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OPTIMIZATION OF MACHINING PARAMETERS ON SURFACE ROUGHNESS BY TAGUCHI APPROACH

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Abstract

The optimization of the machining parameters on surface roughness by Taguchi method can reduce the trial and error type experiments by using a matrix design. In this study, L9(3^3) orthogonal array of Taguchi experiment is selected for three parameters (speed, feed, depth of cut) with three levels for optimizing the surface roughness in precision turning on an HE-100-CNC-PC CNC (Computerized Numerical Controlled) lathe. The material used in this experimental is the alloy of aluminum (AM-40, Material number ENAW-5083) having excellent corrosion resistance with good weldability and formability in the form of round bar having diameter of 20 mm dimension. It is machined according to Taguchi's L9 orthogonal array. Turning operation experiments were carried out on a CNC lathe that provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at specified rate and depth of cut. Therefore three cutting parameters namely cutting speed, feed and depth of cut need to be optimized. The feasible space for the cutting parameters was defined by varying the turning speed in the range 1000-1600rpm, feed in the range 0.02-0.04mm/rev. and depth of cut from 0.25 mm to 0.35mm.

Keywords: Analysis of Variance (ANOVA), Taguchi Method, Surface Roughness, Turning, Optimization.

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INTRODUCTION

Turning is the most widely used among all the cutting processes. The increasing importance of the turning operations is gaining new dimensions in the present industrial era, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts and surface finish is one of the most critical quality measures in mechanical products. As the competition increases, the customers are having increasingly high demands on quality, making surface roughness and dimensional accuracy the most competitive parameters in today's manufacturing industry. In a machining operation, the selection of cutting parameters is the most critical job. It requires a number of experiments and considerable knowledge to get optimum cutting parameters for a particular machining operation. Recently, rapid developments in the manufacturing industry have increased the significance of machining processes. CNC turning is one of the most popular and efficient machining operations, with which, the high surfaces finish and dimensional accuracy of work piece can easily be obtained. Surface roughness is an essential requirement in determining the surface quality of a product.

Surface roughness is a measure of irregularities on the surface of a component resulting from machining operations. The controlled parameters in a turning operation that under normal conditions affect surface finish most profoundly are feed rate and cutting speed. Recent studies, that explore the effect of setup and input parameters on surface finish, find that there is a direct effect of feed rate where as the spindle speed's effect is generally nonlinear and often interactive with other parameters, and that depth of cut can have some effect due to heat generation or chatter. This is indicating that these controlled parameters are playing an important role in optimizing roughness of the surface. Using an efficient Taguchi Parameter Design study requires review of literature regarding turning parameters and common studies. The most quickly and easily controlled factors in a turning operation are cutting speed, feed rate and depth of cut; each of which may have an effect on surface finish. Several studies explored that the feed rate, spindle speed and depth of cut effect the surface finish (Feng and Wang, 2003; Gökkayaa and Nalbant, 2007; Kirby *et al*., 2004; Lalwani, 2008; Rafi and Islam, 2009). These studies all supported the idea that feed rate has a strong influence on the surface finish. Depth of cut and Spindle speed were found to have differing levels of effect in every study, often playing a stronger role as part of an interaction.

This gives us an indication that these controlled parameters would play an important role in optimizing surface roughness. Feng and Wang (Feng and Wang, 2003; Feng and Wang, 2002) investigated for the prediction of surface roughness in finish turning operation by developing an empirical model through considering working parameters: work piece hardness (material), feed, cutting tool point angle, spindle speed , cutting time and depth of cut. Data mining techniques and nonlinear regression analysis with logarithmic data transformation were employed for developing the empirical model to predict the surface roughness. Kirby *et al*. (2004) developed the prediction model for surface roughness in turning operation. By a single cutting parameter a regression model was developed and vibrations along three axes were chosen for in-process surface roughness prediction system. By using the multiple regression and Analysis of Variance (ANOVA) a strong linear relationship among the parameters (feed rate and vibration measured in three axes) and the response (surface roughness) was found. The authors demonstrated that depth of cut and spindle speed might not necessarily have to be fixed for an effective surface roughness prediction model.

Rafi and Islam (2009) presented experimental and analytical results of an investigation into dimensional accuracy and surface finish achievable in the dry turning operation. The Taguchi method and Pareto ANOVA analysis were used to determine the effects of the major controllable machining parameters, namely, feed rate, cutting speed and depth of cut, on three key quality characteristics, which are diameter error, surface roughness and circularity, and consequently to find their optimum combination. The tool and work materials selected are enriched cobalt-coated carbide and alloying steel AISI 4340, respectively. The results point out that while the surface roughness can be optimized through proper selection of optimization of diameter error, feed rate and circularity is complicated due to complex interactions between the input parameters.

