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Simultaneous Optimization of Machining Parameters and Tool Geometry Specifications in Turning Operation of AISI1045 Steel

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***Abstract*—**Machining is an important manufacturing process used to produce a wide variety of metallic parts. Among various machining processes, turning is one of the most important one which is employed to shape cylindrical parts. In turning, the quality of finished product is measured in terms of surface roughness. In turn, surface quality is determined by machining parameters and tool geometry specifications. The main objective of this study is to simultaneously model and optimize machining parameters and tool geometry in order to improve the surface roughness for AISI1045 steel. Several levels of machining parameters and tool geometry specifications are considered as input parameters. The surface roughness is selected as process output measure of performance. A Taguchi approach is employed to gather experimental data. Then, based on signal-to-noise (S/N) ratio, the best sets of cutting parameters and tool geometry specifications have been determined. Using these parameters values, the surface roughness of AISI1045 steel parts may be minimized. Experimental results are provided to illustrate the effectiveness of the proposed approach.

***Keywords*—**Taguchi method; turning parameters; tool geometry specifications; S/N ratio; statistical analysis

I. INTRODUCTION

MANY industrial parts are produced by various machining operations, among which turning is one of the important one used in wide variety of industrial application [1]. This method relies on cutting action of a tool to remove material from the surface of the work piece. As in the case of all machining processes, the quality of turning operation is significantly affected by the process tuning parameters. There are several process parameters in turning. The most important ones include cutting speed, feed rate, rake angle, clearance angle, end cutting edge angle and side cutting edge angle [2]. In terms of machined product, the main quality measure is the attainable surface quality. Therefore, it is of great interest to study the effects of tuning parameters on the process response characteristic. Many attempts have been made to determine the optimum values of the process parameters in turning operation [3-8]. Several research have been focused on study the effects of tool geometry specifications on quality characteristics and determined their optimum values [9-12].

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However, in these researches machining parameters and tool geometry were considered separately. In this study, the surface roughness is considered as the performance measure since in many industrial applications, it is the main constraint on the process applicability. In addition, machining parameters and tool geometry specifications are simultaneously taken into account. The proposed approach employs design of experiments (DOE) and analysis of variance (ANOVA) for process modeling and optimization.In recent years, determining an optimal set of process parameters values to achieve a certain output characteristics has been the prime interest by many researchers. Although there are few studies in modeling and optimization of process parameters in turning, most of them are limited to the particular circumstances and are computationally complex.The present study attempts to make use of experimental data to relate important process parameters to process output variable, through developing analysis of variance.In the next stage, the Signal to Noise ratio is used in order to identify a proper set of process parameters that can produce the best roughness quality in the considered range.

II. EXPERIMENTAL PROCEDURE

The material used for these experiments was AISI1045 steel, with chemical composition presented in Table 1.

TABLE I
COMPOSITION OF MATERIAL USED FOR EXPERIMENTS

Chemical Composition						
C	Si	Mn	Cr	Mo	Ni	**Others**
0.46	Max. 0.40	0.65	Max. 0.40	Max. 0.10	Max. 0.40	**(Cr+Mo+Ni) = max 0.63**

A medium duty lathe with 2kw spindle power was used to perform experiments. The tool employed in experiments was HSS (5% Cobalt). This was selected since the tool angles can be implemented simply in this kind of cutting tools. Fig 1 shows a number of tools that were used to conduct the experiments. The average surface roughness (Ra) in the direction of the tool movement was measured in three different places of the machined surface using a surface roughness tester, Taylor-Hobson, with a cut off 0.8mm. Finally, surface mean roughness (Ra) in microns value of the three locations was considered for the particular trail.

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Fig. 1 Some sample tools used in experiments

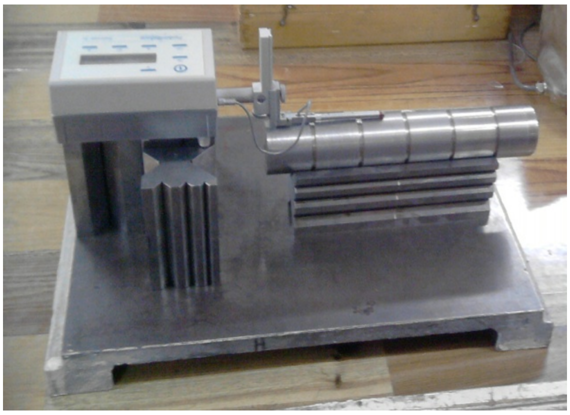

Fig. 2 Overall configuration of a Taylor-Hobson roughness tester

III. MODELING DEVELOPEMENT

The important controlling process parameters and tool geometry in turning include rake angle (γ), side cutting edge angle (χ), end cutting edge angle (χ'), cutting speed (V) and feed rate (f). In turn depth of cut, nose radius and free angle are set as constant parameters. Input parameters accompanied with different levels are shown in Table 2.

