

Optimization of Cutting Parameters During Turning of AISI 1018 using Taguchi Method

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Abstract: This paper presents an optimization method of cutting parameters (cutting speed, feed rate and depth of cut) during turning of AISI 1018 mild steel to achieve the Maximum Material Removal Rate (MRR) and the Minimum Surface Roughness (SR). The design of experiment is based on the Taguchi's L₉ (3³) Orthogonal array technique and analysis of S/N ratio was performed to identify the effect of the cutting parameters on the response variables. The taguchi method is used to optimize cutting parameters for the material removal rate (MRR) and the surface roughness surface. The main effect plots are then generated and then analysed to find the relationship between the cutting parameter and variables. The detailed of the design of experimentation and the analysis are given in the following data

Keywords: Taguchi Method, Orthogonal Array, Material Removal Rate(MRR), Surface Roughness(SR), S/N Ratio and Minitab.

I. INTRODUCTION

Metal cutting is one in all the necessary and widely used producing processes in engineering industries. The metal cutting studies focus on the features of tools, work material composition and mechanical properties, and above all the machine parameter settings that influence the process efficiency and output quality characteristics (or responses). A significant improvement in method potency may be obtained by method parameter improvement that identifies and determines the regions of crucial method management factors resulting in desired outputs or responses with acceptable variations guaranteeing a lower value of producing.

The primary objective in machining operations is to produce products with low Surface Roughness and high Material Removal Rate(MRR). Machining parameter optimization plays an important role in achieving this goal. Machining parameter optimization operations usually involves the optimal selection of cutting speed, feed rate and depth of cut. Determination of optimal cutting parameters for satisfying certain technological and economical conditions has been one of the most important elements in process planning for metal cutting operations. Examining the economics of machining operations has significant practical importance. Machining is outlined as a method, during which the metal is removed within the kind of chips by means that of single or multiple wedge-shaped cutting tools. Spindle speed :The rotational speed of the spindle and the work piece in revolutions per minute (RPM). The spindle speed is nothing but the cutting speed / circumference of the work piece where the cut is done. Feed rate :The speed of cutting tool' movement relative to the work piece as the tool makes a cut. The feed rate is measured in (mm/min).Depth of cut :A large depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. For rough turning depth of cut is not matters because it is not dealing with surface quality.

II. RESEARCH METHODOLOGY AND APPROACH

A. Taguchi Method

Taguchi is the developer of the Taguchi method. He projected that engineering optimization of a processed product to be meted out in an exceedingly three-step approach, as follows.

- 1) System design: In system design, the engineer applies scientific and engineering knowledge to produce a basic functional design prototype, this design including the product design stage and the process design stage.
- 2) Parameter design: The objective of parameter design is to optimize the settings of the process parameter values for improving quality characteristics and to identify the product parameter values under the optimal process parameter values.
- 3) Tolerance design: Tolerance design is used to determine and analyze tolerances for the optimal settings recommend by the parameter design. Tolerance design is required if the reduced variation obtained by the parameter design does not meet the

required performance, and involves tightening tolerances on the product parameters or process parameters that variations lead to an outsized negative influence on the desired product performance.

III. FLOW CHART

To workout this design of experiment, The Taguchi design parameter is used and for the taguchi design parameter consists of following processes for Taguchi design parameter to approach.

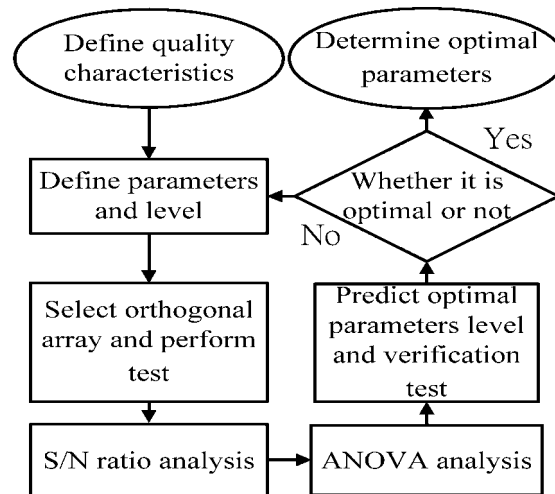


Fig. Flow chart of Taguchi's Method for Optimization

IV. ANALYSIS FOR SELECTED CUTTING PARAMETERS

Following steps are followed to reach the required experimental design of cutting parameters as follows,

A. Orthogonal Array Experiment:

The experimental design for the three cutting parameters and three levels using the L9 orthogonal array is shown in Table . The L9 orthogonal array has three columns, and three levels. L9 Orthogonal Array is selected on the basis of number of parameters and levels i.e, three number of parameters and three number of levels.

