Experimental Investigation of Turning of EN-9 using Taguchi Approach

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Abstract *- The main objective of today's manufacturing industries is to produce low cost, high quality products in short time. The selection of optimal cutting parameters is a very important issue for every machining process in order to enhance the quality of machining products and reduce the machining costs. Surface inspection is carried out by manually inspecting the machined surfaces. As it is a post-process operation, it becomes both time-consuming and laborious. In addition, a number of defective parts can be found during the period of surface inspection, which leads to additional production cost. In the present work the cutting parameters (cutting speed, depth of cut, feed rate, cutting fluids) have been optimized in turning of EN-9 of in turning operations on and EN-9 as a result of that the combination of the optimal levels of the factors was obtained to get the lowest surface roughness. The Analysis of Variance (ANOVA) and Signal-to-Noise ratio were used to study the performance characteristics in turning operation. The analysis also shows that the predicted values and calculated values are very close, that clearly indicates that the developed model can be used to predict the surface roughness in the turning operation of mild steel.*

Keywords: *EN-9, Cutting Parameters, Taguchi Method, ANOVA, S/N Ratio.*

I. INTRODUCTION

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material as shown in Figure 1.The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine.

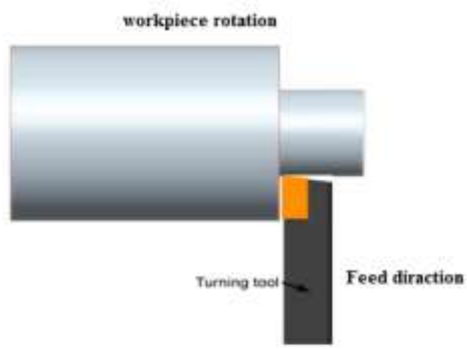


Fig 1: Diagram for Turning Process

II MATERIALS AND METHOD

A. Work Piece Material

The work piece material used in this project was EN-9 Stainless Steel of length of 250mm and diameter 40mm. The work piece material is shown below

Fig 2: EN-9 work piece material

Table I: Chemical composition of EN-9 steel materials

C	Mn	Si	P	S
0.50-0.60	0.50-0.90	0.10-0.40	0.050 max	0.050 max

Table II: Physical properties of En-9 material

Density gm/cm3	Melting Point (□C)	Thermal conductivity at 100^0C (W/m K)	Coefficient of thermal expansion (µm/m □C)
7800	1600-1750	26	11 x10^{-6}

Table III: Mechanical properties of EN-9 steel materials

Tensile Strength (MPa)	Yield Strength (MPa)	% of Elongation
700	355	16-23%

B. Carbide Coated Tip Cutting Tool

Coatings are frequently applied to carbide tool tips to improve tool life or to enable higher cutting speeds. Coated tips typically have lives 10 times greater than uncoated tips. Common coating materials include titanium nitride, titanium carbide and aluminium oxide, usually 2-18 micro-m thick. Often several different layers may be applied, one on the top of another, depending upon the intended application of the tip. The techniques used for applying coatings include chemical vapour deposition, plasma assisted CVD and physical vap our deposition.

Fig 3: Carbide coated tip cutting tool

C. Selections of Control Factors

Cutting experiments are conducted considering four cutting parameters: Cutting Speed (m/min), feed rate (mm/rev), Depth of Cut (mm) and cutting fluids. Overall 9 experiments were carried out. Table shows the values of various parameters used for experiments:

TABLE IV. MACHINING PARAMETERS AND LEVELS

FACTORS	LEVELS		
	1	***2***	***3***
A. CUTTING SPEED (rpm)	455	683	1025
B. FEED (mm/rev)	110	150	175
C. DEPTH OF CUT (mm)	0.3	0.9	1.2
D. CUTTING FLUIDS	Sherol B	Sherol ENF	Straight cutting oil

III EXPERIMENTAL PROCEDURE

Turning is popularly used machining process. In this project work turning is done on the lathe machine which is shown in the figure

Fig 4: Banka 40 Lathe Machine

A. Taguchi Approach

Process Steps of Taguchi Method

- Define the process objective
- Identify test conditions
- Identify the control factors and their alternative levels
- Create orthogonal arrays for the parameter design
- Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
- Complete data analysis to determine the effect of the different parameters on the performance measure.
- Predict the performance at these levels
- Confirmation experiments.

