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Optimization of Cutting Parameters in Rough Turning using Taguchi Method

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***Abstract* –A machining process involves many process parameters which directly or indirectly influence the surface quality of the product. Current investigation on turning process is a Taguchi optimization technique applied on the most effective process parameters i.e. feed, cutting speed and depth of cut. In this project Taguchi method is used to optimize cutting parameter for surface roughness and material removal rate. The obtained results were verified by using minitab software. The optimized value of cutting speed, feed rate and depth of cut is obtained for both MRR (material removal rate) and Surface roughness. Confirmation test is carried out for the purpose of verification. Main effect plots are generated and analyzed to find out the relationship between cutting parameter and variables. The details of experimentation and analysis are given in the following context.**

***Keywords* -Taguchi method, ANOVA, MRR, Surface roughness**

I. INTRODUCTION

Machining is a preferred manufacturing process to produce products with low cost and high quality. Machining economics are especially important since the advent of computer numerically controlled (CNC) machines, which require a large capital investment. The cost of machining on these machines is sensitive to the cutting conditions [6]. Hence, determining the optimum values for parameters like cutting speed, feed, and depth of cut, is critical. The selection of optimal machining parameters plays an important part in computer-aided manufacturing. The optimization of machining parameters is still the subject of many studies.

Selecting proper values for machining parameters such as cutting speed, feed rate, and depth of cut directly affects the machining economics in metal-cutting processes [3]. Several cutting constraints must be considered in machining operations. In turning operations, a cutting process can possibly be completed with a single pass or by multiple passes. Multi-pass turning is preferable over single-pass turning in the industry for economic reasons. A multi-pass cutting operation involves several roughing cuts and a single finishing cut. That makes the problem of determining the optimal cutting conditions more difficult and complicated. Machining parameters can be determined based on the machine operator's experience or by following the cutting handbook supplied by the equipment manufacturer. However, those data are not guaranteed to be optimal or even good for a particular cutting environment.

The purpose of this study is to efficiently determine the optimum turning operation parameters for achieving the lowest surface roughness and greater material removal rate, while considering a noise factor [1] [4].

Optimization is the act of obtaining the best result under given circumstances. In design, construction, and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function [5].

II. RESEARCH METHODOLOGY AND APPROACH

A.Taguchi Method

Taguchi is the developer of the Taguchi method. He proposed that engineering optimization of a processor product should be carried out in a three-step approach, i.e.

1. System design.
2. Parameter design.
3. Tolerance design.

The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following steps,

a) Identify the performance characteristics and select process parameters to be evaluated.
b) Determine the number of levels for the process parameters and possible interactions between the process parameters.

c) Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
d) Conduct the experiments based on the arrangement of the orthogonal array.

