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Application of Taguchi Method in the Optimization of Turning Parameters for Material Removal Rate of En-36 Material

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Abstract-*In the present work, by using Taguchi approach, the Turning of EN-36 steel alloy is carried out in order to optimize the turning process parameters. The present paper deals with the optimization of selected process parameters, i.e. Speed, Feed rate, Depth of cut and type of tool. Taguchi orthogonal array is designed with three levels of machining parameters and different experiments are done using L_9 (3^4) orthogonal array. Taguchi method stresses the importance of studying the response variation using the signal to noise (S/N) ratio, resulting the minimization of quality characteristic variation due to uncontrollable parameter. The material removal rate is considered as the quality characteristic in the concept of "the larger the better". The material removal values measured from experiment and their optimum value for material removal rate are calculated. The S/N ratio of predicted value and verification test values are valid when compared with the optimum value. It is found that S/N ratio value of verification test is within the limits of predicted value and the objective of the work is full filled.*

Key words-*Taguchi Method, Optimization, EN-36 steel alloy, turning, material removal rate, signal to noise (S/N) ratio etc.*

I. INTRODUCTION

In this work, Taguchi robust design methodology is used to obtain the optimum conditions of the experimental data. The output parameter is material removal rate. Robust design is an engineering methodology for improving productivity during design and development so that high quality products can be produced at low cost. The aim of Robust design method is to choose the levels of design factors to make product or process performance intensive to uncontrollable variations such as manufacturing variations, deterioration and environmental variations Dr. Genichi Taguchi has popularized the robust design method which employs experimental design techniques to help identify the improved factor levels. Experimental design techniques are extremely effective for improving quality in problems that involve in a large number of factors. Taguchi's approach has been successfully applied by engineers in many leading Japanese and American companies for improving performance and competitiveness of their key products. The robust design method uses a mathematical tool called Orthogonal Array to study large number decision variables with a small number of experiments. It also uses a measure of quality called Signal-to-Noise (S/N) ratio, to predict the quality. The principle of robust design methodology is to minimize the variation without eliminating the causes and maximizing S/N ratio (signal to noise ratio). This is achieved by optimizing the product and process designs to make the performance insensitive to the various causes of variations.

Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving more or less linearly while the workpiece rotates.The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear. Usually the term "turning" is reserved for the generation of external surfaces by this cutting action, whereas this same essential cutting action when applied to internal surfaces is called "boring". Thus the phrase "turning and boring" categorizes the larger family of processes. The cutting of faces on the workpiece whether with a turning or boring tool, is called "facing", and may be lumped into either category as a subset. Turning machines used in manufacturing are classified as engine, automatics, and computer numerical control etc. The Turning used for machining in this work is CNC Turning machine. Basically Turning machines are classified according to the operation required.

EN 36 is nickel- chromium high hardenability, case hardening (carburizing) steel, generally available in the annealed condition with a maximum brinell hardness of 255, characterized by high core strength, excellent toughness and fatigue resistance in relatively large sections with case hardness upto RC62 when carburized, hardened and tempered. EN 36 can also be used (uncarburized) as a high tensile steel which when suitably hardened and tempered can be utilized for various applications requiring good tensile strength and excellent toughness.

The objective of the paper is to find out the set of optimum values for the selected control factors in order to improve material removal rate using Taguchi's robust design methodology. In the present work, Taguchi method is used to determine the optimum cutting parameters more efficiently. Four control factors viz. cutting speed, feed rate, depth of cut and type of tool are investigated at three different levels. The work piece material used is EN 36 steel alloy. Taguchi method is used to optimize the process parameters i.e. material removal rate using signal-to-noise ratio for turning process of the work piece material. Experiments are carried out using $L_9(3^4)$ orthogonal array.

II. LITERATURE REVIEW

Literature survey reveals that a considerable amount of work has been carried out by previous investigators for modeling and parametric optimization of the product in turning operation, Issues related to metal removal rate etc., have been addressed too. Optimizing a response (process output), have been solved using Taguchi method. These studies all discovered clear and useful correlations between their control and response parameters.

Nirav M. Kamdar et al [1] -In this paper, the EN 36 Steel specimens heated with gas flame were machined on a lathe under different cutting conditions of Surface temperatures, Cutting speeds and Feed rates. Cutting force, feed force and surface roughness were studied under the influence of machining parameter at 200 °C, 300 °C, 400 °C, 500 °C and 600 °C at constant depth of cut 0.8 mm. The optimum result was achieved in the experimental study by employing Design of experiments with Taguchi. . In this study, Analysis found that varying parameters are affected in different way for different response. The ANOVA analysis was used to obtain optimum cutting parameters.