Traditional Optimization Techniques

Traditionally, the selection of the cutting conditions for metal cutting is left to the machine operator. In these types of cases, the experience of the operator plays a key role, but even for a skilled operator it is very difficult to attain the optimum values each and every time. Feed rate, cutting speed and depth of cut are the Machining parameters in metal turning. The quality characteristics of turned parts is determined by the setting of these parameters. Different analytical and experimental approaches for the optimization of machining parameters have been investigated using the original work of Taylor and his famous tool life equation. Gilbert (Gilbert, 1950) studied the optimization of machining parameters in turning with respect to maximum production rate and minimum production cost as criteria. Armarego and Brown (Armarego and Brown, 1969) investigated unconstrained machine-parameter optimization using differential calculus. Brewer and Rueda (Brewer, 1966) carried out simplified optimum analysis for non-ferrous materials. For cast iron (CI) and steels, the employed the criterion of reducing the machining cost to a minimum. A number of monograms were worked out to facilitate the practical determination of the most economic machining conditions.

They pointed out that the more difficult-to machine materials have a restricted range of the parameters over which machining can be carried out and thus any attempt at optimizing their costs is artificial. Brewer (Brewer and Rueda, 1963) suggested the use of Lagrangian multipliers for optimization of the constrained problem of the unit cost, with cutting power as the main constraint. Bhattacharya *et al.* (1970) optimized the unit cost for the turning, subject to the constraints of surface roughness and cutting power by the use of Lagrange's method. Walvekar and Lambert (1970) discussed the use of geometric programming to selection of machining variables. They optimized feed rate and cutting speed to yield minimum production cost. Petropoulos (1973) investigated optimal selection of machining rate variables, namely . feed rate and cutting speed, by geometric programming. A constrained unit cost problem in turning was optimized by machining SAE 1045 steel with a cemented carbide tool of ISO P-10 grade.

Sundaram (1978) applied a goal-programming technique in metal cutting for selecting levels of machining parameters in a fine turning operation on AISI 4140 steel using cemented tungsten carbide (WC) tools. Ermer and Kromodiharajo (1981) developed a multi-step mathematical Optimization of machining techniques model to solve a constrained multi-pass machining problem. They accomplished that in some cases with certain constant total depths of cut, multipass machining was more reasonable than single-pass machining, if the depth of cut for each pass was accurately allocated. They used high speed steel (HSS) cutting tools to machine carbon steel. Tsai (1986) studied the relationship between the two machining process: the single-pass machining and multi-pass machining. He obtained the idea of a break-even point, i.e. the point at which value of depth of cut is equal for both which single-pass and double-pass machining. If the depth of cut is lower the break-even point, the single-pass is more reasonable than the double-pass, and when the depth of cut above this break-even point, double-pass is better. Carbide tools are used to turn the carbon steel work material.

Gopalakrishnan and Khayyal (1991) described the design and development of an analytical tool for the selection of machine parameters in the turning. Geometric programming was used as the basic methodology to determine values for feed rate and cutting speed that minimize the total cost of machining SAE 1045 steel with cemented carbide tools of ISO P-10 grade. Surface finish and machine power were taken as the constraints while optimizing cutting speed and feed rate for a given depth of cut.

Parameters	Symbols	Units	Level-1	Level-2	Level-3
Speed	A	Cutting speed (mm/min.)	1674.66	1360.66	1046.66
Feed	B	mm/rev.	0.04	0.03	0.02
Depth of cut	C	mm	0.35	0.3	0.25

Experimental Works

Machine Tool: In this study, L9(3^3) orthogonal array of Taguchi experiment is selected for three parameters (speed, feed, depth of cut) with three levels for optimizing the surface roughness in precision turning on an HE-100-CNC-PC CNC (Computerized Numerical Controlled) lathe.

MATERIALS AND METHODS

This experimental investigation was carried out in AFSET, Dhauj. Objective of the experiments under reference was to optimize important output parameter namely surface roughness.

Taguchi approach of design of experiment (DOE) was adopted in this case and orthogonal array L-9 was used for determining the number of experiments. The material used in this experimental is the alloy of aluminum (AM-40, Material number ENAW-5083) having excellent corrosion resistance with good weldability and formability in the form of round bar having diameter of 20 mm dimension. It is machined according to Taguchi's L9 orthogonal array. The chemical composition of flat bar material is given in Table 4.1.