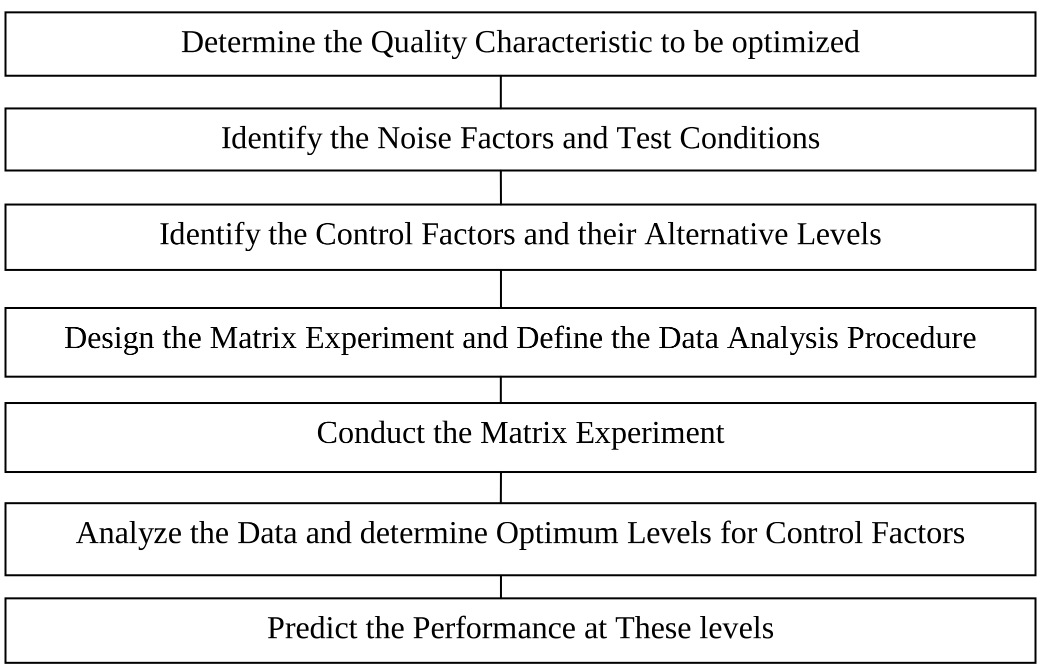
However, parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. To obtain high cutting performance in turning, the parameter design proposed by the Taguchi method is adopted in this project. Basically, experimental design methods were developed originally by Fisher. However, classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Taguchi recommends the use of the S/N ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the nominal the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the 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. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. Therefore, three objectives can be achieved through the parameter design of the Taguchi method, i.e.:

1. Determination of the optimal design parameters for a process or a product;
2. Estimation of each design parameter to the contribution of the quality characteristics; and
3. Prediction of the quality characteristics based on the optimal design parameters.

The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value.

III. METHODOLOGY

To carry out experiment, Taguchi design parameter was used and flow chart for Taguchi to Parameter Design is shown below. Flowchart of the Taguchi Method shown below provides a brief overview of the process followed by Taguchi's approach to parameter design.



IV. ANALYSIS FOR CUTTING PARAMETERS

Following steps are taken to complete the experimental work as per the project.

1. Orthogonal array experiment.
2. Analysis of the S/N ratio.
3. Analysis of variance.
4. Confirmation tests.

A. Orthogonal Array Experiment

The experimental layout for the three cutting parameters using the *L*9 orthogonal array is shown in Table 1. The *L*9 orthogonal array has three columns, and three levels.

TABLE 1 ORTHOGONAL ARRAY SELECTION CHART

Number of Levels	Number of Parameters (P)																													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32																					
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

- L9 Orthogonal was selected on the basis of number of parameters and levels

V. EXPERIMENT DETAILS

Turning operations are accomplished using a cutting tool; the high forces and temperature during machining create a very harsh 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. Therefore, surface roughness is another important index to evaluate cutting performance. Basically, MRR and surface roughness correlated strongly with cutting parameters such as cutting speed, feed rate, and depth of cut. Proper selection of the cutting parameters can secure better MRR and better surface roughness. Hence, design optimization of the cutting parameters based on the Taguchi method is adopted to improve the MRR and the surface roughness in a turning operation.

A. Work Material

GCI 25, (Gray Cast Iron)
Chemical Composition:
C 3.2%, Si 1.95%, Mn 0.7% ,Cr 0.15%
Tensile strength 250 n/mm^2, Brinell hardness 197-241 BHN

B. Cutting Tool

Turning Tool MVVNN 2020-K16 WIDAX.
Turning insert VAMG160408

C. Experimental Setup

CNC Turning Centre,
MTAB Make , Maxturn+ Ltd.
Spindle Speed: 150-3000rpm,
Feed range: 0-10000 mm/min