KaushalPratap Singh, Girish DuttGautam, [2] -In this research paper, L_{18} orthogonal array based Taguchi optimization technique is used to optimize the effect of various cutting parameter for surface roughness and Material Removal Rate (MRR) of EN 36 work material in turning operation. The orthogonal array, the signal to noise ratio and analysis of variance are employed to study the performance characteristics in both dry and wet machining conditions of cylindrical work pieces using Tin coated tungsten carbide cutting tool on CNC lathe. Five machining parameter such as spindle speed, feed rate, depth of cut, nose radius and the cutting environment (wet & dry) are optimized with consideration of surface roughness. Results of this study indicate for optimal cutting parameter, minimum surface roughness (Ra) and maximum material removal rate were obtained and developed model can be used to increase the machine utilization at low production cost in manufacturing environment.

A thorough study of literature suggests that the machining of EN-36 Steel Alloy is very difficult, compared to other alloy materials. Very few works have been done in the Optimization of process parameters in turning process of EN-36 steel alloy with different controlled parameters such as cutting speed, feed rate and depth of cut and type of tool.

The study demonstrates detailed methodology of the proposed optimization technique i.e. Taguchi method is used; and validates its effectiveness through material removal rate, characteristics of a Turning product. Hence the literature survey helped in proper selection of speed, feed rate, depth of cut and other related parameters.

III. EXPERIMENTAL SETUP

The aim of the work is to find out the set of optimum values for the selected control factors in order to improve material removal rate using Taguchi's robust design methodology. The work material selected isEN-36 steel alloy. The dimensions of the EN-36 steel alloy, selected are of 30mm diameter X 110mm length. The turning operations are carried out on CNC machine. The machining tests are conducted under the different conditions of Cutting speed, Feed rate, Depth of cut and different types of tool.

A. Specifications of CNC Turning Machine:

The experiments are conducted at BRD ROCK DRILLS, cherlapally and the machine tool used is WASINO LJ-63m CNC MACHINE.

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Figure No. 1: CNC Machine (*Source: BRD Rock Drills, Cherlapally)

Table No. 1: Specifications of CNC Machine

Clamping surface	420x180mm
Repeatability	+0.005mm
Positional accuracy	0.010mm
Coolant tank capacity	40 liters
Power rating	415v
Spindle motor speed	3500rpm
X,Y and Z axis drive	6000rpm
Electrical motor	14p 3phase
Pump	4lpm
Pressure	70 bar

B. Work piece Material:

EN 36 is nickel- chromium high hardenability, case hardening (carburizing) steel, generally available in the annealed condition with a maximum brinell hardness of 255, characterized by high core strength, excellent toughness and fatigue resistance in relatively large sections with case hardness upto RC62 when carburized, hardened and tempered.

Figure No. 2: EN36 Steel Alloy Work Pieces

Table No. 2: Composition of EN-36 Steel Alloy

Element	Weight percentage (%)
C	0.16
Mn	0.52
Si	0.31
S	0.040
P	0.040
Cr	1.05
Ni	3.62

C. Cutting Inserts:

The cutting inserts used are TNMG carbide tools from KORLOY company, which are

- UNCOATED tool with grade ST15 (shown in Fig. 3(a))
- PVD coated (TiAlN) with grade PC 9030(shown in Fig. 3(b))
- CVD coated (CVD Al_2O_3 film MT-TiCN + TiC + Al_2O_3) with grade NC 3010 (shown in Fig. 3(c))

(a) UNCOATED *(b) PVD* *(c) CVD*

Figure No. 3: Carbide Tool Inserts

D. Tool Holder:

The specification of tool holder used for machining is BT30-ER16, side lock adapter system

Figure No. 4: Tool Holder

E. Material Removal Rate Calculations:

The Material Removal Rate (MRR) in turning operation is the volume of material removed per unit time in mm^3/min. For each revolution of the work piece, a ring shaped layer of material is removed. Material removal rate (MRR) has been calculated using equation (1), i.e., the difference of weight of work piece before and after experiment. The weight of the specimen is measured with the help of digital weighing machine before and after machining the work piece. The machining time is also noted during the machining process for each work piece.

