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Optimization of Cutting Parameters for Surface Roughness in Turning of Alloy Steel EN 47

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Abstract

The purpose of this paper is to examine how the surface roughness of alloy steel EN47 is affected by hard turning. Tests were conducted on the CNC lathe using different cutting parameters. The surface was evaluated in terms of surface roughness. Tests showed that hard turning provide good surface finish. Process parameters (insert radius, cutting speed, depth of cut and feed rate) are used as input parameters. Taguchi method is implemented to find out the optimum cutting parameters for surface roughness (Ra) in hard turning. The L9orthogonal array , signal to noise ratio and analysis of variance has been employed to study the performance characteristics in turning of alloy steel EN 47 using carbide inserts (TNMG 160408-FMTN8135). Experimental data have been used to generate, compare and evaluate the proposed model of surface roughness for the considered material.

Keywords

Surface Roughness, Taguchi Method, Orthogonal Array, Process Parameters, Turning Process.

I. Introduction

Predicting process of machinability models and determining the optimum values of process parameters in manufacturing system have been areas of interest for researchers and manufacturing engineers. To allow for high productivity, high flexibility hard turning is now a days an alternative to grinding in the finishing of work pieces. The surface roughness of machined parts is a significant design specification that is known to have considerable influence on properties such as wear resistance and fatigue strength and refers to deviation from the nominal surface. The quality of a surface is a factor of importance in the evaluation of machine tool productivity. Hence it is important to achieve a consistent surface finish and tolerance because it plays an important role in many applications such as precision fits, fastener holes etc. In a turning operation an important task is select the appropriate cutting parameters for achieving high cutting performance. Cutting parameters affect surface roughness, surface texture of the product.

Surface roughness is a factor that greatly influences manufacturing cost and also describes the geometry of the machined surface combine with the surface texture. To select the cutting parameters properly several mathematical models which are based on statistical regression or neural network techniques have been developed to establish the relation between cutting parameters and their performances [1].

A considerable amount of studies have investigated the general effect of process parameters (insert radius, cutting speed, feed rate, depth of cut) on process functions such as surface roughness, tool life, cutting forces etc. [2,3]. Most of these models are based on the regression analysis (RA), a very few researchers used computational neural networks techniques (CNN) [4-9].

In this paper data of factorial for the response (surface roughness) when turning of alloy steel EN 47 are used to predict the machinability model using taguchi concept. The obtained models are compared using relative error analysis, descriptive statistics. Four machining parameters were considered (cutting speed (v, m/min.) feed rate (f, mm/rev.)

depth of cut (d, mm) insert radius (r, mm)). Therefore this paper present the following contribution: first it applies taguchi concept to design the process for machining using orthogonal array. Second it applies response to perform analysis of mean and analysis of variance to optimize the cutting parameters to improve surface roughness using Minitab 15 software [10]. Finally the resulting models are compared against each other to illustrate the most appropriate approach for predicting the best models of the considered response.

Several experimental investigation have been carried over the years in order to study the effect of cutting parameters on the surface finish of the work piece, tool life using work pieces of different materials.

Abu-Sinna et al. [11] investigated the effect of the loading frame stiffness on the deadweight force machine–load cell interaction. In order to perform the finite element analysis efficiently, he utilized the Taguchi technique, as this typically reduces the total required simulations. The validity of the finite element analysis was confirmed through experiments.

M.Nalbant et al. [12] implemented the taguchi method to find out optimum cutting parameters for surface roughness in turning. ANOVA method were employed to study the performance characteristics in turning of AISI 1030 steel bar using TiN coated tools. The study reveals that the feed rate and the insert radius were the main parameters that affect the surface roughness in turning of AISI 1030.

Ilhan Asilturk et al. [13] focus on optimization of turning parameters based on taguchi method to minimize surface roughness (Ra&Rz). Experimental have been carried out using L9 orthogonal array in CNC turning. Dry turning tests were carried out on hardened AISI 4140 with coated carbide tools. It has been observed that feed rate has the most significant effect on surface roughness.

Kilickap [14] investigated the use of the Taguchi method and the Response Surface Methodologies (RSM) for minimizing the burr height and the surface roughness in drilling Al-7075. The Taguchi method, a powerful tool to optimize design quality, was used to find optimal cutting parameters. The optimization results showed that the combination of low cutting speed, low feed rate and high point angle were necessary to minimize burr height.

