APPLICATION OF TAGUCHI METHOD FOR OPTIMIZATION OF PROCESS PARAMETERS FOR MINIMUM SURFACE ROUGHNESS IN TURNING OF 45C8

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Abstract

Industries across the world are struggling to overcome the problem of rejection rate. In order to meet the customer's satisfaction, it is important to maintain the better quality of the product which can only be afforded by reducing the rejection rate. Surface roughness is one the important parameter in reducing the rejection rate. In this study, the Taguchi Method is used in order to find out the optimal cutting parameters to get the better surface roughness of 45C8 steel. Various cutting parameters viz: cutting speed, fed and depth of cut were taken and Taguchi method is used to find out the optimal combination so as to get the better surface roughness. Orthogonal arrays of Taguchi, the signal-to noise ratio (S/N) ratio, the analysis of variance (ANOVA) are employed to find the optimal levels and to analyze the cutting parameters on surface roughness. Finally confirmation tests with the optimal levels of cutting parameters are carried out in order to demonstrate the effectiveness of Taguchi optimization method.

Key words— ANOVA, 45C8 (EN8), Surface roughness, S/N Ratio, Taguchi Method.

I. INTRODUCTION

Metal cutting is one of the most important processes and broadly used manufacturing processes in mechanical industries (Yang et al., 1998) (Aggarwal .A et al, 2008). Highly competitive market requires high quality products at minimum cost. Products are manufactured by the transformation of raw materials (Davis, R et al, 2013). Industries in which the cost of raw material is a big share of the cost of finished goods, higher productivity can be achieved through proper selection and use of the materials. Surface finish is an important factor in manufacturing engineering and it can control the performance of mechanical parts and the production costs (Harsh Y Valeraa et al, 2014). Surface roughness is one of the important parameter in conventional machining. Optimizing this parameter is most challenging task in turning process. Industries are working more on reducing the rejection rate and improving the surface roughness. Better quality of the product can afford finest customer satisfaction. Highly competitive market requires high quality products at minimum cost. Products are manufactured by the transformation of raw materials in to finished goods. Surface roughness says about the quality of machining and also about the quality of product. The materials which have good surface finish posses better property as compared to lower surface finish of that material.

Surface roughness says about the quality of machining and also about the quality of product. The materials which have good surface finish posses better property as compared to lower surface finish of that material. Such surface roughness plays a very important role as one of the parameter in machining process. Industries across the world are struggling to overcome the problem of rejection rate. By reducing rejection rate and optimally utilization of machines and their working conditions, we can not only be able to produce good products but can also reduce the cost significantly. Industries are more dependent on the working skills of the machine tool operators in selection of best cutting conditions. This helps not only in producing the product with less rejection rate, but also help in reducing the cost of the product.

The various literature reviews has revealed that several researchers attempted to analyze the optimal cutting conditions in turning operations. Armarego and Brown used the concept of maxima / minima of differential calculus to optimize machining variable in turning operation (E.J.A Armarego et al , 1969) . Brewer and Rueda have developed different monograms which assist in the selection of optimum conditions (R.C Brewer and R. Rueda). Few of the other techniques that have been used to optimize the machining parameters include goal programming (R.M Sundaram, 1978) and geometrical programming (P.G Petropoulos, 1973). Accuracy and surface roughness of the product are the matter of more attention in the industries now days. Surface roughness is the most significant criterion in determining the metal removal rate of the material. Surface roughness and dimensional accuracy are the key factors needed to forecast the machining performances of any machining operation (A.Mital, et al. 1988).

The main aim of this study is to obtain the significant factor those affect the surface roughness during the turning operation on EN 8 steel material on CNC turning center.

II. EXPERIMENTAL DETAILS

A. Material

The specimen used in the study is EN8 steel (40C8) in the form of round bar with 20 mm diameter and 60 mm cutting length. This steel is generally used for the manufacturing of shafts, studs, general purpose axles, keys, cam shafts etc. EN8 is a very popular grade of through-hardening medium carbon steel, which is readily machineable in any condition. 45C8 (EN8) in its heat treated forms possesses good homogenous metallurgical structures, giving consistent machining properties.

Fig 1: Sample of EN 8 steel

Fig 2: EN8 rods after machining operations

B. Experimental Setup

The experimental setup is carried out on CNC turning center. Computer Numerical Control (CNC) is a machine in which the functions and motions of a machine tool are controlled by means of a set of program based on G and M code. Experimental setup was carried out on CNC Lathe MCL12. This machine works on two X and Z direction along with spindle encoder feedback. Various programmes are designed by CAD/CAM on PC. Programme input and DNC online is executed from PC through RS232C interface. It has 4 station automatic tool turrets on which four tools can be mounted and used during the program. Other specification of the CNC Lathe MCL12 is given below.