$$MRR = \frac{1000 \times W_w}{\rho_w \times t} \ \mathrm{mm^3/min} \quad \text{———— (1)}$$

Where, Ww= Wi –Wf

Wi is the initial weight of work piece in gms; Wf is the final weight of work piece in gms; t is the machining time in minutes; ñw is the density of EN 36 steel alloy. The weight of the work piece has been measured in a high precision digital balance meter (Model: DHD – 200 Macro single pan DIGITAL meter made by DELMER) which can measure up to the accuracy of 10^{-3} gms and thus eliminates the possibility of large error while calculating Material Removal Rate (MRR) in straight turning operation.

Figure No. 5: Digital Weighing Machine (*Source: Civil department lab, NNRESGI)

IV. DESIGN OF EXPERIMENTS

A. Selection of Control Factors and Levels:

A total of four process parameters with three levels are chosen as the control factors such that the levels are sufficiently far apart so that they cover wide range. The process parameter and their ranges are finalized using literature, books and machine operator's experience. The four control factors selected are spindle speed (A), feed rate (B), depth of cut(C) and types of tools used (D). EN-36 STEEL Alloy work pieces are used in experimentation. The machining is performed individually. The control levels and their alternative levels are listed in table no.3.

Table No. 3: Control Factors and Levels

FACTORS/ LEVELS	SPEED (A) (m/min)	FEED (B) (mm/rev)	DEPTH OF CUT (C) (mm)	TYPE OF TOOL (D)
1	60	0.2	0.5	Un-Coated
2	80	0.3	1	PVD
3	100	0.4	2	CVD

B. Selection of Orthogonal Array:

Selection of particular orthogonal array from the standard O.A depends on the number of factors, levels of each factor and the total degrees of freedom.

i) Number of control factors = 4
ii) Number of levels for each control factors = 3
iii) Total degrees of freedom of factors = 4x(3-1)=8
iv) Number of experiments to be conducted =9

Based on these values and the required minimum number of experiments to be conducted 9, the nearest Orthogonal Array fulfilling this condition is L_9 (3^4). It can accommodate a maximum four number of control factors each at three levels with 9 numbers of experiments. Here the requirement is to accommodate four control factors at three levels, which can be easily done in this Orthogonal Array. In L_9 (3^4) orthogonal array, 9 represents number of experiments, 3 represents number of levels and 4 represents number of factors.

Table No. 4: Standard L_9 (3^4) Orthogonal Array

EXPERIMENT NUMBER	COLUMN			
	1	**2**	**3**	**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	3	2
8	3	2	1	3
9	3	3	2	1

C. Plan of Experiments and Data Collection:

The scope and objectives of the present work have already been mentioned in the fore going chapter. Accordingly the present study has been done through the following plan of experiment.

1. Cutting steel bars by power saw and performing initial turning operation in CNC machine to get desired dimension (30mm Dia X110 mm Length) of the work pieces.
2. Checking and preparing the CNC machine ready for performing the machining operation.
3. A detailed study has been carried out for the selections of the cutting parameters i.e., Speed, feed and depth of cut are taken according to the machine standards.
4. Selection of appropriate tool depending upon the cutting parameters i.e., speed, feed, depth of cut and material and the tools are changed depending upon the experimental design.

5. Performing operations on specimens in various cutting environments involving different tools and various combinations of process control parameters like: spindle speed, feed and depth of cut.
6. Measuring weights both initial and final, checking machining time, for the calculation of MRR as shown in eq. 1, for each experiment and the corresponding S/N values are tabulated in table no. 6.

Table No. 5: Experimental Design

EXPERIMENT NUMBER	COLUMN			
	SPEED (A) (m/min)	FEED (B) (mm/rev)	DEPTH OF CUT (C) (mm)	TYPE OF TOOL (D)
1	60	0.2	0.5	Un-Coated
2	60	0.3	1	PVD
3	60	0.4	2	CVD
4	80	0.2	0.5	CVD
5	80	0.3	2	Un-Coated
6	80	0.4	1	PVD
7	100	0.2	2	PVD
8	100	0.3	0.5	CVD
9	100	0.4	1	Un-Coated