Wang and Lan [15] in their experiments implemented orthogonal array of Taguchi method coupled with the Grey Relational Analysis (GRA) in considering the four parameters of cutting speed, depth of cut, feed rate and tool noise radius which were used for optimizing the following three responses: surface roughness, tool wear and material removal rate in precision turning on an ECOCA-3807 CNC lathe. They studied the proposal of optimization approaches using Orthogonal Array and the GRA and contributed a satisfactory technique for improving the multiple machining performances in precision CNC turning with profound insight.

Shetty et al. [16] used Taguchi and Response Surface Methodologies for minimizing the surface roughness in turning of discontinuously reinforced aluminium composites (DRACs) having aluminium alloy 6061 as the matrix and containing 15 vol.% of silicon carbide particles of mean diameter 25 lm under pressured steam jet approach. The effect of cutting parameters on surface roughness was evaluated and the optimum cutting condition for minimizing the surface roughness was also determined.

The literature survey reveals that the traditional methods for designing the process are very complicated but also very difficult to use because the number of experiments increases when the number of process parameters increases. To solve this problem taguchi method uses a design of orthogonal array to study the entire process parameters with small number of experiments [17].

II. Material and Method

Turning is a machining process in which a single point cutting tool removes the material from the surface of the rotating work piece. Four cutting parameters insert radius, cutting speed, feed rate and depth of cut must be determined in cutting operation. Optimization of the cutting parameters based on the parameters design of the taguchi method using L_9 array is used in this study to improve surface roughness.

In this study the work piece of alloy steel EN 47 was used. The sizes of the samples were 32 × 102 mm. The chemical composition of the material after the spectro analysis which was used in the study is shown in the table 1 below [18]:

Table 1: Chemical composition of EN 47

C %	Si %	Mn%	Cr %	Mo%	Ni %	Cu %	Al %	S %	P %	V %
0.542	0.388	0.633	0.9414	0.0161	0.0997	0.1380	0.0177	0.0464	0.0443	0.1710

The experimental studies were carried out on CNC lathe model LL20T L5. The experiments were carried out under full flooded coolant conditions. The tool holder was model: MTJNR2525M16 and carbide inserts TNMG 160408-FMTN8135 were used as a cutting tool material. The surface roughness was measured using a mitutyo Surf test SJ-201P portable surface tester with sampling length 2.5 cm.

The values of the cutting parameters and cutting parameter range were chosen from the research paper [19] for the tested material. These cutting parameters are shown in table 2 below:

Table 2 : Cutting parameters with levels

Process parameters	Notation	Level 1	Level 2	Level 3
Insert radius (mm)	A	0.4	0.8	1.2
Cutting speed (m/min)	B	47	79	103
Feed rate (mm/rev.)	C	0.05	0.1	0.2
Depth of cut (mm)	D	0.4	0.6	0.8

The taguchi method and L_9 orthogonal array were used to reduce the number of experiments. The design of experiment and measured R_a are shown in table 3. The experiments were conducted three times for each combination of process parameters.

Table 3 : the result of experiment with surface roughness (R_a) values

Experiment number	A	B	C	D	R_a
1	1	1	1	1	2.9166667
2	1	2	2	2	1.2777778
3	1	3	3	3	2.3288889
4	2	1	2	3	3.3455556
5	2	2	3	1	2.5955556
6	2	3	1	2	2.0244444
7	3	1	3	2	2.5400000
8	3	2	1	3	2.2888889
9	3	3	2	1	3.0277778

III. The Experimental Design using Taguchi Method

The traditional methods to design the process are very complicated and difficult to use. Moreover with increase in the number of process parameters, the number of experiments increases which have to be carried out. Therefore the factors causing vibrations should be determined and checked in the laboratory under favourable conditions such type of studies are considered the scope of off- line quality improvement [20]. The taguchi is an experimental design technique which is used to reduce the number of experiments by using orthogonal arrays and also tries to control the factors which are going out of control. The basic philosophy of taguchi is to provide quality in design phase. The greatest advantage of the taguchi is that it reduces experiment time which reduces cost to find out significant factors in shortest possible time.

