to investigate the machinability behavior of different materials by changing the machining parameters to obtain optimal results. The machinability of a material provides an indication of its adaptability to manufacturing by a machining process. Good machinability is defined as an optimal combination of factors such as low cutting force, good surface finish, low tool tip temperature, and low power consumption. Process modeling and optimization are the two important issues in manufacturing products. S/N ratio analysis is performed to find the optimum level of the optimum machining parameters from the experimentation is obtained. ANOVA is used to find the percentage of contribution of each parameter. Linear Regression model is used to find the relationship between their control and response parameters and correlations between them. Optimization algorithm is the process that is executed iteratively by comparing various solutions until the optimum or satisfactory solution. Accepting the best solution after comparing a few design solutions is the way of achieving optimization in many industrial design activities. Taguchi parameter design approach and Genetic Algorithm (GA) is used here to optimize the machining parameters. The selection of optimal cutting parameters, like depth of cut, feed and speed is a very important issue for every machining process, hence, the objectives of this paper is to find the best combinations of cutting parameters like speed (N), feed (f), depth of cut (d) to get the optimal cutting force and finally compare these results with the experimental results.

2. Experimental setup and conditions

For the measuring cutting force the experiments are carried out on a lathe machine which is origin in Sweden and the motor power of lathe is 3500 watt. A Photographic and schematic view of experimental setup shown in Fig.1 (a) and (b) respectively. In this experiment three different types of the force are measured with a Cutting force measurement device which is called Dynamometer, produce by Gunt Humburg Co. (Model no. FT-102).



(a)



(b)

Fig. 1 (a) Photographic and (b) Schematic view of Experimental Setup.

Cutting condition for the experimental setup is given below:
Cutting Environment : Dry
Work piece dimension: Diameter 50 mm and Length 400mm
Cutting tool : v type carbide insets
Cutting tool geometry : Side cutting edge angle-65 degree; End cutting edge angle-65 degree;
Nose radius-50 degree; Side relief angle-4 degree; End relief angle-4 degree

3. Taguchi orthogonal arrays of 3r rows for r = 2

There is an experiment having 3 factors which have three levels, then total number of experiment is (3^3) = 27. Then results of all experiments will give 100 accurate results. In Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 27 with almost same accuracy. A complete three-element orthogonal array with 3^r rows has $(3^r-1)/(3-1)$ columns and it is constructed in three steps:

Step 1: Write in the r columns specified by column numbers 1,2,5,14,..., $(3^r-1)/(3-1)+1$ a complete factorial plan in r factors each having three test levels represented by 0,1, and 2, respectively. In order to match Taguchi's display format, write this plan in such a way that the entries of the left-most columns change less frequently than do the entries of the right-most columns. Mark these columns as x_1, x_2, x_3,……., x_r respectively.

Step 2: As before the generators of the remaining columns are of the form $a_1x_1+a_2x_2+………+a_3x_3$ where x_1, x_2, x_3, …………x_r denote the r basic columns and the coefficients a a_1, a_2, a_3………, a_r for a particular column are given in the appropriate row of table . List the generators in the order of column numbers.

Step 3: Compute the entries of the remaining columns by using the entries of the r basic columns and the appropriate generators. All calculations are done in module 3 arithmetic. All these steps are shown in the Table 1, Table 2 ,Table 3 and Table 4.

Table 1: Coefficients of the generators of two-element orthogonal arrays of *2'* rows for r = 2

Column no	a_1	a_2	Column no	a_1	a_2	
1	1	0	7	2	0	First$(3^{r-1})/(3-l)$ entries are 0
2	0	1	8	0	1	Next (3^{r-1}) entries are 1
3	1	1	9	1	1	Next (3^{r-1}) entries are 0
4	2	1	10	2	1	Next (3^{r-1}) entries are 1
5	0	0	11	0	2	Next (3^{r-1}) entries are 2
6	1	0				

Construction of an OA9 (3^3) Here N = 9= 3^2 so r =2.