D. Parameters for Experiments with their levels

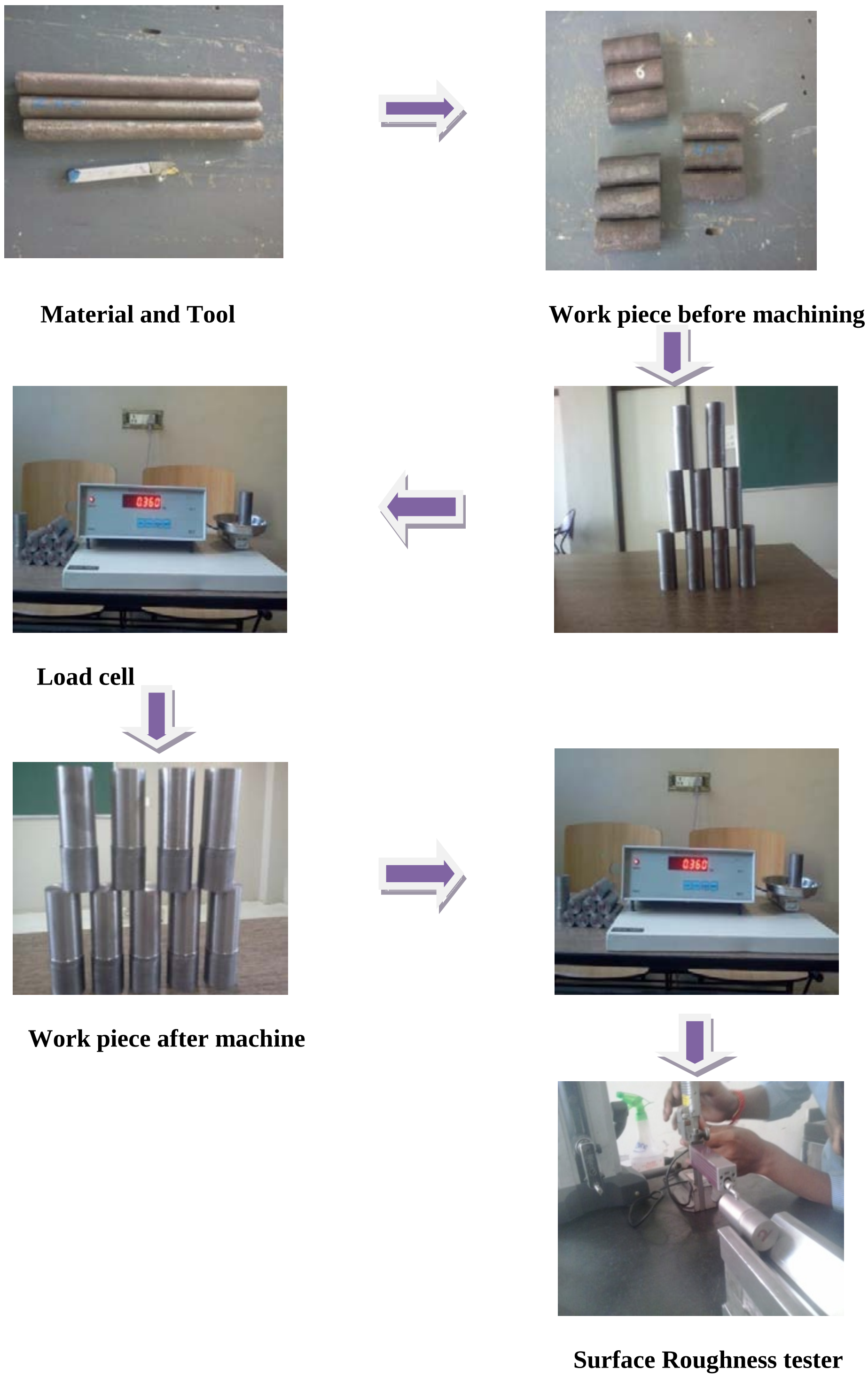
The machining parameters (control factors) chosen for experiment were (i) cutting speed, (ii) feed rate,(iii)depth of cut. The feasible space for the cutting parameters was defined by varying the cutting speed in the range 80-120 m/min, the feed rate in the range270-365 mm/min, and the depth of cut in the range 0.8-1.6 mm were shown in Table No.2. In the cutting parameter design, three levels of the cutting parameters were selected, shown in Table 3.Cutting speed, feed & depth of cut selected from design data book.