In selecting an appropriate OA, the following prerequisites are required:

1. Selection of process parameters and/or their interactions to be evaluated.
2. Selection of number of levels for the selected parameters.

The determination of which parameters to investigate, hinges upon the product or process performance characteristics or responses of interest (Ross, 1996). Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are (Ross, 1996): a. Brainstorming b. Flow charting c. Cause-effect diagrams The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increase because the DOF of a parameter is the number of levels minus one. Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment (Ross, 1996). If curved or higher order polynomial relationship between the parameters under study and the response is expected, at least three levels for each parameter should be considered (Barker, 1990). The standard two-level and three level arrays (Taguchi and Wu, 1979) are: a) Two-level arrays: L4, L8, L12, L16, L32 b) Three-level arrays: L9, L18, L27 The number as subscript in the array designation indicates the number of trials in that array. The degrees of freedom (DOF) available in an OA are: $f = LN - 1$ where $LN = f = \text{total degrees of freedom of an OA}$ $LN = \text{OA designation}$ $N = \text{number of trials}$ When a particular OA is selected for an experiment, the following inequality must be satisfied (Ross, 1996): $LN - f \geq \text{Total DOF required for parameters and interactions}$. Depending on the number of levels in the parameters and total DOF required for the experiment, a suitable OA is selected. Walia et al. (2006, 2006a, 2006b, 2006c) successfully employed Taguchi technique for optimizing the parameters of

Centrifugal Force assisted Abrasive Flow Machining (CFAFM) process. Singh et al. (2011, 2010, 2008) successfully optimized the process parameters of Ceramic Shell Investment Castings using Taguchi method.

B. Analysis of the S/N Ratio:

Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. The S/N ratio n is defined as,

$$n = -10 \log (\text{M.S.D.}) \quad (1)$$

Where M.S.D. is the mean-square deviation for the output characteristic. As mentioned earlier, there are three categories of quality

characteristics, i.e. the-lower-the-better, the higher-the-better, and the-nominal-the-better. To obtain optimal cutting performance,

the-higher-the-better quality characteristic for material removal rate must be taken. The mean-square deviation (M.S.D.) for the higher-the-better quality characteristic can be expressed as:

$$\text{M.S.D.} = 1/m \sum 1/T_i^2 \quad (2)$$

Where m is the number of tests and T_i is the value of material removal rate and the i th test. On the other hand, the-lower-the-better

quality characteristics for surface roughness should be taken for obtaining optimal cutting performance. The M.S.D. for the the-lower-the-better quality characteristic can be expressed as:

$$\text{M.S.D.} = 1/m \sum s_i^2 \quad (3)$$

Where S_i is the value of surface roughness for the i th test. Regardless of the-lower-the-better of the higher-the-better quality characteristic, the greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value. This is

to accomplished by separating the total variability of the SIN ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations

SST from the total mean SIN ratio \bar{n}_m can be calculated as:

$$SS_T = \sum (n_i - \bar{n}_m)^2 \quad (4)$$

Where n is the number of experiments in the orthogonal and n_i is the mean S/N ratio for the i th experiment. The total sum of squared deviations SS_T is decomposed into two sources: the sum of squared deviations SS_d due to each design parameter and the sum of squared error SS_e . The percentage contribution % by each of the design parameters in the total sum of squared deviations SS_T is a ratio of the sum of squared deviations SS_d due to each design parameter to the total sum of squared deviations SS_T .

MSD denotes mean square deviation, which presents the average of squares of all deviations from the target value rather than around the average value.

Taguchi transformed the loss function into a concurrent statistic called S/N ratio, which combines both the mean level of the quality characteristic and variance around this mean into a single metric (Ross, 1996; and Barker, 1986). The S/N ratio consolidates several repetitions (at least two data points are required) into one value. A high value of S/N ratio indicates optimum value of quality with minimum variation. Depending upon the type of response, the following three types of S/N ratio are employed in practice (Byrne and Taguchi, 1987).

1. Larger the better: 2. Lower the better: 3. Nominal the best:

It is to be mentioned that for nominal the best type of characteristic, the standard definition of MSD has been used. For smaller the better type the target value is zero. For larger the better type, the inverse of each large value becomes a small value and again the target value is zero. Therefore, for all the three expressions the smallest magnitude of MSD is being sought. The constant 10 has been purposely used to magnify S/N number for each analysis and negative sign is used to set S/N ratio of larger the better relative to the square deviation of smaller the better.