Capacity of the Machine

Longitudinal Travel (Z axis)	300m
Cross Slide Travel (X axis)	150mm
Chuck size	5 inches (127mm)
Spindle Drive	3 H.P ac motor with VFD
Max Spindle Speed	2000 – 2800 rpm
Max Machining Diameter	50mm
Type of Drive	AC Servo
Circulating Coolant	Available
Number of Axis	Two
Transmission	Ball Screw
Automatic Lubrication	Provided

CNC System of Machine
3 +1 Axis CNC System
Individual Industrial Controller
Define G, M, F, S, T, I, J, R Codes
DNC functions
Interface with PC through RS232
CAD/CAM/FSM compatibility

Fig 3: CNC Lathe – MCL 12

C. *Design Layout*

Experiment is carried out under dry condition using CNC Lathe MCL12 which has maximum spindle speed of 2800 rpm. During the process three things were kept constant viz: cutting tool, machining condition i.e. dry and diameter of rod (EN8 steel). Experiment was carried out with three different parameters viz: cutting speed (rpm), feed (mm/rev) and depth of cut with their three different levels as given in the table below. Most of these range of various parameters used were selected in view of data available in the literature, machine technical data. Optimal value of surface roughness was measured to get the result, which was measured by SURFCOM FLEX machine with a sampling length of 30 mm.

Fig 4: Surfcom Flex Machine

Table 1: Cutting Parameters

Factor	Cutting parameters	Level 1	Level 2	Level 3
N	Speed (rpm)	650	800	950
f	Feed (mm/rev)	0.1	0.2	0.3
d	Depth of Cut (mm)	0.2	0.4	0.6

III. DESIGN OF EXPERIMENT

A. *Taguchi Method*

In order to find out the optimal value of various combinations of our parameters taken to get the best surface finish, we have taken Taguchi method for analysis of parameters. Any research involves investigation of various parameters taken with different level. Doing an experiment with all the considered parameters factors is the most complicated and tough and also time consuming as well. Manually it is not easy to perform or study many experiments. Here the factor represents the any variables that impact the result of our experiment. Level is defined as the different setting in the variable can be set. There by priority some are considered factors and others are left behind. In CNC machining only two factors can be varied at one time while keeping the third one as fixed parameters, to understand the change in the surface roughness.

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs.

This technique helps to study effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined (Roy, R.K., 2001). Taguchi is one of the solutions to such a problem. It allows us to vary the entire factor at time and still allow us to evaluate effect of each individual factor. It also allows us to experiment in limited number and predict the remaining combinations of the factors. Taguchi method provides a simple, competent and methodical approach to optimize the designs for performance, quality, and cost. The greatest advantages of the Taguchi method are to reduce the cost and to find out significant factors in a shorter time period (M.Sanylmaz, 2006).

In order to introduce the Taguchi's approach and his experimental design as well which may be used as under (Ross PJ, 1988):

- Processes as well as designing products which may be sounds to environmental conditions;
- Both designing and developing products/processes which may be sounds to component variation;
- Reducing deviation around a target value.

Taguchi has addressed Design, Engineering (offline) as well as Manufacturing (online) quality. This concept differentiates Taguchi technique from Statistical Process Control (SPC) which is entirely an online quality control technique (Ryan Thomas P, 1988), (Benton W C, 1991) .Taguchi ideas can be reduced into two fundamental concepts i). Quality losses should be defined as deviation from target, not conformance to arbitrary specifications. (Benton W C, 1991) ii). In order to achieve high system quality levels which may also be frugal which needs quality to be designed into product? It does not manufacture in to the product but only designs the quality (Daetz D, 1987) (Taguchi G).

It was proposed by Taguchi that engineering optimization of a process or product may be carried out in three steps viz; (i) system design, (ii) parameter design, and (ii) tolerance design. These three steps may be explained in bird's eye view as under

i. System Design: In this design, an engineer applies scientific and engineering Knowledge, which produce a basic functional prototype design. This design including the product design stage and the process design stage and further the process design stage as well.
ii. Product Design: It involves the selection of materials, components, tentative product parameter values, etc. In process design stage apart from tentative process parameter values it also includes the analysis of processing sequences and selections of production equipments.

