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Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation

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ABSTRACT: *Taguchi Method is a statistical approach to optimize the process parameters and improve the quality of components that are manufactured. The objective of this study is to illustrate the procedure adopted in using Taguchi Method to a lathe facing operation. The orthogonal array, signal-to-noise ratio, and the analysis of variance are employed to study the performance characteristics on facing operation. In this analysis, three factors namely speed; feed and depth of cut were considered. Accordingly, a suitable orthogonal array was selected and experiments were conducted. After conducting the experiments the surface roughness was measured and Signal to Noise ratio was calculated. With the help of graphs, optimum parameter values were obtained and the confirmation experiments were carried out. These results were compared with the results of full factorial method.*

Keywords: *Annova, Design of Experiments, Facing Operation, Orthogonal Array, S/N Ratio, Taguchi Method.*

I. Introduction

Taguchi method is a statistical method developed by Taguchi and Konishi [1]. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in Engineering, such as Biotechnology [2] etc. Professional statisticians have acknowledged Taguchi's efforts especially in the development of designs for studying variation. Success in achieving the desired results involves a careful selection of process parameters and bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors. Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyze the data and predict the quality of components produced.

Here, an attempt has been made to demonstrate the application of Taguchi's Method to improve the surface finish characteristics of faced components that were processed on a lathe machine. Surface roughness is a measure of the smoothness of a products surface and it is a factor that has a high influence on the manufacturing cost. Surface finish also affects the life of any product and hence it is desirable to obtain higher grades of surface finish at minimum cost.

II. Approach to Product/Process Development

Many methods have been developed and implemented over the years to optimize the manufacturing processes. Some of the widely used approaches are as given below:

1.1 Build-Test-Fix

The "Build-test-fix" is the most primitive approach which is rather inaccurate as the process is carried out according to the resources available, instead of trying to optimize it. In this method the process/product is tested and reworked each time till the results are acceptable.

1.2 One Factor at a Time

The "one-factor-at-a-time" approach is aimed at optimizing the process by running an experiment at one particular condition and repeating the experiment by changing any other one factor till the effect of all factors are recorded and analyzed. Evidently, it is a very time consuming and expensive approach. In this process, interactions between factors are not taken in to account.

1.3 Design of Experiments

The Design of Experiments is considered as one of the most comprehensive approach in product/process developments. It is a statistical approach that attempts to provide a predictive knowledge of a complex, multi-variable process with few trials. Following are the major approaches to DOE:

1.3.1 Full Factorial Design

A full factorial experiment is an experiment whose design consists of two or more factors, each with a discrete possible level and whose experimental units take all possible combinations of all those levels across all such factors. Such an experiment allows studying the effect of each factor on the response variable, as well as on the effects of interactions between factors on the response variable. A common experimental design is the one with all input factors set at two levels each. If there are k factors each at 2 levels; a full factorial design has 2^k runs. Thus for 6 factors at two levels it would take 64 trial runs.

1.3.2 Taguchi Method

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better.

III. Steps Involved in Taguchi Method

The use of Taguchi's parameter design involves the following steps [3].

a. Identify the main function and its side effects.
b. Identify the noise factors, testing condition and quality characteristics.
c. Identify the objective function to be optimized.
d. Identify the control factors and their levels.
e. Select a suitable Orthogonal Array and construct the Matrix
f. Conduct the Matrix experiment.
g. Examine the data; predict the optimum control factor levels and its performance.
h. Conduct the verification experiment.

IV. Approach to the Experimental Design

In accordance with the steps that are involved in Taguchi's Method, a series of experiments are to be conducted. Here, facing operation on mild steel components using a lathe has been carried out as a case study. The procedure is given below.

4.1 Identification of Main Function and its side effects

Main function: Facing Operation on MS work piece using lathe machine.
Side effects : Variation in surface finish.

Before proceeding on to further steps, it is necessary to list down all the factors that are going to affect or influence the facing process and from those factors one has to identify the control and noise factors. The "Factors" that affect facing operation on a lathe machine are listed in the table 4.1.

Table 4.1: Factors that affect facing operation

Control factors	Noise Factors
Cutting speed	Vibration
Depth of cut	Raw material variation
Feed rate	Machine Condition
Nose radius	Temperature
Coolant	Operator Skill

After listing the control and the noise factors, decisions on the factors that significantly affect the performance will have to be ascertained and only those factors must be taken in to consideration in constructing the matrix for experimentation. All other factors are considered as Noise Factors.