C. Confirmation Tests:

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. The estimated S/N ratio n^* using the optimal level of the design parameters can be calculated as,

$$n^* = n_m + \sum_{i=0}^0 (n_i - n_m)$$

Where n_m is the total mean S/N ratio, n_i is the mean S/N ratio at the optimal level, and i is the number of the main design parameters that affect the quality characteristic.

V. EXPERIMENTATION

Turning operations are accomplished using a cutting tool, the high forces and temperature during machining create a very hot environment for the cutting tool. Therefore, MRR is an important index to evaluate cutting performance in a turning operation. In addition, the purpose of turning operations is to produce a low Surface Roughness of the machined work piece and with the high Material Removal Rate. Therefore, Surface Roughness is another important index to evaluate cutting performance. The cutting experiments are carried out in our collage workshop on CNC Turning Centre, Minitab software.

A. Work Material:

- 1) Material selected is : MILD STEEL(AISI 1018)
- 2) Yield strength : 370 Mpa
- 3) Tensile Strength : 440 Mpa
- 4) Specimen Dimensions: D= 32mm , L=80mm

B. Cutting Insert Used for Operation:

Turning insert: VNMG160408

symbol	Cutting Parameters	Level 1	Level 2	Level 3
A	Cutting speed	450	600	750
B	Feed rate	0.04	0.07	0.1
C	Depth of cut	0.5	1	1.5

Fig: Table according to selected cutting parameters with respect to levels

VI. OBSERVATIONS OF EXPERIMENT

The experimental observations are as shown in the table below,

Expt.no	Cutting speed (m/min)	Feed rate (mm/min)	DOC (mm)	Initial wt. (gm)	Final wt. (gm)	Cycle time (sec)
1	450	0.04	0.5	510.5	505.5	131.4
2	450	0.07	1	510	497.5	73.8
3	450	0.1	1.5	509	489	59
4	600	0.04	1	511	498.5	88.8
5	600	0.07	1.5	509	488.5	78
6	600	0.1	0.5	514	509	44
7	750	0.04	1.5	510.5	484.5	76.8

8	750	0.07	0.5	510.5	505.5	50
9	750	0.1	1	514	500.5	36

Table: Experimental results for MRR

A. MRR Calculations:

For calculation of Material Removal Rate the mild steel bar of 32 diameter and 80mm in length is selected. Initial weight of each test bar is taken before machining and final weight after machining. Depth of cut, speed & feed rate are selected as per L9 orthogonal array. Machining is carried out on specified length of material. Machining cycle time is taken for each specific component/job directly from CNC machine. After machining, final weight of each test bar is determined. Finally MRR is calculated by using formula,

$$\text{MRR} = (\text{Initial weight} - \text{Final weight}) / \text{machining time}$$

The S/N ratio is defined as,

$$S/N = -10 \log (\text{M.S.D.})$$

Where, M.S.D. is the mean-square deviation for the output characteristic. To obtain optimal cutting performance, the higher-the-better quality characteristic for MRR must be taken. The mean-square deviation (M.S.D.) for the higher-the-better quality characteristic can be expressed as:

$$\text{MSD} = 1/n \sum (1/y^2)$$

The calculations of S/N ratio for Material Removal Rate is shown in table below as follows,

Expt. No.	Cutting Speed (m/min)	Feed Rate (mm/min)	Depth of cut (mm)	MRR (gm/sec)	S/N ratio
1	450	0.04	0.5	0.038	-28.403
2	450	0.07	1	0.169	-15.443
3	450	0.1	1.5	0.339	-9.3960
4	600	0.04	1	0.141	-17.016
5	600	0.07	1.5	0.263	-11.609
6	600	0.1	0.5	0.114	-18.869
7	750	0.04	1.5	0.339	-9.3960
8	750	0.07	0.5	0.100	-20.000
9	750	0.1	1	0.375	-8.5194

Table: Experimental results for MRR and S/N ratio

Calculation of S/N ratio for MRR:

$$S/N = -10 \log (\text{M.S.D.})$$

Where, $\text{MSD} = 1/n \sum (1/y^2)$

Calculation is done according to above formula:

For the Example ,

Expt. No. I:

Initial Weight (gm) = 510.5,

Final Weight (gm) = 505.5,

Machining Time (sec) = 131.4,

$$MRR = (510.5 - 505.5) / 131.4$$

$$MRR = 0.038 \text{ gm/sec}$$

For S/N Ratio,

$$S/N = 10 \log [1/1 * [1/0.038^2]] = -28.4043.$$

For quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio.