TABLE 2 CUTTING PARAMETERS

Cutting speed (m/min)	80 to 120
Feed rate (mm/min)	270 to 365
Depth of Cut (mm)	0.8 to 1.6

TABLE 3 CUTTING PARAMETERS AND THEIR LEVELS

Symbol	Cutting Parameters	Level 1	Level 2	Level 3
A	Cutting Speed	120	100	80
B	Feed Rate	270	340	365
C	Depth of Cut	0.8	1.2	1.6



Flow Diagram of experiment

VI. OBSERVATIONS OF EXPERIMENT

The experimental layout for the three cutting parameters using L_9 orthogonal array is shown in Table No.4

TABLE 4 L9 FOR CUTTING PARAMETERS

Expt. No	**Cutting Speed(m/min)**	**Feed Rate(mm/min)**	**Depth of Cut(mm)**
1	120	270	1.6
2	120	340	1.2
3	120	365	0.8
4	100	270	1.2
5	100	340	0.8
6	100	365	1.6
7	80	270	0.8
8	80	340	1.6
9	80	365	1.2

A.MRR (Material Removal Rate) Calculations

For calculation of MRR the casting bar 80mm length and 28mm diameter is selected. Initial weight of each test bar is taken from load cell. Depth of cut, speed & feed rate are selected as per L9 orthogonal array. Machining is carried out on specified length of material (50mm). Machining time is taken directly from CNC machine.

After machining, final weight of each test bar is determined from load cell. Finally MRR is calculated by using formula,

MRR= (Initial weight – Final weight) / machining time

Following table shows observations taken for calculation of MRR.

TABLE 5 EXPERIMENTAL RESULTS FOR MRR

Expt. No	**Cutting Speed (m/min)**	**Feed Rate (mm/min)**	**Depth of Cut(mm)**	**Initial Weight(gm)**	**Final Weight(gm)**	**Machining Time (s)**
1	120	270	1.6	0.369	0.343	12
2	120	340	1.2	0.360	0.339	10
3	120	365	0.8	0.365	0.355	9
4	100	270	1.2	0.352	0.336	12
5	100	340	0.8	0.361	0.349	10
6	100	365	1.6	0.366	0.343	9
7	80	270	0.8	0.360	0.347	12
8	80	340	1.6	0.352	0.328	10
9	80	365	1.2	0.359	0.340	9

The S/N ratio is defined as, S/N= - 10 log (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:

$$MSD= 1/n\sum (1/y^2).$$

TABLE 6 EXPERIMENTAL RESULTS FOR MRR AND S/N RATIO

Expt. No	Cutting Speed (m/min)	Feed Rate (mm/min)	Depth of Cut(mm)	MRR (kg/s)	S/N Ratio
1	120	270	1.6	2.166	6.7131
2	120	340	1.2	2.100	6.444
3	120	365	0.8	3.333	10.456
4	100	270	1.2	1.333	2.4966
5	100	340	0.8	1.200	1.5831
6	100	365	1.6	2.555	8.1478
7	80	270	0.8	1.083	0.6925
8	80	340	1.6	2.400	7.6042
9	80	365	1.2	2.111	6.4897

Regardless of the category of the 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. The S/N response table for MRR is shown in Table7

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TABLE 7 S/N RESPONSE TABLE FOR MRR

Symbol	Cutting Parameters	Mean S/N Ratio		
		Level 1	Level 2	Level 3
A	Cutting Speed	7.8710*	4.0758	4.9282
B	Feed Rate	3.3007	5.2104	8.3635*
C	Depth of Cut	4.2438	5.1434	7.4883*