TABLE II
INPUT PARAMETERS IN DIFFERENT LEVELS

	γ **(Degree)**	χ **(Degree)**	χ' **(Degree)**	V **(m/min)**	f **(mm/rev)**
1	2	0	4	18	0.05
2	5	10	8	36	0.2
3	10	20	12	52	0.35
4	15	30	16	73	0.5
5	20	40	20	104	0.65

In this study, surface roughness has been chosen as the main process response characteristics to investigate the influence of the above parameters. The experimental results were obtained using design of experiment (DOE) technique by Taguchi approach. Taguchi espoused an excellent philosophy for quality control in the manufacturing industries. Indeed. his doctrine is creating an entirely different breed of engineers who think, breathe and live quality. His philosophy has far reaching consequences, yet it is founded on three very simple and fundamental concepts. The whole of the technology and techniques arise entirely out of these three ideas. These concepts are as follows:

- Quality should be designed into the product and not inspected into it.
- Quality is best achieved by minimizing the deviation from a target.
- The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

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

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

The optimum condition is identified by studying the main effects of each of the factors. The process involves minor arithmetic manipulation of the numerical results and usually can be done with the help of a simple calculator. The main effects indicate the general trend of the influence of the factors [13]. Knowing the characteristic, i.e., whether a higher or lower value produces the preferred result, the levels of the factors which are expected to produce the best results can be predicted. The knowledge of the contribution of individual factors is a key to deciding the nature of the control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factor. Study of the ANOVA table for a given analysis helps to determine which of the factors need control and which do not.Once the optimum condition is determined, it is usually a good practice to run a confirmation experiment. It. is, however, possible to estimate performance at the optimum condition from the results of experiments conducted at a non-optimum condition. It should be noted that the optimum conditions may not necessarily be among the many experiments already carried out, as the Orthogonal Array for experiments represents only a small fraction of all the possibilities.Taguchi suggests two different routes to carry out the complete analysis. First, the standard approach, where the results of a single run, or the average of repetitive runs, are processed through main effect and ANOVA analysis as identified above. The second approach, which he strongly recommends for multiple runs, is to use signal to noise ratio *S/N* for the same steps in the analysis. *S/N* analysis determines the most robust set of operating conditions from variations within the results [13].

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Table 3 shows some of the experiment settings obtained by Taguchi DOE matrix, Orthogonal Array L_{25}. As shown, a total of 25 experiments were performed to gather the required data. In this table, the first five columns show the process parameters settings given by Taguchi DOE matrix. The last column (Ra) is the measured process output resulted from different experiments.

TABLE III
DOE MATRIX AND RESULTS FOR THE TURNING

Row	γ	X	X'	V	f	$\overline{R}_a$
1	1	1	1	1	1	8.13
2	1	2	2	2	2	9.12
3	1	3	3	3	3	28.6
4	1	4	4	4	4	20.6
5	1	5	5	5	5	2.11
6	2	1	2	3	4	8.38
7	2	2	3	4	5	4.01
8	2	3	4	5	1	1.5
9	2	4	5	1	2	5.17
10	2	5	1	2	3	40.2
11	3	1	3	5	2	2.1
12	3	2	4	1	3	9.88
13	3	3	5	2	4	7.53
14	3	4	1	3	5	15.5
15	3	5	2	4	1	3.37
16	4	1	4	2	5	3.25
17	4	2	5	3	1	1.9
18	4	3	1	4	2	4.1
19	4	4	2	5	3	4.42
20	4	5	3	1	4	39.4
21	5	1	5	4	3	1.85
22	5	2	1	5	4	3
23	5	3	2	1	5	14.6
24	5	4	3	2	1	1.58
25	5	5	4	3	2	2.1

A. Signal to Noise Ratio

In Signal to Noise (S/N) analysis, the term "signal" represents the desirable values; while the "noise" delineates the undesirable values. The formulae for signal-to-noise are designed such that the experimentalist can always select the larger factor level settings to optimize the quality characteristics of an experiment. Therefore, the method of calculating the signal-to-noise ratio depends on whether the quality characteristic smaller-the-better, larger-the-better or nominal-the-better formulation is desired [8].In this sense the smaller the better characteristic is given by:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}(yi)^2\right) \quad (1)$$

The larger the better output is represented as:

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}\right) \quad (2)$$

Finally the nominal the better characteristic may be stated by:

$$S/N = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}(yi-yo)^2 \quad (3)$$

In the above equations, (y_i) is the value of the output (surface roughness) for the test in *ith* trial and (n) is the number of tests in the trial. In the problem under consideration, the high signal-to-noise ratios are always preferred. For lower-the-better characteristics, this translates into lower process average and improved consistency from one unit to the next or both. In this study the quality characteristic has smaller-the-best formulation and hence Eq. (1) has been used. However, the cutting parameters for surface roughness still need to be known so that optimal combinations of the cutting parameter levels can be determined more accurately. This matter will be discussed using analysis of variance in the next section.