4.2 Identifying the Testing Conditions and Quality Characteristics To Be Observed

Quality Characteristic: Surface finish
Work piece material: Mild Steel

Cutting tool: Tungsten: Carbide Tipped tool
Operating Machine: Lathe machine
Testing Equipment: Portable surface tester

4.3 Identify The Objective Function

Objective Function: Smaller-the-Better

S/N Ratio for this function: $\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} {y^2}_i\right)$ [4]

Where, n= Sample Size, and y= Surface Roughness in that run.

4.4 Identifying the Control Factors and their levels

The factors and their levels were decided for conducting the experiment, based on a "brain storming session" that was held with a group of people and also considering the guide lines given in the operator's manual provided by the manufacturer of the lathe machine. The factors and their levels are shown in table 4.2.

Table 4.2 Selected Factors and their Levels.

FACTORS	LEVELS		
	1	**2**	**3**
Cutting speed(v, rpm)	960	640	1280
Depth of cut(t, mm)	0.3	0.2	0.4
Feed rate(f, mm/min)	145	130	160

4.5 Selection of Orthogonal Array

To select an appropriate orthogonal array for conducting the experiments, the degrees of freedom are to be computed. The same is given below:

Degrees of Freedom: 1 for Mean Value, and
8= (2x4), two each for the remaining factors
Total Degrees of Freedom: 9

The most suitable orthogonal array for experimentation is L9 array as shown in Table 4.3[5]. Therefore, a total nine experiments are to be carried out.

Table 4.3 Orthogonal Array (OA) L9

Experiment No.	Control Factors		
	1	**2**	**3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

4.6 Conducting The Matrix Experiment

In accordance with the above OA, experiments were conducted with their factors and their levels as mentioned in table 4.2. The experimental layout with the selected values of the factors is shown in Table 4.4. Each of the above 9 experiments were conducted 5 times (45 experiments in all) to account for the variations that may occur due to the noise factors. The surface roughness (Ra) was measured using the surface roughness tester. The table 4.5 shows the measured values of surface roughness obtained from different experiments.

Table 4.4 OA with Control Factors

Experiment No.	Control Factors		
	V(rpm)	**t(mm)**	**F(mm/min)**
1	960	0.3	145
2	960	0.2	130
3	960	0.4	160
4	640	0.3	160

5	640	0.2	145
6	640	0.4	130
7	1280	0.3	130
8	1280	0.2	160
9	1280	0.4	145

Table 4.5 Measured values of surface roughness

Experiment No.	**Surface Roughness (R_a, m)**					
	1	**2**	**3**	**4**	**5**	**Mean**
1	2.35	2.43	1.94	2.91	2.77	2.48
2	2.5	3.6	2.66	2.98	2.64	2.876
3	2.43	2.82	4.01	2.96	4.1	3.264
4	2.24	3.38	2.45	4.05	4.79	3.382
5	2.54	3.67	2.70	4.25	4.37	3.506
6	4.76	4.25	3.19	3.36	4.35	3.982
7	2.04	2.49	3.84	1.71	3.79	2.834
8	4.4	2.5	3.15	3.24	3.1	3.278
9	3.94	2.19	2.31	2.44	3.30	3.306

4.7 Examination of Data

The following are the experimental results of the work carried out.

4.7.1 Experimental Details

Since the objective function (Surface Finish) is smaller-the-better type of control function, was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated as shown in Table 4.6.

Table 4.6 Tabulated S/N ratios

Experiment No.	**S/N Ratio (dB)**
1	-7.9702
2	-9.2568
3	-10.4539
4	-10.9196
5	-11.0971
6	-12.1010
7	-9.2385
8	-10.4642
9	-9.2941

The S/N ratio for the individual control factors are calculated as given below:

$S_{s1}=(\eta_1+\eta_2+\eta_3)$, $S_{s2}=(\eta_4+\eta_5+\eta_6)$ & $S_{s3}=(\eta_7+\eta_8+\eta_9)$

$S_{f1}=(\eta_1+\eta_4+\eta_7)$, $S_{f2}=(\eta_2+\eta_5+\eta_8)$ & $S_{f3}=(\eta_3+\eta_6+\eta_9)$

$S_{t1}=(\eta_1+\eta_5+\eta_9)$, $S_{t2}=(\eta_2+\eta_6+\eta_7)$ & $S_{t3}=(\eta_3+\eta_4+\eta_8)$

For selecting the values of η_1, η_2, η_3 etc. and to calculate S_{s1}, S_{s2} & S_{s3} see table 4.3.