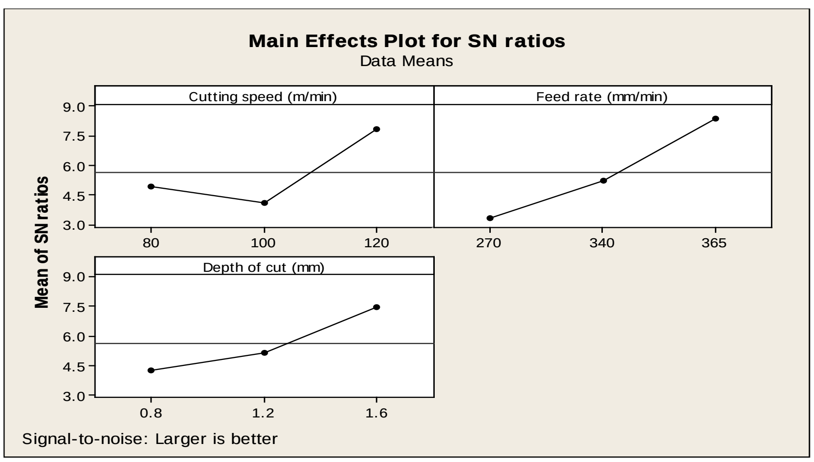

Fig.1 S/N vs. feed rate, Depth of cut, Cutting Speed for MRR

The above fig shows the graph of mean s/n ratio verses cutting parameters i.e. cutting speed, feed rate and depth of cut for material removal rate. On y axis mean s/n ratio is plotted and on x axis cutting parameter.

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N 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 S/N ratio n_m can be calculated as, $SS_T = \sum (n_i - n_m)^2$ 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. Results analysis of variance for MRR is shown in Table No.8.

TABLE 8 ANALYSIS OF VARIANCE FOR MRR

Symbol	Cutting Parameters	Sum of Squares	Contribution (%)
A	Cutting Speed	23.7902	27.4470
B	Feed Rate	39.2224	45.251
C	Depth of Cut	16.8346	19.4223
Error		6.82	7.87
Total		86.6761	99.99%

B.Computation of Surface Roughness

Surface roughness is measured by surface roughness tester; Unit of surface roughness is microns. Surface roughness is a measure of the technological quality of a product and a factor that greatly influences manufacturing cost. It describes the geometry of the machined surfaces and combined with the surface texture. The mechanism behind the formation of surface roughness is very complicated and process dependent. The average surface roughness , which is the most widely used surface finish parameter in industry, was selected for this study, being the arithmetic average of the absolute value of the heights of roughness irregularities from the mean value measured within a sampling length of 5 mm. Following Table N.9 shows the readings for surface roughness.

TABLE 9 EXPERIMENTAL RESULTS FOR SURFACE ROUGHNESS

Expt. No	Cutting Speed(m/min)	Feed Rate(mm/min)	Depth of Cut(mm)	Surface Roughness
1	120	270	1.6	3.93
2	120	340	1.2	4.83
3	120	365	0.8	5.20
4	100	270	1.2	4.97
5	100	340	0.8	7.29
6	100	365	1.6	9.67
7	80	270	0.8	7.57
8	80	340	1.6	10.39
9	80	365	1.2	13.34

The-lower-the-better quality characteristics for surface roughness should be taken for obtaining optimal cutting performance. The M.S.D. for the-lower-the-better quality characteristic can be expressed as, MSD= $1/m\sum (y^2)$ .Experimental results for Surface Roughness and S/N ratio is shown in Table No 10.

TABLE 10 EXPERIMENTAL RESULTS FOR SURFACE ROUGHNESS AND S/N RATIO

Expt. No	Cutting Speed (m/min)	Feed Rate (mm/min)	Depth of Cut(mm)	Surface Roughness	S/N Ratio
1	120	270	1.6	3.93	-11.8878
2	120	340	1.2	4.83	-13.6789
3	120	365	0.8	5.20	-14.320
4	100	270	1.2	4.97	-13.9279
5	100	340	0.8	7.29	-17.2545
6	100	365	1.6	9.67	-19.7085
7	80	270	0.8	7.57	-17.8519
8	80	340	1.6	10.39	-20.3322
9	80	365	1.2	13.34	-22.5031

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. The S/N response table for surface roughness is shown in Table11.