B. Surface Roughness:

A roughness tester is used to quickly and accurately determine the surface texture or surface roughness of a material. A roughness tester shows the measured roughness depth (Rz) as well as the mean roughness value (Ra) in micrometers or microns (µm). Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface metrology, roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose. Roughness plays an important role in determining how a real object will interact with its environment. In tribology, rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities on the surface may form nucleation sites for cracks or corrosion. On the other hand, roughness may promote adhesion. Generally speaking, rather than scale specific descriptors, cross-scale descriptors such as surface fractality provide more meaningful predictions of mechanical interactions at surfaces including contact stiffness and static friction.

Although a high roughness value is often undesirable, it can be difficult and expensive to control in manufacturing. For example, it is difficult and expensive to control surface roughness of fused deposition modelling (FDM) manufactured parts. Decreasing the roughness of a surface usually increases its manufacturing cost. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Roughness can be measured by manual comparison against a "surface roughness comparator" (a sample of known surface roughness), but more generally a surface profile measurement is made with a profilometer. These can be of the contact variety (typically a diamond stylus) or optical (e.g.: a white light interferometer or laser scanning confocal microscope).

However, controlled roughness can often be desirable. For example, a gloss surface can be too shiny to the eye and too slippery to the finger (a touchpad is a good example) so a controlled roughness is required. This is a case where both amplitude and frequency are very important.

Expt.No	Cutting speed (m/min)	Feed rate (mm/min)	DOC (mm)	SR (micrometer)	S/N ratio
1	450	0.04	0.5	2.894	-9.23
2	450	0.07	1	4.033	-12.1126
3	450	0.1	1.5	1.628	-4.2331
4	600	0.04	1	2.387	-7.5570
5	600	0.07	1.5	0.786	2.0915
6	600	0.1	0.5	2.960	-9.4258
7	750	0.04	1.5	1.830	-5.2490
8	750	0.07	0.5	2.110	-6.4856
9	750	0.1	1	1.617	-4.1742

Table: Experimental results for SR and S/N ratio.

Calculation of S/N ratio for Surface Roughness:

$$S/N \text{ ratio} = -10 \log (M.S.D)^2$$

Calculation is done according to above formula,

For example,

Expt. No. 1

$$S/N = -10 \log (2.894^2) = -9.230$$

The lower – the – better of the higher –the –better quality characteristics ,the greater s/n ratio corresponds to smaller variance of the output characteristics around the desired value the S/N for Surface Roughness is shown in table.