System Design: System design may define as an initial functional design. It may be far from optimum in terms of quality and cost. The aim of the parameter design (Montgomery DC, 1997) may be defined, to optimize the settings of the process parameter values. It improves the performance characteristics as well to identify the product parameter values. In this regard it is expected that the optimal process parameter values which have been obtained from the parameter design are not sensitive to the variation of environmental conditions and other concern noise factors. In this way it may be seen that the parameter design is the key step in the Taguchi method which achieves high quality without increasing cost.

B. Orthogonal Array L9

Taguchi's L9 Orthogonal Array was used in the design of experiment. There is powerful tool for design of high quality systems, i.e. Taguchi technique which has been used by many researchers tacitly. It also provides simple, efficient and systematic approach to optimize quality, cost and designs for performance. Taguchi technique is efficient tool for designing process that operates consistently and optimally over a variety of conditions. Taguchi technique is an experimental design technique, which is useful in reducing the number of experiments by using orthogonal arrays. Taguchi's approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community (D.C.Montgomery, 1997). The main objective of Taguchi method is to ensure quality in the design phase. Taguchi technique also allows controlling the variations caused by the uncontrollable factors which are not taken into consideration at traditional design of experiment.

Table 2: L9 Orthogonal Array (a)

Experiment No	Variable 1	Variable 2	Variable 3	Variable 4
1	1	1	1	-
2	1	2	2	-
3	1	3	3	-
4	2	1	2	-
5	2	2	3	-
6	2	3	1	-
7	3	1	3	-
8	3	2	1	-
9	3	3	2	-

Table 2: L9 Orthogonal Array (b)

Experiment No	Variable 1	Variable 2	Variable 3	Variable 4
1	650	0.1	0.2	-
2	650	0.2	0.4	-
3	650	0.3	0.6	-
4	800	0.1	0.4	-
5	800	0.2	0.6	-
6	800	0.3	0.2	-
7	950	0.1	0.6	-
8	950	0.2	0.2	-
9	950	0.3	0.4	-

C. Signal to Noise ratio (S/N)

The signal to noise ratio (S/N ratio) is used to measure the proneness of the quality characteristic which was being investigated in a controlled manner. Well known Taguchi method reveals that the term 'signal' represents the desirable effect (mean) for the output attribute whereas the term 'noise' represents the undesirable effect (signal disturbance, S.D) for the output attribute which has got influence of outcome because of external factors viz; noise factors. The S/N ratio can be computed as

Nominal is the best $S/N_T = 10\log\left(\frac{\bar{y}}{s_y^2}\right)$

Larger-is-the better (maximize) $S/N_L =$

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

Smaller-is-the better (minimize) $S/N_S =$

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

Where y is the average of observed data, s^2y is the variance of y, n is the number of observations and y is the observed data.

It is notable that these S/N ratios are explicit on a decibel scale. In this regard S/N_T is used if the aim is to reduce variability around a specific target, S/N_L in case the system is optimized when the response is as large as possible, and S/N_S in case the system is optimized when the response is as small as possible. Its factor level maximizes the appropriate S/N ratio are known as optimal. The object of this research was to create minimum surface roughness (Ra) in a turning operation. By virtue of this research smaller Ra values signify better or improved surface roughness. Therefore, a smaller-the-better quality attribute was implemented and introduced in this study (Montgomery DC, 1997).

Table 3: S/N Ratio

Experiment	SR (1)	S/N Ratio
1	5.009	-13.99
2	7.031	-16.94
3	10.16	-20.13
4	4.664	-13.37
5	2.96	-9.42
6	8.468	-18.55
7	2.148	-06.64
8	2.187	-06.79
9	6.403	-16.12

D. Analysis of Variance (ANOVA):

The purport of the analysis of variance (ANOVA) was to gain those parameters which are significantly affecting the quality attribute. The total sum of square deviation, SS_T can be calculated using (Roy, R.K., 1990).

$SS_T = \sum_{i=1}^{y} y_i^2 - C.F$

where, *n* represents the number of experiments in the orthogonal array, y_i is the total surface roughness of *i*th experiment and *C.F.* is the correction factor. *C.F* may be computed as (Roy, R.K., 1990).

$$C.F = \frac{T^2}{N}$$

where, *T* is the sum of all total surface roughness.

The total sum of square deviations i.e. SS_T was segregated into two ways: the sum of squared deviation, SS_d *owing* to each process parameter and the sum of square error, SS_e. The percentage contribution which is denoted by *P*, in which each process parameter is the total sum of square deviation, SS_T that is a ratio of the sum of square deviation, SS_d because of each process parameter to the total sum of square deviation, SS_T.