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TABLE 11 S/N RESPONSE TABLE FOR SURFACE ROUGHNESS

Symbol	Cutting Parameters	Mean S/N Ratio		
		Level 1	Level 2	Level 3
A	Cutting Speed	-13.2955*	-16.9633	-20.1391
B	Feed Rate	-14.4656*	-17.0885	-18.8438
C	Depth of Cut	-16.3854*	-16.7030	-17.3095

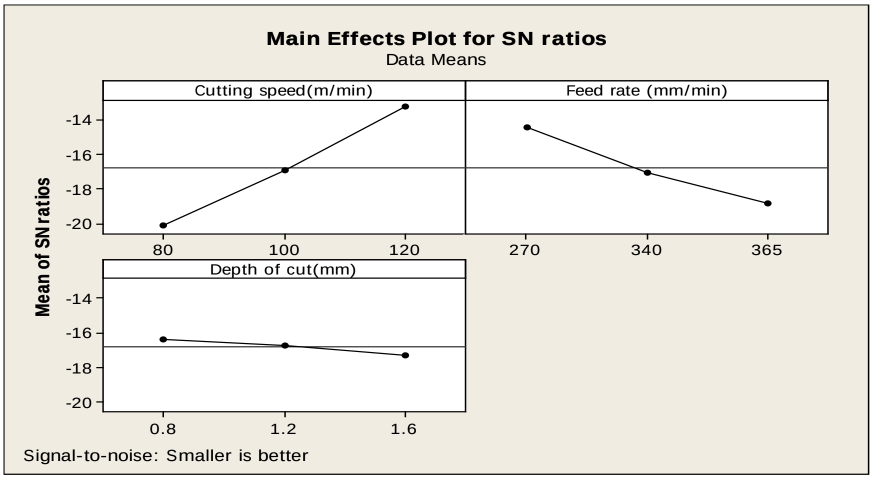

Fig.2 S/N Vs Cutting Speed, Feed Rate And DOC For Surface Roughness

The above fig shows the graph of mean s/n ratio verses cutting parameters i.e. cutting speed, feed rate and depth of cut for surface roughness. On y axis mean s/n ratio is plotted and on x axis cutting parameter.

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N 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 S/N ratio n_m can be calculated as:

$SS_T = \sum (n_i - n_m)^2$ Results analysis of variance for Surface Roughness is shown in Table No.12

TABLE 12 ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS

Symbol	Cutting Parameters	Sum of Squares	Contribution (%)
A	Cutting Speed	70.3733	68.62
B	Feed Rate	29.1293	28.40
C	Depth of Cut	1.3227	1.29
Error		1.7294	1.64
Total		102.554	99.98

C. Confirmation Test

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristics using the optimal level of the design parameters. The estimated S/N ration n^{-} using the optimal level of the design parameters can be calculated as:

$$n^{-} = n_m + \sum_{i=0}^{0} (ni - nm)$$

Table 13 shows the comparison of the predicted MRR with the actual MRR using the optimal cutting parameters, good agreement between the predicted and actual MRR being observed.

TABLE 13 CONFIRMATION EXPERIMENT FOR MRR

	Initial cutting parameters	**Optimal Cutting Parameters**	
		Prediction	**Expt.**
Level	A1B1C3	A1B3C3	A1B3C3
MRR	2.166	4.1783	2.875
S/N ratio	6.7131	12.47	9.1727

Table 14.Shows the comparison of the predicted surface roughness with the actual surface roughness using the optimal cutting parameters, where a predicted surface roughness consistent with the actual surface roughness is noted.