B. Selection of Orthogonal Array

The selection of orthogonal array for experiment was done by use Minitab-17 statistical software. By putting parameter variation levels in Minitab-17 statistical software, the Minitab suggests that L_9 (3*3) fractional factorial orthogonal array is most compatible for our experiment. This design reduces the number of experiments from 24 (i.e. factorial 4*3*2*1) to a designed set of 9 experiments without compromise quality of experiment. The experiment table suggested by Minitab- 17 for L_9 Orthogonal array is shown in Table.

TABLE V. EXPERIMENT DESIGN BY USE OF L_9 ORTHOGONAL ARRAY

S.No	Parameter-1	Parameter-2	Parameter -3	Parameter-4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	2	2
8	3	2	3	1
9	3	3	1	3

In L_9 (3^4) orthogonal array, five columns bearing the numbers '1', '2', '3', '4', represents factors. And each set of numbers below these columns represent levels of that factors respectively. As the index in the first column depicts, each row represents an experiment.

TABLE VI. FACTOR ASSIGNMENT (EXPERIMENTAL DESIGN)

Factors EXPT NO	Cutting speed (rpm)	Feed (rev/min)	Depth of cut (mm)	Cutting fluids
1	455	110	0.3	Sherol B
2	455	150	0.6	Sherol ENF
3	455	175	0.9	Straight cutting oil
4	683	110	0.6	Straight cutting oil
5	683	150	0.9	Sherol B
6	683	175	0.3	Sherol ENF
7	1025	110	0.9	Sherol ENF
8	1025	150	0.3	Straight cutting oil
9	1025	175	0.6	Sherol B

C. Measurement of Surface Roughness

In this project stylus type surface roughness meter was used to measure the surface roughness of the specimens. There were two main reasons behind selecting stylus type surface roughness one is its easy availability and other is the ease with which it can be operated. The surface roughness measuring instrument used in this experiment is Talysurf.

Fig 5: Stylus Movement on Work piece Material

D. Procedure Followed To Measure Surface Roughness (Ra)

For each and every experiment the surface roughness of the machined work material is found out. One point on the work material is considered for each sample and each measurement is about 90 degrees apart. The stylus moves to and fro on the work material at this point. The Ra values are displayed on the digital meter and the three values of Ra are considered for that particular experiment. Similarly 9 (Ra) values are considered for 9 experiments. The S/N ratios of surface roughness are calculated.

TABLE VII: RESULT TABLE FOR SURFACE ROUGHNESS (RA) VALUES IN MM

Sr.No	Cutting Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Cutting fluids	Surface Roughness (µm)
1	455	110	0.3	Sherol B	2.186
2	455	150	0.6	Sherol ENF	2.500
3	455	175	0.9	Straight cutting oil	3.675
4	683	110	0.6	Straight cutting oil	2.370
5	683	150	0.9	Sherol B	1.645
6	683	175	0.3	Sherol ENF	2.633
7	1025	110	0.9	Sherol ENF	2.491

8	1025	150	0.3	Straight cutting oil	1.764
9	1025	175	0.6	Sherol B	2.852

E. Optimization for Surface Roughness

1) S/N ratio calculation of surface roughness:

In this the observe value of surface roughness is transform in S/N ratio values to find out the optimum combination of parameters for response variable. In surface roughness "smaller is better" is objective characteristic, since the minimization of the quality characteristic is interested.

The S/N ratios are calculated using the below mentioned formula (smaller the better type formula).