η_k is the S/N ratio corresponding to Experiment k.

Average S/N ratio corresponding to Cutting Speed at level 1 = $S_{s1}/3$

Average S/N ratio corresponding to Cutting Speed at level 2 = $S_{s2}/3$

Average S/N ratio corresponding to Cutting Speed at level 3 = $S_{s3}/3$

j is the corresponding level each factor. Similarly S_{fj} and S_{tj} are calculated for feed and depth of cut.

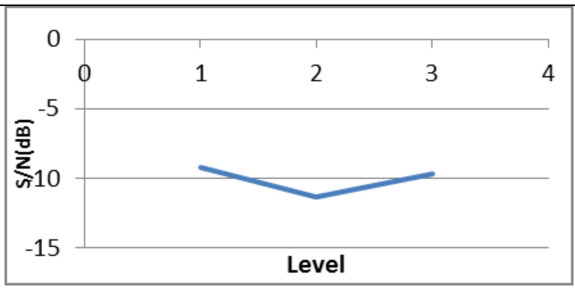
The average of the signal to noise ratios is shown in table 4.7.

Similarly S/N ratios can be calculated for other factors.

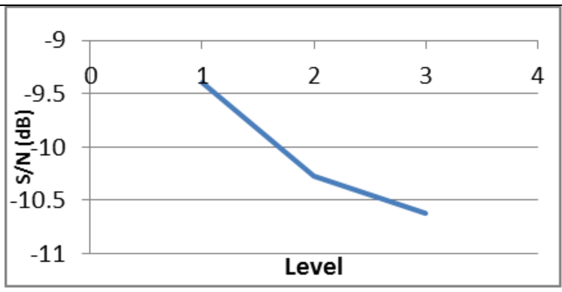
Table 4.7: Average S/N Ratios for each factor

Level	**Speed**		**Feed**		**Depth of Cut**	
	Sum (S_{sj})	**Avg S/N ratio**	**Sum (S_{fj})**	**Avg S/N ratio**	**Sum (S_{tj})**	**Avg S/N ratio**

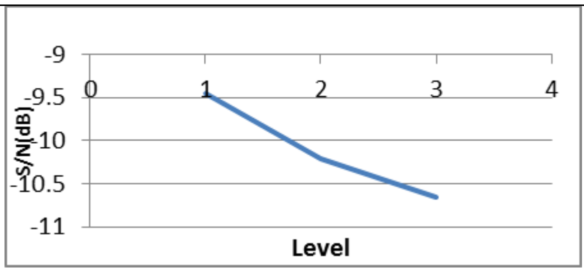
1	-27.6809	-9.2268	-28.3614	-9.3909	-28.1283	-9.45
2	-34.1177	-11.3722	-30.5963	-10.273	-30.8181	-10.21
3	-28.9968	-9.68	-31.8377	-10.616	-31.849	-10.65



(a). Speed



(b). Feed Rate



(c). Depth of Cut

For calculating the Surface Roughness the objective function, "smaller-the-better" type was used as shown.

$$\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as given in table 4.8.

Fig-1 Charts Showing Parameter Level v/s S/N Ratio

Table 4.8 Optimum values of factors and their levels

Parameter	**Optimum Value**
Speed (rpm)	960
Feed Rate (mm/min)	145
Depth of cut (mm)	0.3

4.7.2. Full Factorial Analysis

A full factorial analysis consists of conducting experiments taking into account all the possible combinations of the factors and their levels. As far as the following experiments are concerned the 3 factors i.e.; speed, feed, and depth of cut were considered at 3 different levels as shown in Table 4.9. These were compared with the results of the fractional factorial that was conducted using Taguchi method.