Table 1. Chemical composition of Aluminum alloy

Material	Al	Mg	Mn
Al-Alloy	94.8%	4.5%	0.7%

The cutting tool selected for turning operation is made of High speed steel.

Selection of Parameters and Their Levels: Turning operation experiments were carried out on a CNC lathe that provides the power to turn the work piece at a given rotational speed and to feed to the cutting tool at specified rate and depth of cut. Therefore three cutting parameters cutting speed, feed and depth of cut need to be optimized.

Therefore, three parameters (Speed, Feed and Depth of cut) as the input parameters and the surface roughness as the output parameters are taken in the present experimental setup. After deciding the three parameters for the study, which is done as discussed in the literature review on turning process and the selection of three levels of each parameter has been taken on the bases of past practical experience of the operators. The feasible space for the cutting parameters was defined by varying the turning speed in the range 1000-1600rpm, feed in the range 0.02-0.04mm/rev. and depth of cut from 0.25 to 0.35mm.

Table-2. Experimental Layout Using an L-9 Orthogonal Array

Exp no.	Process Parameter Levels		
	Cutting Speed (mm/min.)	Feed rate (mm/rev.)	Depth of cut (mm)
1	1674.66	0.04	0.35
2	1674.66	0.03	0.3
3	1674.66	0.02	0.25
4	1360.66	0.04	0.25
5	1360.66	0.03	0.35
6	1360.66	0.02	0.3
7	1046.66	0.04	0.3
8	1046.66	0.03	0.25
9	1046.66	0.02	0.35

Three levels of each cutting parameters were selected as shown in Table 4.1. Selected cutting parameters were fed with the help of in-built control panel of the CNC machine itself. Corresponding Cutting speed in mm/min. is found for work piece is (1046.66,1360.66,1674.66 mm/min.) by V=(3.14*20*N)/60

RESULTS

Observations:

Three levels of each input parameters Cutting Speed, Feed rate and depth of cut are taken and the experimental layout of three parameters using the L9 orthogonal array is formed as shown in Table 5.1. Nine experiments are conducted for the above mentioned nine sets of parameters (speed, feed rate and depth of cut) and the average value surface roughness in microns are listed in Table 5.2

Analysis of Results:

In the Taguchi method results of the experiments are analyzed to achieve one or more of the following three objectives:

- To establish the best condition for a product or a process.
- To estimate the contribution of the individual factors.
- To estimate the response under the best conditions.

Analysis of the S/N Ratio:

In the Taguchi method, the term "signal" represents the desirable value (mean) for the output characteristic and the term "noise" represents the undesirable value (S.D.) for the output characteristic. Therefore, the S/N ratio is ratio of the mean to the S.D. The relevant graphs for the S/N ratio for all the three process parameters are obtained by using the MINITAB software.

Analysis Of Variance (ANOVA)

Analysis of variance is a computational technique to quantitatively estimate the relative contribution, which every controlled parameter makes to the overall measured response and expressing it as a percentage (%). Thus the information about how significant the effect of each controlled parameter is on the experimental results can be obtained. ANOVA uses S/N ratio responses to investigate which control factors significantly affect the quality characteristic. It is the accomplished by separating the total variability of the S/N ratios, which is measured by sum of the squared deviations from the total mean S/N ratio, into contributions by each of the control factors and the errors. In this experimental study ANOVA (Analysis of Variance) was used to determine the significant parameters influencing the surface roughness. The factors associated with analysis are shown in Table no.5.7.

Table-3. Experimental Results

Exp no.	Factors			Results	
	Cutting Speed (mm/min.)	Feedrate (mm/rev)	Depth of cut (mm)	Surface Roughness (Microns)	S/N Ratio Surface Roughness (db)
1	1674.66	0.04	0.35	2.813	-8.98
2	1674.66	0.03	0.3	1.210	-1.65
3	1674.66	0.02	0.25	1.372	-2.74
4	1360.66	0.04	0.25	1.302	-2.29
5	1360.66	0.03	0.35	1.385	-2.82
6	1360.66	0.02	0.3	1.172	-1.37
7	1046.66	0.04	0.3	2.894	-9.22
8	1046.66	0.03	0.25	1.240	-1.86
9	1046.66	0.02	0.35	2.854	-9.10