S/N ratio (η) = $-10\text{Log}_{10}\left[\left(\frac{1}{n}\right)\sum_{i=1}^{n} yi^2\right]$

Where

n : no. of tests in trial (no. of repetitions regardless of noise levels)

y_i : is the i^{th} observation of the quality characteristic.

- For example the S/N ratio is calculated for first experiment is as follows:

$\eta_1 = -10\ \log_{10}[(1/1)\ (2.186)^2]$

$\eta_1 = -6.7930$

Similarly all the S/N ratios are calculated. These values of S/N ratio and averages will then further be analyzed to detect the most responsible factor and the percentage contribution of each factor on the surface roughness (response variable).

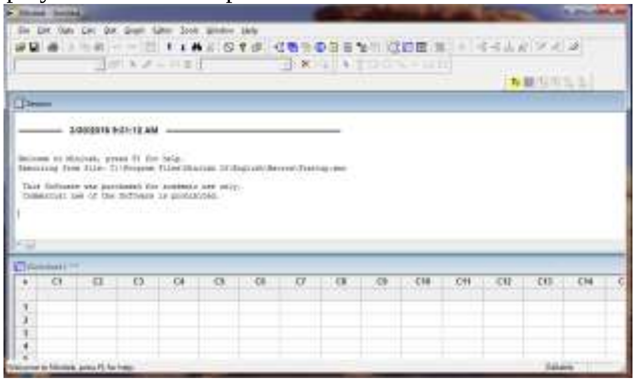
Table VIII: S/N ratio calculation of SR

Expt No	Surface Roughness (µm)	S/N ratio of SR (dB)
1	2.186	-6.7930
2	2.500	-7.9588
3	3.675	-11.3051
4	2.370	-7.4949
5	1.645	-4.3233
6	2.633	-8.4090
7	2.491	-7.9274
8	1.764	-4.9299
9	2.852	-9.1029
Average of S/N ratios of SR (dB) (η)		-7.5827

2) MINITAB statistical software: MINITAB statistical software has been used for the analysis of the experimental work. The Minitab software studies the experimental data and then provides the predicted equations of surface roughness for a work piece material. After analysis of data, for the surface roughness based on the factors cutting speed, feed rate, depth of cut, cutting fluid for a work piece material i.e., EN-47 stainless steel is given below.

After analysis the entire procedure and final results are given down in the form of screen shots from the mintab17 software:

Step1: Open minitab17 software and a window are displayed on the desktop as shown below.

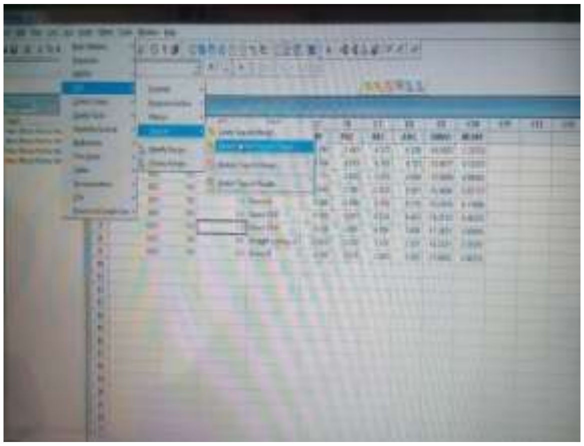


Step 2: Firstly in order to get results from Minitab software by taguchi method we need to define the parameters considered and obtained experimental values. And by going on clicking as the procedure shown below completes the defining procedure in Minitab software.

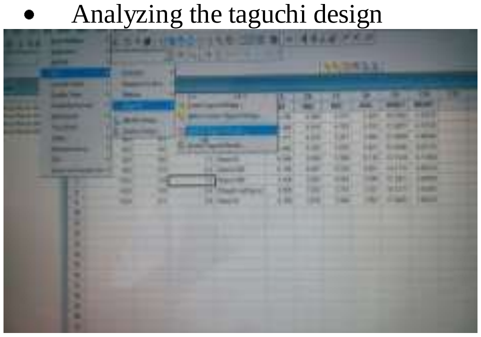
Click on STAT >> DOE >> TAGUCHI >> DEFINE CUSTOM TAGUCHI DESIGN...