Table 4.9 Full Factorial Experiment Matrix

Experiment No.	**Parameters**			**Mean Surface Roughness, R_a(□m)**
	Speed(rpm)	**Depth of cut(mm)**	**Feed (mm/min)**	
1	960	0.3	145	2.48
2	960	0.2	145	3.26
3	960	0.4	145	2.57
4	960	0.3	130	2.62
5	960	0.2	130	2.876
6	960	0.4	130	2.87
7	960	0.3	160	2.74
8	960	0.2	160	4.35
9	960	0.4	160	3.264
10	640	0.3	145	3.82
11	640	0.2	145	3.506

12	640	0.4	145	3.41
13	640	0.3	130	2.96
14	640	0.2	130	3.45
15	640	0.4	130	3.982
16	640	0.3	160	3.382
17	640	0.2	160	5.04
18	640	0.4	160	4.25
19	1280	0.3	145	4.02
20	1280	0.2	145	4.03
21	1280	0.4	145	3.306
22	1280	0.3	130	2.834
23	1280	0.2	130	4.14
24	1280	0.4	130	3.3
25	1280	0.3	160	2.6
26	1280	0.2	160	3.278
27	1280	0.4	160	2.76

4.7.3 Comparison of full factorial analysis with Taguchi parameter design:

It is evident from the results of the full factorial analysis shown in Table 4.9, the best surface finish characteristics obtained were at 960 rpm, 0.3 mm depth of cut and 145 mm/min feed rate. From Taguchi parameter design the optimum parameter levels obtained were also the same (see Table 4.8). Thus, it can be noted that Taguchi parameter design will also give accurate results with lesser number of experiments to be performed.

4.8 Confirmation Experiment

The following table 4.10 shows confirmation experiments conducted using 960 rpm, 0.3 mm depth of cut and 145 mm/min feed rate. Total five sets of experiments were conducted and their surface roughness values were checked. It can be seen that the results are consistent.

Table 4.10 Confirmation Experiment

Experiment No.	**Surface Roughness, R_a (μm)**
1	2.43
2	2.23
3	2.86
4	2.51
5	2.21
Mean	2.448

V. ANNOVA AND ITS SIGNIFICANCE

Analysis of variance (ANOVA) is used to evaluate the response magnitude in (%) of each parameter in the orthogonal experiment. It is used to identify and quantify the sources of different trial results from different trial runs (i.e. different cutting parameters). The basic property of ANOVA is that the total sums of the squares (total variation) is equal to the sum of the SS (sums of the squares of the deviations) of all the condition parameters and the error components, i.e., adding the variations of each factors,

$$SS_T = SS_S + SS_f + SS_t + SS_e \qquad \text{(Eqn. 5.1)}$$

$$SS_T = \sum_1^n y_i^2 - \frac{G^2}{n} \qquad \text{(Eqn. 5.2)}$$

Where, G = *is the sum of the resulting data of all trial runs;* and *n* is the total number of the trial runs .

$$SS_k = \sum_{j=1}^{t} \left(\frac{{Sy_j}^2}{t}\right) - \frac{G^2}{n} \qquad \text{(Eqn. 5.3)}$$

Where k represents one of the tested parameters; j is level number of this parameter; Sy_j is sum of all trial results involving this parameter *k* at level j; *n* is the total number of trial runs. The following table 5.1 shows the results of the ANOVA.

Table 5.1 Sum of all squares of all deviations

Parameter	**DOF**	**SS**	**SS%**
Speed, S	2	7.7329	58.49
Feed, f	2	2.0689	15.65
Depth of cut, t	2	2.4541	18.56
Noise, e	2	0.9655	7.3
Total	8	13.2214	100

It can be seen from this table that for the surface finish (Ra), the contribution of cutting speed (58.49%) is more significant than depth of cut which is (18.56%). These factors are more significant than the feed rate (15.65%). It is clear that the effect of noise factor (7.3%) on surface finish is very low as compared to the control factors.

VI. CONCLUSION

This paper illustrates the application of the parameter design (Taguchi method) in the optimization of facing operation. The following conclusions can be drawn based on the above experimental results of this study:

- Taguchi's Method of parameter design can be performed with lesser number of experimentations as compared to that of full factorial analysis and yields similar results.
- Taguchi's method can be applied for analyzing any other kind of problems as described in this paper.
- It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameters.

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