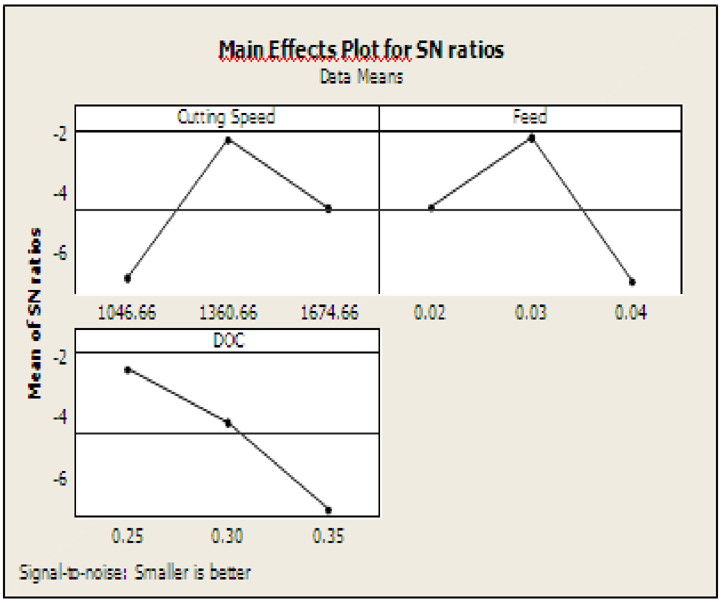

Figure 1a. Main Effects Plot For S/N Ratio

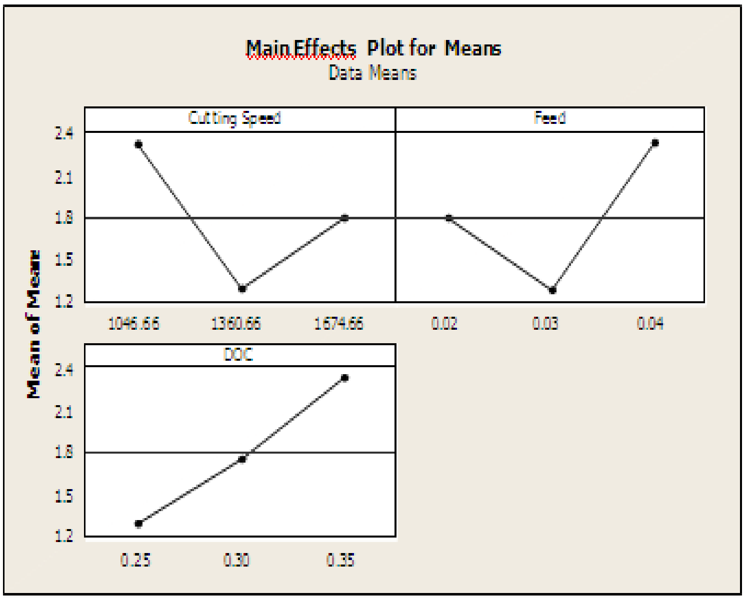

Figure 1b. Main Effects Plot For S/N Ratio

Calculation for the Contribution of Individual Factors

The calculation has made for the following:

- A factor that can be pooled
- The factor with the most influencing the variation of results.

For each parameter at levels 1, 2, and 3 for S/N data, S/N response is computed by MINITAB software. For manual calculation of S/N response table. The delta statistic is the highest minus the lowest average for each factor.

MINITAB assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest delta value and so on. Ranks indicate the relative importance of each factor to the response.

From the Table 5.5 it is clearly shown that the parameter B is having highest effect on the process as compared to the other parameters because these having highest max-min value (4.717). It is also shown that maximum value of mean S/N ratio of A is at level 2 (-2.167), B is at level 2 (-2.118), C is at level 1 (-2.303).

Table 4. S/N response table for Surface roughness

Level	Cutting Speed (A)	Depth of cut (B)	Feed (C)
1	-6.736	-4.412	-2.303
2	-2.167	-2.118	-4.088
3	-4.462	-6.835	-6.974
Delta	4.569	4.717	4.671
Rank	3	1	2

So the optimal cutting parameters are Cutting speed at level 2 i.e. 1360.66mm/mim, depth of cut at level 2 i.e. 0.3mm, feed at level 1 i.e.0.03 mm/rev.

S/N ratio and response effects data plotted are shown in Fig. 5.2a, it can be used to decide the optimal combination of parameters for Surface roughness.

Fig. 5.2a shows that the Surface roughness decreases with the increase of depth of cut, and increases with increase in spindle speed and feed up to certain limit.

Calculation for Response under the Optimum Conditions

To calculate the response under optimal condition, regression analysis has been done with the help of Mini-tab software.