Step 1: Write the r = 2 basic columns

Table 2: Basic column

Column No. / Row No.	1	2	3
1	0	0	-
2	0	1	-
3	0	2	-
4	1	0	-
5	1	1	-
6	1	2	-
7	2	0	-
8	2	1	-
9	2	2	-

Step 2: List the generators (see rows 1 to 3)

Table 3: Generators

Column no	Generator
1	x_1
2	x_2
3	x_1+x_2

Step 3: Complete the array (Column No. 3) using the generators identified in step 2.

Table 4: Complete Array

Column No. / Row No.	1	2	3
1	0	0	0
2	0	1	1
3	0	2	2
4	1	0	1
5	1	1	2
6	1	2	0
7	2	0	2
8	2	1	0
9	2	2	1

4. Experimental data analysis

In the experiment, three cutting parameters (Speed, Feed and Depth of cut) are considered with three different levels. All these cutting parameters with different level is shown in the Table 5.

Table 5: Cutting Parameters

Level	Speed in rpm	Feed in mm/rev	Depth of cut in mm
1	395	0.12	0.4
2	490	0.14	0.7
3	650	0.16	1

Taguchi method stresses the importance of studying the response variation using the signal-to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The Cutting force was considered as the quality characteristic with the concept of "the smaller-the-better". That is, it will be better if there is produced lower cutting force for turning operation. The S/N ratio for the smaller-the-better is given by the equation (i).

$$S/N = -10\log_{10}\sum_{i=1}^{n}(y_i^{2}/n) \qquad \text{(i)}$$

Where, n is the number of measurements in a trial and y is the measured value in a run. The S/N ratio values are calculated by taking into consideration the above equation and with the help of software Minitab 16. Three different types of cutting force (Feed force, Thrust force and Axial force) at different level with S/N ratio are shown in Table 6.

Table 6. Experimental data and S/N ratios for Cutting Force

Experiment No.	Speed, V in rpm	Feed, f in mm/rev	Depth of cut, D in mm	Cutting Force				S/N ratio
				F1 in KN	F2 in KN	F3 in KN	Mean F in KN	
1	395	0.12	0.4	0.10	0.09	0.10	0.096667	20.2841
2	395	0.14	0.7	0.17	0.19	0.17	0.176667	15.0446
3	395	0.16	1.0	0.19	0.19	0.18	0.186667	14.5759
4	490	0.12	0.7	0.15	0.13	0.11	0.13	17.6531
5	490	0.14	1.0	0.20	0.19	0.18	0.19	14.4169
6	490	0.16	0.4	0.11	0.14	0.13	0.126667	17.9048
7	650	0.12	1.0	0.14	0.13	0.15	0.14	17.0627
8	650	0.14	0.4	0.10	0.09	0.12	0.103333	19.6524
9	650	0.16	0.7	0.17	0.15	0.14	0.153333	16.2586

5. Result analysis and discussion

Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore the optimal level of the machining parameters is the level with the greatest value.
Using Minitab-16 Table 7 and Table 8 are found.

Table 7. Response for S/Noise Ratios of Cutting Force

Level	Speed	Feed	Depth of cut
1	16.63	18.33	19.28
2	16.66	16.37	16.32
3	17.66	16.25	15.35
Delta	1.03	2.08	3.93
Rank	3	2	1

Table 8. Response for Means of Cutting Force

Level	Speed	Feed	Depth of cut
1	0.1533	**0.1222**	**0.1089**
2	0.1489	0.1567	0.1533
3	**0.1322**	0.1556	0.1722
Delta	0.0211	0.0344	0.0633
Rank	3	2	1