The most reliable thing of taguchi technique is the use of parameter design which is an engineering method to design the process that focus on determining the parameter setting producing best level of quality characteristic with least possible variation. The important stage in the design of any experiment lies in the selection of best control factors. Taguchi uses the signal-to-noise (s/n) ratio as a quality characteristic. S/N ratio is used as a measured value instead of standard deviation because as the standard deviation decreases, mean also decreases and vice versa. The higher the ratio of desired signal to the background noise, the less obtrusive the background noise. In the other words the standard deviation cannot be minimized first the mean should be brought to the target value [21]. Taguchi has find out that the two stage optimization procedure involving S/N ratio indeed gives the parameter level condition where the standard deviation is minimum keeping mean at the target value [22]. In daily practice the mean value targeted may change during the process development. The concepts of S/N ratio are useful in the improvement of quality through variability reduction and improvement of measurement. The S/N ratio can be classified into three categories given by equation when the characteristic is continuous:

The S/N ratio with a lower-the-better characteristic can be expressed as:

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$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right) \quad (1)$$

The S/N ratio with a higher-the-better characteristic can be expressed as:

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} \frac{1}{y_{ij}^2}\right) \quad (2)$$

The S/N ratio with a nominal-the-better characteristic can be expressed as:

$$\eta_{ij} = -10\log\left(\frac{1}{ns}\sum_{j=1}^{n} y_{ij}^2\right) \quad (3)$$

This implies that the system behaves in such a way that the manipulated production factor can be divided into three categories: where y_{ij} is the i_{th} response of j_{th} experiment, n is the total number of the tests and s is the standard deviation. With the above S/N ratio transformation smaller the value of S/N ratio better the result if we are considering tool wear, cutting forces, surface roughness etc. Deviation between experimental and desired value is known as loss function in taguchi method. This loss is converted into signal-to-noise ratio [23]. In the taguchi concept the optimum parameter which gives minimum surface roughness can be obtained by using equation (3) and the "smaller-the-better" S/N ratio and desired level can be calculated by using equation (2).The result for the experiment with S/N ratio "smaller-is-better" obtained from MINITAB 15 is given below in table 4:

Table 4 : Value of S/N ratio for surface roughness

Surface Roughness	S/N Ratio
2.916666667	-9.297735966
1.277777778	-2.129106618
2.328888889	-7.342975377
3.345555556	-10.48936492
2.595555556	-8.28460658
2.024444444	-6.126117264
2.54	-8.096674332
2.288888889	-7.192494219
3.027777778	-9.622479943

IV. Analysing and Evaluating Results of the Experiments using Taguchi Method

The most important data in taguchi method for analysing the experiment data is signal-to-noise ratio. In this study the S/N ratio should have maximum value to obtain optimum cutting conditions. According to taguchi the optimum cutting condition was found as -2.1291 S/N ratio for Ra respectively in L9orthogonal array table 4. The optimum cutting conditions which were insert radius 0.4mm, cutting speed 79m/min, feed rate 0.1mm/rev. and depth of cut 0.6 mm were obtained for the best Ra values. Level values of the factor obtained for Ra according to the taguchi design is given in table 5 below. Figure 2 shows the graphical representation of the level values A, B, C, D factors given in table 5 and figure 2 in determining the optimum cutting condition of the experiment constructed under the same condition.

Table 5 : S/N response table for R_a factor

Machining parameters	Symbol	Level 1	Level 2	Level 3	Max.-Min.
Insert Radius	A	-6.275	-8.464	-8.298	2.188
Cutting speed	B	-9.323	-5.889	-7.826	3.434
Feed	C	-7.723	-7.390	-7.924	0.534
Depth of cut	D	-9.059	-5.617	-8.361	3.442