REGRESSION ANALYSIS

The regression equation is

Roughness = - 0.99 - 0.000846 Cutting Speed + 26.9 Feed + 10.5 DOC

=-0.99-.000846*1360.66+26.9*.03+10.5*.30
= 1.81
S = 0.706619 R-Sq = 50.0% R-Sq (adj) = 20.0%

Table 5. Performance Factor of Regression Analysis

S.No.	Predictor	Coefficient	SE Coef.	T	P
1	CONSTANT	-0.988	2.316	-0.43	0.687
2	SPEED	-0.0008455	0.0009187	-0.92	0.400
3	FEED	26.85	28.85	0.93	0.395
4	D.O.C	10.460	5.770	1.81	0.130

In order to study the significance of the process variables towards surface roughness, analysis of variance (ANOVA) was performed. The degrees of importance of each parameter considered, namely, cutting speed, depth of cut, feed is given in Table 5.8.

Each three level parameter has 2 degree of freedom (DOF) (Number of level – 1), the total DOF required for three parameters each at three levels is 8(=4x (3-1)). Table 5.8 showed the summary of S/N values and ANOVA results for roughness.

It was found that feed and cutting speed are non significant process parameters. It clearly shows that the cutting speed, feed and depth of cut ratio contribution are varying to each other. In case of surface roughness, dominant parameter followed by depth of cut (B), feed (C) and cutting speed (A), had lower effects.

Depth of cut has greatest influence on the surface roughness for turning operation with 33.70% influence followed by feed with 33.59% and cutting speed 31.30%.

Verification of Results

There are two methods generally used for validation of Taguchi model's. First is based upon confirmation test. It is used to verify the estimated result with the experimental results and in the second method of validation is based upon the comparison between optimized model output results with an example taken from reference. In this study, first method is used in order to validate the Taguchi model for verification.

The objective of the confirmation run was to determine that the selected control parameter values would produce better response than those produced in the first part of the experiment.

The optimum conditions are set for the significant parameters (the insignificant parameters are set at economic levels) and a selected number of tests are run under specified conditions.

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 design parameters. In this experimental study optimal combination of parameters and their levels obtain by Taguchi technique using MINITAB software coincidently match with one of the experiments.

The results obtained were verified by running a separate experiment and manufacturing around 20 pieces of component .Out of these 20 components, randomly selected 3 pieces were selected separately for surface roughness test.

Table 6. Analysis of Variance

S.No.	Source	DF	SS	MS	F	P
1.	Regression	3	2.4967	0.8322	1.67	0.288
2.	Residual Error	5	2.4966	0.4993	-	-
3.	Total	8	4.9932	-	-	-

Table 7. Summary of S/N values and ANOVA results for Surface Roughness

Factor	Degree of Freedom	Average SN Value			Sum of Squares	Percentage of Contribution
		Level 1	Level 2	Level 3		(%)
Cutting speed	2	-6.736	-4.412	-2.303	31.30	31.59
Depth of Cut	2	-2.167	-2.118	-4.088	33.41	33.70
Feed	2	- 4.462	-6.835	-6.974	33.30	33.57
Error	0	-	-	-	1.13	1.13
Total	8	-	-	-	177.42	100

The RA for the component was found out to be 1.76 microns. (Using the Parameter combination A2B2C1).

Conclusion and scope for future work

Conclusion

It is found that the parameter design of the Taguchi method provides a simple, systematic and efficient methodology for the optimization of process parameters. Based on the results obtained in this study, the following conclusions can be drawn:

- The percentage contribution of cutting speed is 31.30 %, feed rate is 33.70%, depth of cut is 33.59% and that of error is 1.13% for minimum value of surface roughness.
- The percentage contribution of the Depth of cut is maximum i.e.33.70 % for obtaining the minimum value of the surface roughness.
- The optimum combination of the parameters and their levels for obtaining minimum surface roughness is A2B2C1.
- Out of the above two combinations the surface roughness was found to be the minimum at A2B2C1 with the RA value of 1.81 microns.
- The initial values of surface roughness were obtained by the operator without the application of Taguchi technique was 1.76 microns.

Thus, it can be safely concluded that the output quality conditions (Surface Roughness) are greatly advanced by the application of Taguchi technique. Hence, one can very well conclude that the project work is successfully completed.

Scope for Future Work

In this study only 3 process parameters were taken into consideration and the interaction between them were not considered. The percentage influences of the various contributing factors vary as a result of interaction between the parameters. Similarly there would be variations in the results if we consider a greater number of influencing factors like tool and work piece material etc. Cycle time, Power consumption and Geometrical error may also be the parameters that are to be the optimized. Some suitable interpolation/extrapolation technique along with GRA could then perhaps be used to solve the problem of optimal parameter determination. Similar study can be conducted in which more than 3 process parameters and the interaction between them can be carried out as an extension to the present project work.

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