To the point of view of statistical study, there is a test called *F*-ratios (variance ratio) to study which parameters have significant effects. For performing the *F* test, the mean of square deviation, SS_m *due* to each process parameter requires due calculation. The mean of square variations, SS_m *is* equal to the sum of square deviation, SS_d *divided* by the number of degree of freedom linked with the process parameters. As a result of it, the *F* value for each process parameter is merely the ratio of the mean of square deviation, SS_m to the mean of square error, SS_e.

Table 4 shows the results of pooled ANOVA for the surface roughness test. In experiment, the F-ratios were obtained for 90% level of confidence. In addition to this, percentage contribution of each parameter was also calculated. The most significant factors were feed that contributed maximum to the total surface roughness. The contributions from these parameters were cutting speed (38.62%), feed (50.27%), depth of cut (8.70%) & other factor/error (2.39%). The optimal combination of parameters and their levels for achieving minimum surface roughness which are based on the S/N ratio and ANOVA analyses is A3B2C3 i.e. Cutting speed at level 3, feed at level 2, and depth of cut at level 3.

Table 4: ANNOVA

Para meters	**DOF**	**Sum of Squares (S)**	**Variance Ratio F Ratio**	**% Contribution = S' /SS Total**
		SS due to each Design	**V treatment /V error**	
Cutting Speed	2	77.33	65.57	**38.62**
Feed	2	100.31	85.05	**50.27**
Depth of Cut	2	18.33	15.54	**8.70**
All Others/ Error	2	1.179	0.58	2.39
Total	8	**197.17**		

Table 5: Mean S/N response table

Para meters	**DOF**	**Levels**		
		1	2	3
Cutting Speed	2	-17.02	-13.78	-9.85
Feed	2	-11.33	-11.05	-18.27
Depth of Cut	2	-13.11	-15.48	-12.06

E. Confirmation test

In order to verify the estimated results with the experimental results as well, the confirmation tests are performed. The confirmatory test is only required when the optimal permutation of parameters and their levels coincidently do not match with one of the experiments in the OA. The calculation of estimated value of the total surface roughness at optimum condition is done by adding the average performance to the contribution of each parameter at the optimum level using the following equations

Yopt = m + (mAopt – m) + (mBopt – m) + (mCopt - m) m = $\frac{T}{n}$

where m is the average performance, *T* is the grand total of average total surface roughness for each experiment, *n* is the total number of experiments and *mAopt* is the average total surface roughness for parameter A at its optimum level, *mBopt* is the average total surface roughness for parameter B at its optimum level, *mCopt* is the average total surface roughness for parameter C at its optimum level.

When optimum combination of parameters and their levels did not correspond to any experiment of the orthogonal array then the necessity of confirmation test arises in this study. Since optimum combination of parameters i.e.A3B2C3 is not available in experiment list, hence experiment has been performed with this combination and found following result.

Table 6: Orthogonal Array (a)

Experiment No	Variable 1	Variable 2	Variable 3	Variable 4
10	3	2	3	-

Table 7: Orthogonal Array (a)

Experiment No	Variable 1	Variable 2	Variable 3	Result
10	950	0.2	0.3	2.015 μm

IV. RESULT

On the basis of various experiments and analysis carried out, following are the results that we obtained.

The graph to show the effect of cutting speed has been plotted (fig 5.).

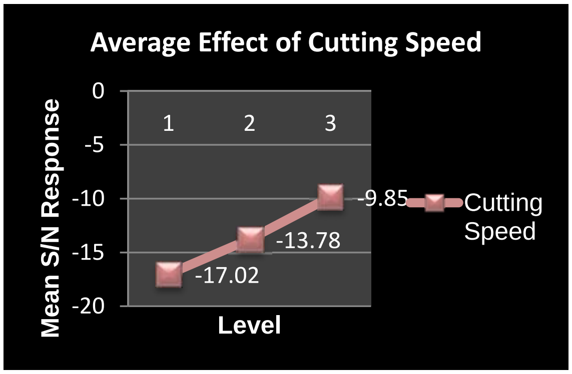

Fig 5: Effect of Cutting speed

The graph to show the effect of feed has been plotted (fig 6)