- The widow as shown in the figure below.

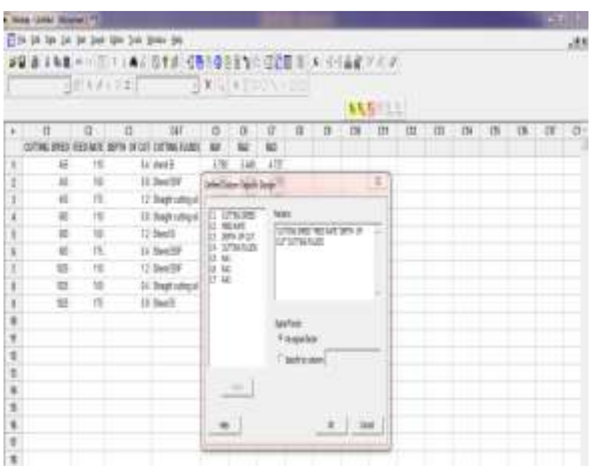
- Defining the custom Taguchi design



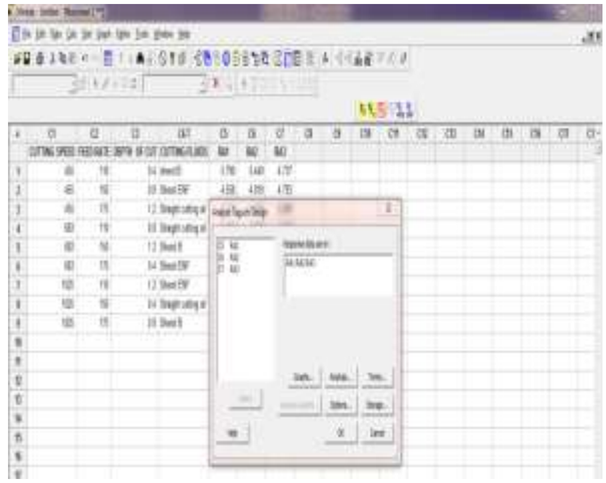
- Analyzing the taguchi design



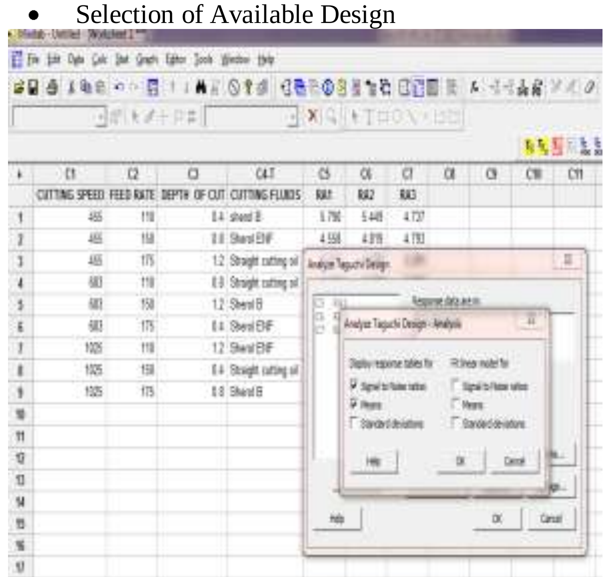
- Now various steps involved in getting the final results are as shown in the figures below.



- Create Taguchi Design



- Selection of Available Design



Finally click on ok in the window which shows the analyses of Taguchi design. S/N ratio is generated as shown below in the form of screen shot:

3) Main effects plot of surface roughness

The main effects plot for S/N ratio of surface roughness verses cutting speed, feed rate, depth of cut and cutting fluid, which is generate form the value of S/N ratio of surface roughness as per Table in Minitabe-17 statistical software is useful to find out optimum parameter value -for response variable. The graph generate by use of Minitab-17 statistical software for surface roughness is shown in graph.