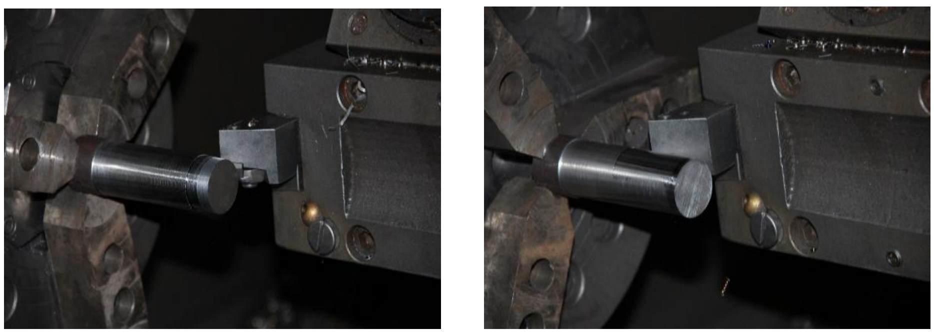

Figure No. 6. Machining of Work Piece EN 36 Alloy

V. RESULTS AND DISCUSSIONS

In the present paper, the performance characteristics namely the Material Removal Rate is to be maximized; hence larger the better type quality characteristic has been selected for response.

Table No. 6: Experimental Data Related to Material Removal Rate (MRR)

EXP NO.	MATERIAL REMOVAL RATE (mm^3/min)	S/N RATIO
1	0.000599	-64.45
2	0.001144	-58.86
3	0.002442	-52.25
4	0.000780	-62.15
5	0.001536	-56.30
6	0.00246	-52.18
7	0.001176	-58.59
8	0.001631	-55.75
9	0.003856	-48.27

Table No. 7: Summary of S/N Ratios

Factor	Level 1	Level 2	Level 3
Speed(A)	-58.42	-56.87	-54.20
Feed(B)	-61.83	-56.97	-50.90
Depth of Cut(C)	-60.78	-53.10	-55.71
Type of Tool (D)	-56.34	-56.543	-56.716

A. Optimization of Cutting Parameters:

Taguchi's robust design methodology has been successfully implemented to identify the optimum settings for selected control parameters in order to improve the material removal rate of the selected work piece material for their improved performance, after analysis of data from the robust design experiments the optimum set of control factors are found is tabulated in Table No.8 These optimum settings combination is validated by conducting confirmation test, which concluded that the results (Table No.9 and 10) were within the acceptable limits of the predicted value and can be implemented in the real time application.

The best condition for Spindle Speed factor is level 3 (100m/min), for Feed Rate is level 3 (0.4mm/rev), for Depth of Cut is level 2 (1mm) and Type of Tool is level 1 (UNCOATED). Thus, the optimum conditions chosen were: **A3-B3-C2-D1**

Table No. 8: Optimum Set of Control Factors

Factors /Levels	Speed(A) (m/min)	Feed(B) (mm/rev)	Depth of Cut(C) (mm)	Type of Tool(D)
Optimum Value	**100**	**0.4**	**1**	**UN-COATED**

Table No. 9: Conformation Test Results

MATERIAL REMOVAL RATE(MRR)	S/N RATIO
0.00254	-51.20

Table No. 10: Comparison of S/N Ratios

$\eta_{\text{predicted}}$	0.059
$\eta_{\text{conformation}}$	0.00254

B. Effect of Cutting Parameters on Material Removal Rate (MRR):

From the Fig. no.7, it is observed that, the material removal rate is low at low cutting speed and it is increasing at moderate cutting speed conditions, again from moderate to high cutting speeds, the material removal rate increases.