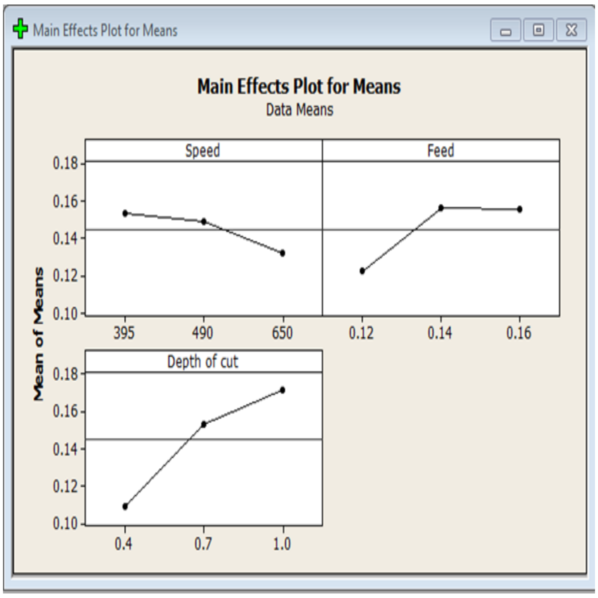


Fig. 2. Mean of cutting force form Data

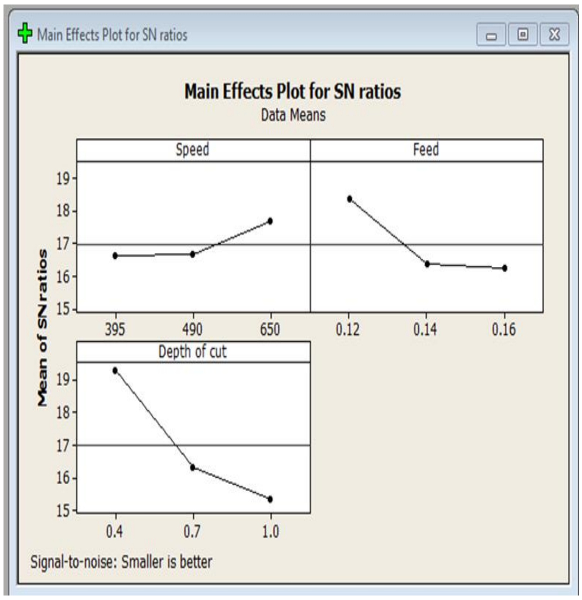


Fig. 3. S/N ratio of cutting force form Data

From Fig. 2. & Fig. 3. it is clear that cutting force is minimum at the 3rd level of cutting parameter speed (V), 1st level of parameter feed (f) and 1st level of cutting parameter depth of cut (D). The effect of cutting parameters are shown that when the speed is increased from 395 rpm to 650rpm, cutting force is decreased from 0.1533 KN to 0.1322 KN, when the feed rate is increased from 0.12 mm/rev to 0.16 mm/rev, cutting force is increased from 0.1222 KN to 0.1556 KN, when the depth of cut is increased from 0.4 mm to 1 mm, cutting force is also increased from 0.1089 KN to 0.1722 KN. So the best combinations of cutting parameters feed, speed and depth of cut to get the optimal cutting force are given below:

Spindle Speed: The effect of parameters spindle speed on cutting force values is shown above figure for S/N ratio. Its effect is increasing with increase in spindle speed. So optimum spindle the speed is level 3 i.e. 650 rpm.

Feed Rate: The effect of parameters feed rate on cutting force values is shown above figure S/N ratio. Its effect is decreasing with increase in feed rate. So the optimum feed rate is level 1 i.e. 0.12 mm/rev.

Depth of Cut: The effect of parameters depth of cut on cutting force values is shown above figure for S/N ratio. Its effect is decreasing with increase in depth of cut. So the optimum depth of cut is level 1 i.e. 0.4 mm.

From the above, the best combination of cutting parameters (speed, feed and depth of cut) is (650,.12,.4).

Analysis of variance (ANOVA) is the application of a statistical method to identify the effect of individual cutting parameter. Results from ANOVA can determine very clearly the impact of each cutting parameter on the process results. Table 9 shows the analysis of variance with arithmetic average of cutting force. This analysis is carried out for a 5% significance level i.e. for a 95% confidence level.

Table 9. ANOVA data table for Cutting Force

Source	DOF	SS	MS	F ratio	P	Contribution %
Speed	2	0.0007432	0.0003716	7.00	0.125	7.83
Feed	2	0.0022988	0.0011494	21.65	0.044	24.22
Depth of cut	2	0.0063432	0.0031716	59.74	0.016	66.83
Error	2	0.0001062	0.0000531			1.12
Total	8	0.0094914				

From the ANOVA Table 9 of Cutting Force with the suitable F values and contributions of the Factors for 95% confidence level show that the Depth of cut (F = 59.74 and 66.83%) and Feed (F=21.65 and 24.22%) are the two significant factors and other factor Speed (F = 7.00 and 7.83%) is the factor found to be insignificant.