TABLE 14 CONFIRMATION EXPERIMENT FOR SURFACE ROUGHNESS

	Initial cutting parameters	**Optimal Cutting Parameters**	
		Prediction	**Expt.**
Level	A1B2C2	A1B1C1	A1B1C1
Surface Roughness	4.83	3.3681	1.69
S/N ratio	-13.6789	-10.5479	-4.5577

Calculation using Minitab software

1.Taguchi Analysis: MRR (kg/s) versus Cutting speed, Feed rate and Depth of cut

Response Table for Signal to Noise Ratios
Larger is better

Level	**Cutting speed (m/min)**	**Feed rate (mm/min)**	**Depth of cut (mm)**
1	7.871	3.301	4.244
2	4.076	5.211	5.144
3	4.928	8.365	7.488
Delta	3.795	5.064	3.244
Rank	2	1	3

Response Table for Means

Level	**Cutting speed (m/min)**	**Feed rate (mm/min)**	**Depth of cut (mm)**
1	1.865	1.527	1.872
2	1.696	1.900	1.848
3	2.533	2.666	2.374
Delta	0.837	1.139	0.526
Rank	2	1	3

2. Taguchi Analysis: Ra value versus Cutting speed, Feed rate and Depth of cut

Response Table for Signal to Noise Ratios
Smaller is better

Level	Cutting speed (m/min)	Feed rate (mm/min)	Depth of cut (mm)
1	-13.30	-14.47	-16.39
2	-16.96	-17.09	-16.70
3	-20.14	-18.84	-17.31
Delta	6.84	4.38	0.92
Rank	1	2	3

Response Table for Means

Level	Cutting speed (m/min)	Feed rate (mm/min)	Depth of cut (mm)
1	10.433	5.490	6.687
2	7.310	7.503	7.713
3	4.653	9.403	7.997
Delta	5.780	3.913	1.310
Rank	1	2	3

VII. RESULTS AND DISCUSSION

Based on experimental and analytical data obtained, the optimization of a system can be achieved by, setting the levels of parameters in such a way that variation in the output is minimized.

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 surface roughness were determined.

1. Statistically designed experiments based on Taguchi methods were performed using L-9 orthogonal array to analyze MRR and surface roughness as response variable.
2. Based on the S/N ratio results in Table No.7 and Table No. 11, we conclude that the A1B3C3 and A1B1C1 settings are the optimal machining parameters for MRR and surface roughness.
3. Use of cutting speed at level 1 (120m/min), feed at level 3(365 mm/min) and depth of cut at level 3 (1.6mm) is recommended to obtain higher MRR.
4. Use of cutting speed at level 1 (120 m/min), feed at level 1(270 mm/min) and depth of cut at level 1 (0.8mm) is recommended to obtain better surface roughness.
5. Confirmation experiments verified the effectiveness of the present approach in finding optimal machining parameters which is specified in table no 13 and 14.
6. The improvement of the MRR and surface roughness from the initial machining parameters to the optimal cutting parameters is about 26.8% and 66.66%.
7. From Table No.8, the MRR was affected strongly by feed rate (45.251%), whereas cutting speed (27.4470%) and depth of cut (19.4223%).
8. From Table No.12, the surface roughness was strongly affected by feed rate (28.40%) whereas cutting speed 68.42%) and depth of cut (1.29%).

VIII. 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 study was focused on the application of Taguchi optimization technique to find the optimum levels of process parameters used in turning of GCI bars. In doing this, the orthogonal arrays of L9, the S/N ratio, ANOVA were utilized in integrated manner. Taguchi’s robust orthogonal array design method is suitable to analyze the MRR and surface roughness problem. It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters.

This project demonstrates how to use Taguchi parameter design for optimizing machining performance with minimum cost and time to industrial readers. This project has discussed an application of the Taguchi method for optimization the cutting parameters in turning operations. As shown in this study, the Taguchi method provides a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for the most optimization techniques. It has been shown that MRR and surface roughness can be improved significantly for turning operations. The confirmation experiments were conducted to verify the optimal cutting parameters.

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