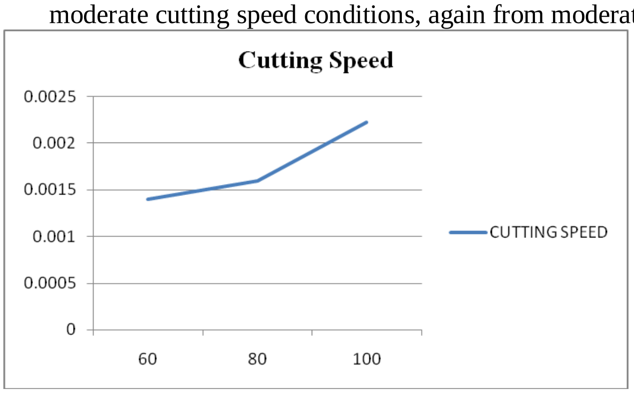

Figure No. 7. Material removal rate V/s Cutting Speed

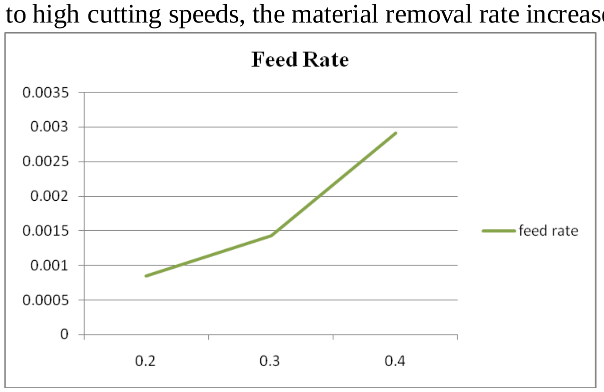

Figure No. 8. Material removal rate V/s Feed Rate

From the Fig. no.8, it is observed that, the material removal rate is low at low feed rate and certainly increasing from low feed rate to moderate feed conditions, and again from moderate to high feed rate, the material removal rate increases, similar to cutting speed condition.

From the Fig. no.9, it is observed that, the material removal rate is low at low depth of cut and certainly increasing from low depth of cut to moderate depth of cut conditions, but from moderate to high depth of cut, the material removal rate decreases.

From Fig. no.10, it is observed that the material removal rate is high when using UNCOATED tool tip, it is gradually decreasing by using PVD tool tip when compared to UNCOATED tip and material removal rate slightly increased while using CVD tool but lower than UNCOATED tip.

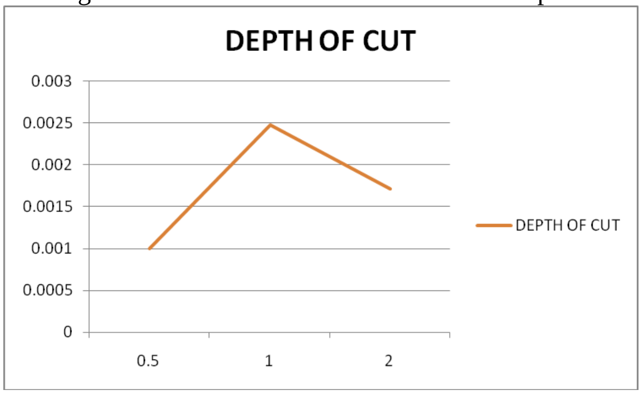

Figure No. 9. Material removal rate V/s Depth of Cut

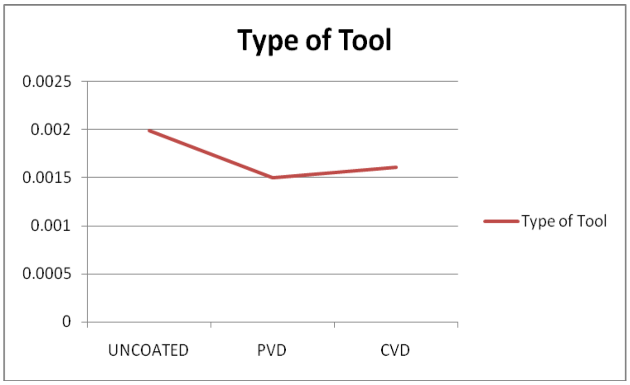

Figure No. 10. Material removal rate V/s Type of Tool

VI. CONCLUSIONS

The objective of the project work is to find out the set of optimum values for the selected control factors in order to improve material removal, using Taguchi's robust design methodology considering the control factors and steel alloy EN-36 work piece.

Based on the results of the present experimental investigations the following conclusions can be drawn:

- The cutting speeds for the experimentation 60m/min, 80m/min, 100m/min in this 100m/min is the optimum speed for obtaining material removal rate. The optimum feed is 0.4mm/rev among used feeds 0.2mm/rev,0.3mm/rev,0.4mm/rev. Depth of cut 1mm is the optimum depth of cut for obtaining material removal rate for the values 0.5mm, 1mm, 2mm used for MRR.
- Optimum type of tool tip obtained for the MRR is UNCOATED.
- The S/N ratio of predicted values and verification test values of material removal rate (MRR) are compared for the validity of the optimum condition. It is found that the S/N ratio value of verification tests are within the limits of the predicted values and the objective is fulfilled. Hence, these suggested optimum conditions can be adopted.
- Taguchi method has been successfully applied in optimizing material removal rate for turning operation.

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