VII. ANALYSIS OF EXPERIMENTAL

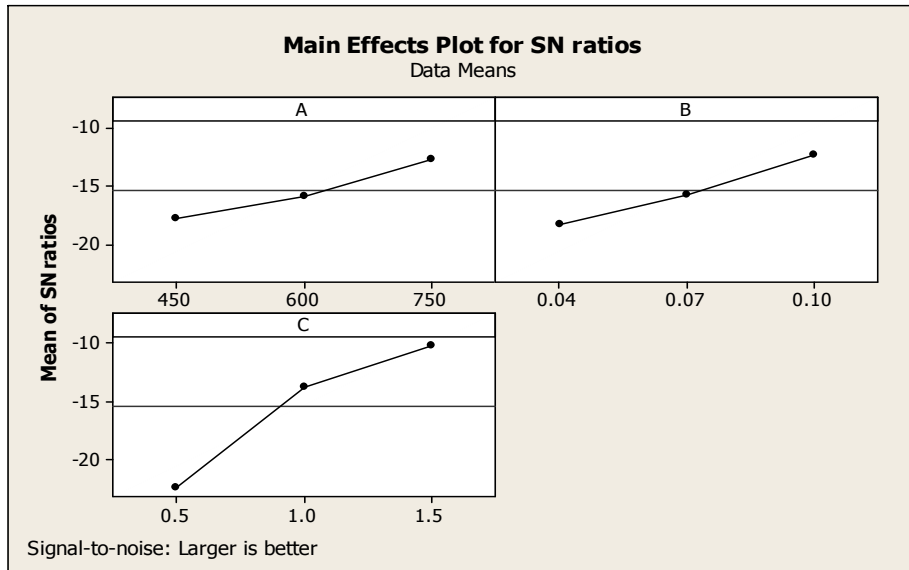


Fig no: Plots for Material Removal Rate

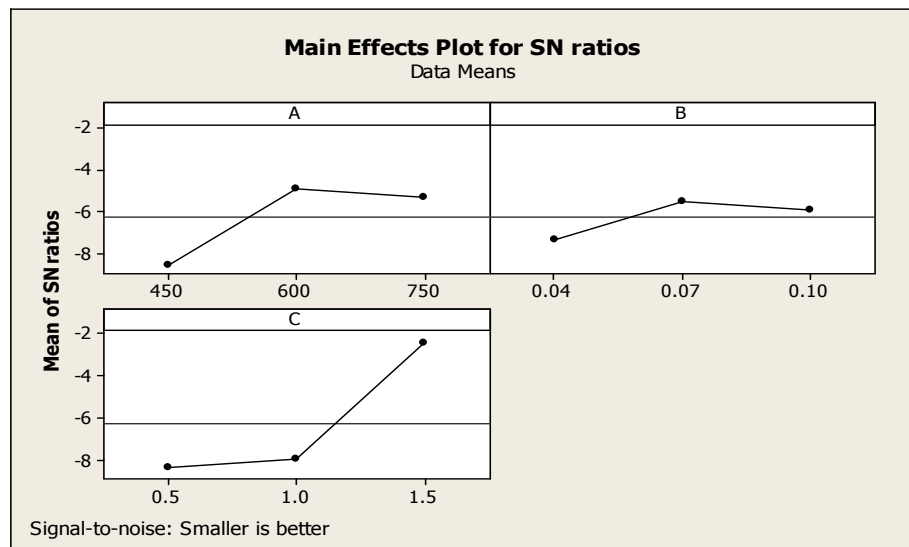


Fig no: Plots for Surface Roughness.

VIII. CONFIRMATION TEST

The estimated S/N ratio (n^{\wedge}) using the optimal level of the design parameter can be calculated as:

$$n^{\wedge} = n_m + \sum_{i=0}^i (n_i - n_m)$$

The estimated S/N ratio using the optimal cutting parameters for MRR and Surface Roughness can be calculated By using above equation.

	Optimal Cutting Parameters	
	Prediction	Experiment
Level	A3B2C1	A1B1C1
MRR (gm/sec)	0.100	0.038
S/N ratio (dB)	-20.000	-28.4043

Table: shows comparison of the predicted MRR with experimental MRR using the optimal cutting parameter, good agreement between the predicted and actual MRR being observed.

The initial cutting parameters were as follows cutting speed 450 m/min, Feed rate 0.04 mm/min and depth of cut 0.5 mm.MRR for initial cutting parameters were 0.038 gm/sec.

	Optimal Cutting Parameters	
	Prediction	Experiment
Level	A2B3C1	A1B1C1
SR (micrometer)	2.960	2.894
S/N ratio (dB)	-9.4258	-9.230

Table: Shows the comparison of the predicted Surface Roughness value with the experimental using the optimal cutting parameter.

The initial cutting parameter were as follows cutting speed 450 m/min, feed 0.04 mm/min and depth of cut 0.5 mm. surface roughness for this initial cutting parameters were 2.894 dB

IX. RESULT AND DISCUSSION

A. Results

In this study, an investigation on the MRR and Surface Roughness based on the parameter design of the Taguchi method in the optimization of turning operations has been investigated and presented. Summarizing the mean, experimental results of this study, the following generalized discussion can be drawn.

B. Discussion

Based on the experimental results, the highly effective parameters on MRR and power consumption were determined.

1. Based on S/N ratio and Main effect plot for MRR, We conclude that are Optimal. Machining parameter for maximizing material remove rate.[Where A= Speed, B=Feed rate, C= Depth of cut and 1,2,3 shows particular level]
2. Use of cutting speed at level 3 (750m/min), feed at level 2 (0.07mm/min) and depth of cut at level 1 (0.5mm) is recommended to obtain higher MRR.
3. Based on S/N ratio and Main effect plot for Surface roughness, we conclude that A1B1C1 are optimal parameter for minimizing the Surface Roughness.
4. Use of cutting speed at level 1 (450m/min), feed at level 1 (0.04mm/min) and depth of cut at level 1 (0.5mm) is recommended to obtain better Surface Roughness.
5. Confirmation experiments verified the effectiveness of the present approach in finding optimal machining parameters.

C. Conclusion

This project has presented an application of the parameter design of the Taguchi method in the optimization of turning operations.

The following conclusions can be drawn based on the experimental results of this study.

This project demonstrates how to use Taguchi parameter design for optimizing machining performance with minimum cost and time to increase production rate/manufacturing rate with best quality. This project has discussed an application of the Taguchi method for optimization the cutting parameters in turning operations. It has been shown that MRR and Surface Roughness can be improved significantly for turning operations

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