5.1 Predicted cutting force for Taguchi method

The predicted cutting force at the optimal levels are calculated by using the following equation:

$$Y_{predicted} = Y_{\exp} + \sum_{n=1} (Y_{im} - Y_{\exp}) \qquad \text{(ii)}$$

Where, Ypredicted - Predicted response value after optimization, Y_{exp}-Total mean value of quality characteristics, Y_{im} - Mean value of quality characteristic at optimal level of each parameter and i - Number of main machining parameters that affect the response parameter.

So, Ypredicted (Cutting force) = 0.1448 + (0.1322 – 0.1448) + (0.1222 – 0.1448) + (0.1089 – 0.1448)

= **0.0737 KN**

5.2 Regression model

The experimental results are used to obtain the mathematical relationship between process parameters (Speed, Feed and Depth of cut) and machine outputs(Cutting Force). The co-efficient of mathematical models is computed using method of general linear regression. For the linear regression equation minitab-16 software is used.

Table 10. Co-efficient of Linear Regression

Predictor	Co-efficient
Constant	-0.0022
Speed	-0.000085
Feed	0.833
Depth of cut	0.106

So the regression equation of Cutting Force, F = - 0.0022 - 0.000085 V + 0.833 f + 0.106 D

5.3 Predicted cutting force for regression model

For the optimal level of machining parameters V=650 rpm, f=0.12 mm/rev and D=0.4 mm. So the Cutting Force of the regression model is-

F = (- 0.0022 - 0.000085 *650 + 0.833 * 0.12 + 0.106 *0.4) = **0.08491 KN**

5.4 Cutting force for genetic algorithm based optimization

GA-based approaches are used for optimization of machining parameters. From the observed data for Cutting Force, the response function has been determined using Regression Model and fitness function is defined as

Minimizing, Cutting force (F) = - 0.0022 - 0.000085 V + 0.833 f + 0.106 D

Subject to:

395 rpm ≤ V ≤ 650 rpm;

0.12 mm/rev ≤ f ≤ 0.16 mm/rev; and

0.4 mm ≤ D ≤ 1 mm;

xil ≤ xi ≤ xiu

where xil and xiu are the upper and lower bounds of process variables xi, x1, x2, x3 are the cutting speed, feed, depth of cut respectively. Form this formulation and using MATLAB, the result of the fitness function and the variables is shown below in Table 11.

Table 11. Output value of the Genetic Algorithm

Machining Parameters	Output of Genetic Algorithm Method
Speed , V in rpm	647.0841
Feed , f in mm/rev	0.12
Depth of cut , D in mm	0.4
Minimum Cutting force , F in KN	0.08516

5.5 Comparisons of the results

The outcome of the calculations and formulation for the optimization of cutting force by the methods i.e. Prediction by Taguchi Method, Regression model and Genetic Algorithm is shown in Table 12. By using the optimal factor level combination suggested by Taguchi Methodology the experiments are conducted. It is found that the optimum experimental cutting force is 0.08333 (KN)

Table 12. Comparison of the Results of Cutting Forces by different methods

	Taguchi Method	Linear Regression Model	Genetic Algorithm	Experimental
Cutting Force	0.0737 (KN)	0.08491(KN)	0.08516(KN)	0.08333(KN)
Best Combination (V , f , D)	650 , 0.12 , 0.4	650 , 0.12 , 0.4	647.084, 0.12, 0.4	650 , 0.12 , 0.4

6. Conclusion

Several conventional techniques are used in the turning process for machining optimization problems. Taguchi L9 orthogonal array GA method is used in this paper for optimizing cutting parameters. In the Orthogonal array, the best combination of cutting parameters is obtained and the result is spindle speed, feed rate and depth of cut respectively 650 rpm, 0.12mm/rev and 0.4mm. From ANOVA it is also found that the Depth of cut has 66.83% and feed has24.22% contribution on cutting force. Optimum cutting force using Regression analysis model and GA is found 0.08491 KN and 0.085682 KN respectively. The experimental cutting force for the best combination of cutting parameters is 0.08333 KN.

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