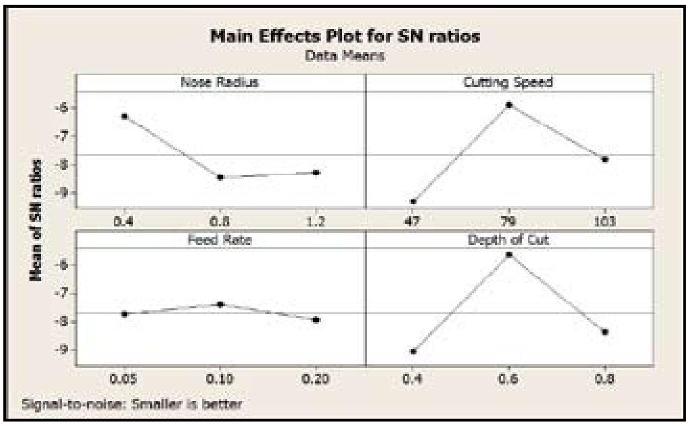

Fig. 1 : The graph of Mean S/N ratio verses factor level

The different values of S/N ratio between maximum and minimum values are shown in table 5. Depth of cut and the cutting speed are the two factors which are having highest difference between values 3.442 and 3.434 respectively. Based on taguchi prediction larger is the difference of S/N ratio value corresponding factor will have more effect on the surface roughness. Thus it can be concluded that with increase in the value of depth of cut and cutting speed, the value of surface roughness (Ra) will also increases. The result for data analysis for Ra values which is calculated with the help of taguchi method are shown in the table 6 below where (SS is sum of squares, DF is degree of freedom, F is variance ratio, P is significant factor, PE is percentage contribution and MS is mean of sum of squares). Thus it seems that in both table 5 and figure 2 that first level of factor A (insert radius), second level of B (cutting speed), second level of C (feed rate) and second level of D (depth of cut) are the optimum cutting parameters for the current turning process.

Table 6 : Result of analysis of variance for surface roughness

Factor	SS	DF	MS	F	% contribution	P value
A	8.3669	2	4.1834	5.196	17.29	0.483
B	17.631	2	8.8157	10.95	36.45	0.043
C	0.3965	2	0.1982	0.246	0.819	0.292
D	20.365	2	10.182	12.64	42.10	0.001
Error	1.6101	2	0.8050		3.32	
Total	48.370	10	4.8370			

Table 6 shows the result of ANOVA for surface roughness. From the data it is found that the most significant parameter among the four can be determined by the P value which should be less than 0.05. So, in this study the value for P is less in case of factor D which refers to depth of cut. The optimum condition for carrying out the final experiment will be A_1 B_2 C_2 D_2 i.e. insert radius 0.4mm, cutting speed 79m/min, feed rate 0.1mm/rev, depth of cut 0.6mm.

V. Confirmation Test

Once the optimum level of process parameters are selected, the final step is to predict and verify the improvement of the performance characteristics using the optimum level of the process parameters. The estimated S/N can be calculated by using the equation (4);

$$n^{i} = n_m + \sum_{i=1}^{q} \cdot (n - n_m) \quad (4)$$

Where n = mean S/N ratio at the optimum level, n_m is the total mean of the S/N ratio and q is the number of the process parameters that significantly affect the performance characteristics. The predicted and calculated surface roughness and S/N values are given in table 7 below;

Table 7 : Result of the confirmation experiment

	Optimum cutting parameters	
	Prediction	Experiment
Level	A1B2C2D2	A1B2C2D2
Surface roughness	1.291111	1.288889
S/N ratio	-2.12927	-2.20431
Improvement in S/N ratio	0.07504	

Good agreement has been found between the predicted machining performance and actual machining performance. The 0.07504dB improvement of the S/N ratio for the individual performance characteristics is needed. The confirmation experiment result confirms the optimum cutting parameters with performance characteristics in turning operation.

VI. Conclusion

The taguchi experimental design was used to determine the optimum cutting parameters in turning of alloy steel EN 47. Experiment results were analysed using ANOM and ANOVA techniques. The result obtained in the study is as follows:

- L_9 Orthogonal array has been selected for three different levels of process parameters i.e. insert radius, cutting speed, feed rate, depth of cut by using taguchi concept as a result nine experiments were conducted instead of 27 experiments. Surface roughness and S/N ratio for the surface roughness were measured and calculated respectively according to L_9 orthogonal array. The maximum value of S/N ratio is calculated using smaller is better equation. Optimum cutting condition which responds to maximum -2.129 S/N value of the smaller R_a value for the surface roughness in hard turning 1.277 were found to be insert radius 0.4mm, cutting speed 79m/min, feed rate 0.1mm/rev, depth of cut 0.6mm.
- Variance analysis was applied to S/N ratio to find out the effect of cutting parameters on surface roughness. According to the ANOVA analysis it was found the depth of cut influence the surface roughness the most at the reliability level of 95%.
- The improvement of the S/N ratio from optimum cutting parameters to the experimental cutting parameters is about 0.07504dB
- The surface roughness is decreased by 3.52%

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