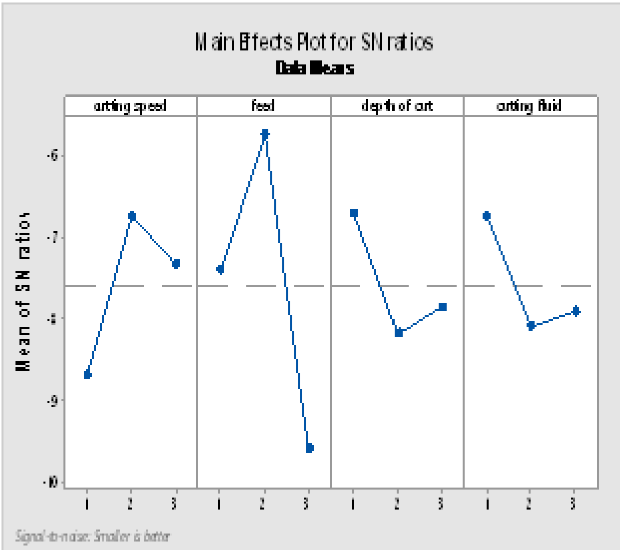


Fig 6: Mean effect plot of surface roughness vs cutting speed, feed, depth of cut and cutting fluid

From the Figure it is conclude that the optimum combination of each process parameter for lower surface roughness is meeting at cutting speed (A2), feed rate (B2), depth of cut (C1), and cutting fluid (D1).

The S/N of the surface roughness for each level of the each machining parameters can be computed in Minitab 17 and it is summarized for finding out rank of each effective parameter for response.

The combination of factors and levels which give maximum S/N ratios give the optimum cutting parameters. That means A_2, B_2, C_1 and D_1combination gives the optimum cutting parameter which minimizes the surface roughness i.e. these levels are applicable to the starting levels of the factors. These are:

A_2 – Cutting speed (683rpm)
B_2 – Feed (150 mm/rev)
C_1 – Depth of cut (0.3 mm)
D_1 –cutting fluid (Sherol B)

F. Selection of Optimum Set of Conditions:

The objective is to maximize the S/N ratio, hence select the factor levels which have maximum S/N ratio values. The best condition for cutting speed factor is level 2 i.e. 683 rpm, for feed is level 2 i.e.150mm/rev, for depth of cut is level 1 i,e. 0.3mm, for cutting fluids is level 1 i.e. Sherol B. Thus optimum conditions chosen were: A_2- B_2- C_1- D_1 combination.

TABLE IX: OPTIMIZED CUTTING PARAMETERS

Control Factor	Cutting Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Cutting fluids
Optimum value	683 rpm	150	0.3	Sherol B

The analyzed value of mean of surface roughness by use of Minitab 17 statistical software is shown in Table.

TABLE X: RESPONSE TABLE OF S/N RATIO FOR SURFACE ROUGHNESS

Level	Cutting Speed	Feed	Depth of cut	Cutting Fluid
1	-8.6856	-7.4051	-6.7106	-6.7397
2	-6.7424	-5.7373	-8.1855	-8.0984
3	-7.3201	-9.6057	-7.8519	-7.9100
Delta	1.943	3.868	1.475	1.359
Rank	2	1	3	4

From Table, it is show that the value of delta for each parameter A, B, C and D are 1.943, 3.868, 1.475 and 1.359 for surface roughness. From delta value of each parameter it is conclude that for surface roughness the most effective parameter is feed followed by cutting speed, depth of cut and cutting fluid.