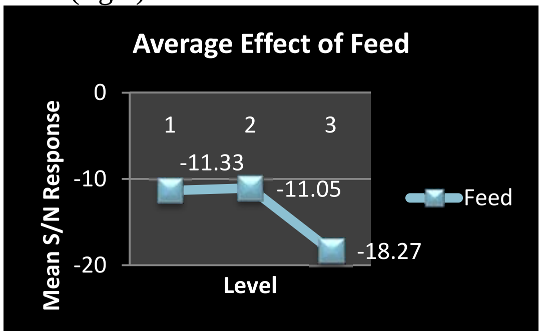

Fig 6: Effect of feed

The graph to show the effect of depth of cut has been plotted (fig 7)

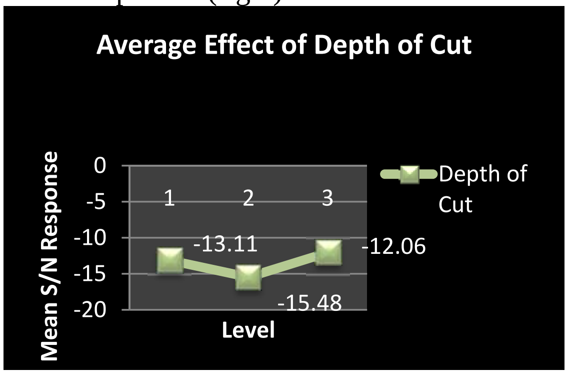

Fig 7: Effect of depth of cut

The combined effect has been shown in the graph (fig 8)

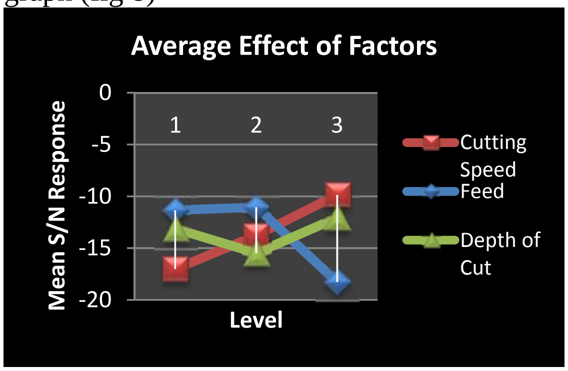

Fig 8: Effect of cutting parameters

Pie diagram and bar chart to show the contribution of various process parameters has been drawn (fig 9 & fig 10)

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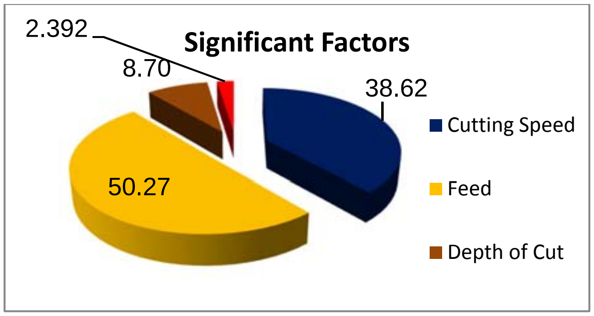

Fig 9: Contribution of Significant Factors (a)

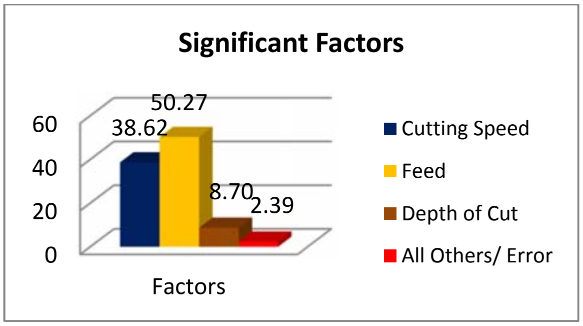

Fig 10: Contribution of Significant Factors (b)

V. CONCLUSION AND SCOPE FOR FUTURE WORK

A. *Conclusion*

From the analysis of the results, the following can be concluded from the present study:

1. The optimum conditions are A3B2C3 i.e. Cutting speed at level 3, feed at level 2, and depth of cut at level 3.
2. The optimum surface roughness is 2.015 µm
3. The most significant factors was feed that contributed maximum to the total surface roughness
4. The contribution of parameters is cutting speed (38.62%), feed (50.27%), depth of cut (8.70%) & other factors/ error (2.39%).

B. *Scope for future work*

The present work has been carried out without considering interaction effect. In future work can be done after considering interaction effect. Work can also be done to find out the optimum combination of process parameters for different steels as well other alloys. The application of this work can also be done in any industry to reduce rejection rate.

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