B. Analysis of Variance

Analysis of variance is a method of portioning variability into identifiable sources of variation and the associated degree of freedom in an experiment. The frequency test (F-test) is utilized in statistics to analyze the significant effects of the parameters, which form the quality characteristics [8].Table IV shows ANOVA analysis of S/N ratio for surface roughness. This analysis was performed for 5% level of significant, i.e., 95% level of confidence. The last column of the table shows the "percent" contribution (P) of each factor as the total variation, indicating its influence on the result.

TABLE IV
RESULTS OF ANOVA ANALYSIS OF S/N RATIO

	DF	SeqSS	Adj SS	AdjMS	F Test	P value	P(%)
X	4	422.7	422.7	105.69	8.80	0.029	14.17
X'	4	312.1	312.1	78.02	6.50	0.049	9.98
γ	4	568.7	568.7	142.18	11.84	0.017	19.69
V	4	629.4	629.4	157.35	13.10	0.014	21.98
f	4	662.8	662.8	165.70	13.80	0.013	23.25
Error	4	48.05	48.05	12.01			10.91
Total	24	2643					100

From the analysis of Table 4 it is apparent that, the F-values of cutting speed, feed rate, rake angle, side cutting edge angle and end cutting edge angle were all greater than $F_{0.05,4,4} = 6.38$ and have statistical as well as physical significance on the

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surface roughness. Fig. 3 shows the percent effect of each parameter on the surface roughness. It is illustrated that feed rate has the most significant effect on the output response (surface roughness). Other significant parameters are, in turn, cutting speed, rake angle, side cutting edge angle and end cutting edge angle. These results can be used to optimally determine the best set of machining parameters as well as tool geometry specification in order to achieve the best possible surface finish.

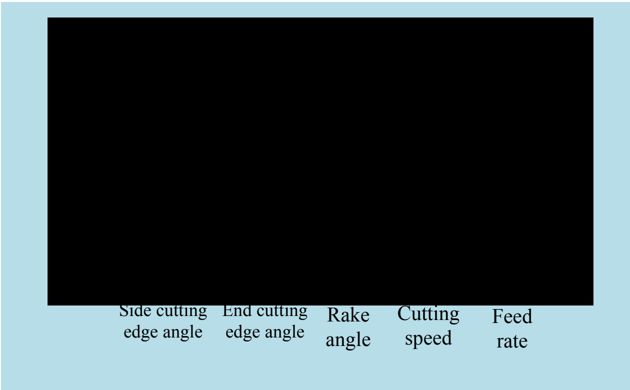

Fig. 3 Relative effects of each parameter on surface roughness (%)

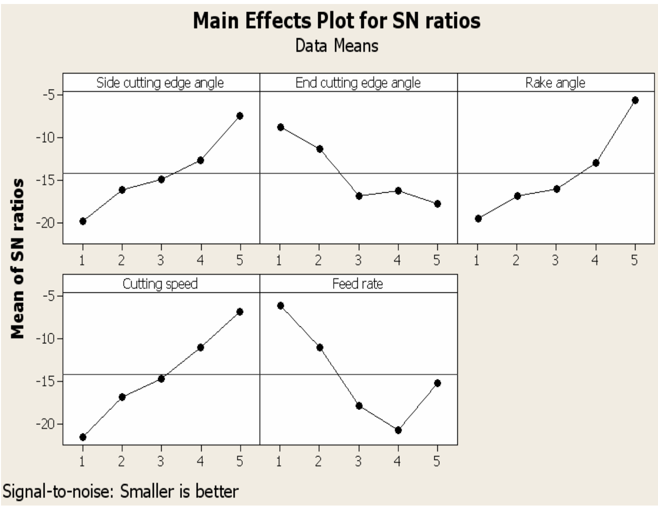

Fig. 4 Means S/N ratio for the input parameters

Fig. 4 shows five graphs, each of which represent the mean S/N ratio for the side cutting edge angle, end cutting edge angle, rake angle, feed rate and cutting speed, respectively.The values of the graphs indicate that, based on S/N ratio, the optimal machining and tool geometry parameters for surface roughness are x_5, x'_1, γ_5, v_5 and f_1.

IV. CONCLUSIONS

In many industrial applications, the quality of machined part is measured in terms of Surface roughness. To achieve a high surface quality, both machining parameters and tool geometry specifications should be set at proper levels. This study investigates the overall effects of turning parameter and tool geometry specifications on surface roughness of AISI 1045 steel parts. The important turning parameters considered here are cutting speed and feed rate. Also, rake angle, side cutting edge angle and end cutting edge angle are considered as tool geometry specifications. To model the turning process, a Taguchi based method has been employed for experimental tests. Next, analysis of variance (ANOVA) was employed to determine optimal values of input parameters to achieve minimum surface roughness; as the process output characteristics. For the material under investigation, the optimal machining and tool geometry parameters are found to be: x_5, x'_1, γ_5, v_5 and f_1. In addition, the percent effect of each these parameters on the output have been determined. The results illustrates that feed rate has slightly more effect on the surface roughness than the cutting speed. With minor modifications, the approach proposed in this study can readily be used to model and optimize other machining operations.

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