G. Prediction of Process Average for Optimum Condition:

Having determined the optimum condition from the orthogonal array experiment, the next step is to predict the anticipated process average $\eta_{predicted}$ under chosen optimum condition. This is calculated by summing the effects of factor levels in the optimum condition (the values of maximum S/N ratios in table). S/N ratios of optimum condition were used to predict the S/N ratio of the optimum condition using the additive model.

$\eta_{predicted} = [A_2 + B_2 + C_1 + D_1] - 3\eta$
$= [(-6.7424) + (-5.7373) + (-6.7106) + (-6.7397)] - (3 \times -7.5827)$
$= -3.1819$ dB.

Where η = average of all S/N ratios

IV CONFIRMATION TEST

Conducting a verification experiment is a crucial final step of the robust design methodology. The predicted results must be conformed to the verification test, with the optimum set of conditions. In this final step, the optimum cutting conditions of cutting speed 683 rpm, cutting feed 150 mm/rev, depth of cut 0.3 mm, cutting fluid are obtained for EN 9 work piece material.

A conformation test is performed with the obtained optimum cutting parameters (cutting speed 683rpm, feed 150 mm/rev, depth of cut 0.3 mm, and cutting fluid is Sherol B) By using these optimum conditions an experiment is conducted on a newly ground tool. The surface roughness values at a sample specimen were taken using Talysurf (surface roughness measuring instrument) and the S/N ratio is calculated by using the smaller-the-better type characteristic formula for this condition. These values are shown in Table. Hence this conformation test performed verifies the obtained results i.e. the optimized cutting parameters which minimize the surface roughness.

TABLE XI: CONFORMATION TEST RESULTS

Control Factor	**A**	**B**	**C**	**D**	**SR**	**S/N ratio**
Optimum value	683	150	0.3	Sherol B	1.263	-2.0280

The S/N ratio of predicted value and verification test values were compared for validity of the optimum condition. These values are shown in figure. It is found that the S/N ratio value of verification test is within the limits of the predicted value and the objective is fulfilled. As the conformation and projected improvements matched, suggested optimum conditions can be adopted. S/N ratio is calculated by using the formula given below.

TABLE XII: COMPARISON OF S/N RATIOS

$\eta_{predicted}$ **(dB)**	-3.1819
$\eta_{onfirmation\ test}$ **(dB)**	-2.0280

The main effects plot for means vs process parameters are shown in below graph:

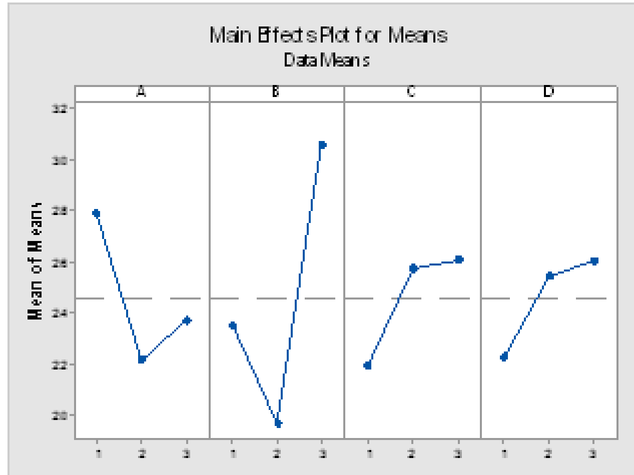


Figure 7: The main effects plot for means VS process parameters

V CONCLUSIONS

- Taguchi design of experiment can be very efficiently used in the optimization of machining parameters in metal cutting process.
- The optimum set of process parameters found are Cutting speed: 683rpm, Cutting feed: 150 mm/rev, Depth of cut: 0.3mm, cutting oil (Sherol B) for EN-9 steel material. With this optimum set of control factors the surface finish on the work piece materials improved. This combination was successfully tested for its validity.
- The significant factors concluded that the effect of feed rate and cutting speed are more on the quality characteristic.
- In this work, the analysis of conformation experiments has shown that Taguchi parameter design can successfully verify the optimum cutting parameters.

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