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Design, Optimization of cutting parameters for EN8 using TAGUCHI Method

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ABSTRACT

Modern manufacturers, seeking to remain competitive in the market, the quality of surface finish is an important requirement as far as turning is concerned. This paper presents the single response optimization of turning parameters for Turning on EN8 material .Experiments are designed and conducted based on Taguchi's L9 Orthogonal array design. This paper discusses an investigation into the use of Taguchi parameter Design optimize the Surface Roughness in turning operations using single point carbide Cutting Tool. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning. The experimental results showed that the work piece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment. The useful results have been obtained by this research for other similar type of studies and can be helpful for further research works on the Tool life.

Keywords— **ANOVA, EN8, Optimization, Surface Roughness, Turning**.

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I. INTRODUCTION

EN8 is an unalloyed medium carbon steel grade with reasonable tensile strength. It is normally supplied in the cold drawn or as rolled condition. Tensile properties can vary but are usually between 500-800 N/mm². EN8 is widely used for applications which require better properties than mild steel but does not justify the costs of an alloy steel. EN8 can be flame or induction hardened to produce a good surface hardness with moderate wears resistance.EN8 is available from stock in bar and can be cut to your requirements. We also offer flame cut plates cut to your required sizes and normalised. EN8 plates The Taguchi method is statistical tool, adopted experimentally to investigate influence of surface roughness by cutting parameters such as cutting speed, feed and depth of cut [3]. The Taguchi process helps to select or to determine the optimum cutting conditions for turning process. Many researchers developed many mathematical models to optimize the cutting parameters to get lowest surface roughness by turning process. The variation in the material hardness, alloying elements present in the work piece material and other the machine tool the work piece set-up, and the use of cutting fluids, etc.In a turning operation, it is an important task to select cutting parameters for achieving high cutting performance. Usually, the desired cutting parameters are determined based on experience or by use of a handbook [1], however, this does not ensure that the selected cutting parameters have optimal or near optimal cutting performance for a particular machine or environment. To select cutting parameters properly it requires a more mediodical approach by using experimental methods and mathematical and statistical models. Not only does this require considerable knowledge and experience to design experiments and analyze data, but traditional design of experiments (DOE) techniques require a large number of samples to be produced. Therefore, a more efficient method is needed to effectively optimize cutting parameters for surface roughness in turning operations. Full factorial designs, fractional factorial designs, orthogonal array designs, and central composite designs have been used as experimental designs in most of the recent works.

In studies that used factorial and orthogonal array designs, experimental data was analysed for effects of the factors and interactions based on level means analysis. Significance of the effects was tested through analysis of variance (ANOVA), and selection of optimum levels for the factors was based on the level means. In some of these works, empirical models, based on regression analysis, were also developed [2-5]. Researchers considered both power-models and polynomial models. Some of the authors adopted neural network modelling in addition to regression analysis [6-7]. Some of the authors considered multi-response optimization based on utility/loss function concept [8-10]. In studies that utilized central composite designs, the primary aim was to develop polynomial models. Selection of optimum values for factors was based on model equations, contour plots and surface plots. Researchers used varieties of central composite designs namely rotatable designs, spherical designs and face-cantered designs.

In this work, a central composite design which provides a most economical way of experimentation was used to study the effects of process parameters on surface roughness while machining EN 8. The main objectives of this work are:

1. To develop empirical model to predict surface roughness as a function of process parameters.
2. To study the effects of process parameters namely cutting speed, feed, and depth of cut on surface roughness.

II METHODOLOGY

A. Taguchi method

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost [5]. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment [6]. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community [7-8]. The desired cutting parameters are determined based on experience or by hand book. Cutting parameters are reflected.

B. Experiments & Material

In this investigation, for the work piece material,, alloy was used. This material was chosen based on its applications in industry. Manufacturers have mere turned to aluminium to improve fuel economy, safety's performance. As a result, EN8 has surpassed the second most used automotive material worldwide work pieces of 300mm length and 70mm diameters considered for conducting experimentation. These were cantered and cleaned by removing a 2mm depth of S from the outside surface prior to the actual machine process. Surface finish of the work piece material measured by Talysurf with 0.8 mm cut-off value, surface roughness parameter used to evaluate roughness, in this study, is the roughness average R. parameter is also known as Arithmetic Average (AA)'.d Centre line average (CLA).R_a is recognized universally a the most common international parameter of roughness The average roughness is the area between the rough profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation-*"' length. The surface roughness was measured at three equally spaced locations around the circumference of the work pieces to obtain the statistically significant data for each test. The surface roughness measurement given in this study is the mathematical average of the three readings taken from the work piece.

We selected EN8 steel work material as: The composition of this material is Manganese 0.8 %,Carbon 0.4%,Silicon 0.25%,Phosphorous 0.015%, Sulphur 0.015%.

TABLE I

CHEMICALS

EN 8 Chemical Composition	
Carbon	0.36--0.44%
Silicon	0.10-0.40%
Manganese	0.60-1.00%
Sulphur	0.050 Max

This enriches the material in properties of:

1. High strength
2. Good toughness
3. Good ductility
4. High hardenability

TABLE III

MECHANICAL PROPERTIES

EN 8 Mechanical properties with specific radius R	
Max Stress	700-850 n/mm2
Yield Stress	465 n/mm2 Min (19mm LRS)
0.2% Proof Stress	450 n/mm2 Min (19mm LRS)
Elongation	16% Min (12% if cold drawn)
Impact KCV	28 Joules Min (19mm LRS)
Hardness	201-255 Brinell

Tool Material - Tungsten Carbide Tipped Tool

Here the chemical composition is: The composition of this material is Tungsten of 94% and Carbide of 6

TABLE IIIII
CHEMICAL PROPERTIES

Chemical composition of Tungsten carbide	
Tungsten	0.36-0.44%
Carbide	0.10-0.40%

The property of the material is:

1. High strength
2. Rigidity
3. Impact resistant
4. Heat and oxidation resistance
5. Resistance to corrosion and wear.

FIGURE NO.1 WORK PIECE BEFORE MACHINING

A. Experimental Design

The most direct method to predict surface quality is by the creation of regression models based on experimental investigation studies. The advantage of such models is that they are able to take into account multiple factors influencing surface quality that would not have been able; to be accounted for in analytical models and for cases where an analytical formulation is not feasible. The purpose of the experiments was to analyze the influence of process parameters and evaluate the performance on the surface roughness in hard turning process. In this study, the three parameters namely cutting speed, feed, and depth of cut were selected for the experimentation. The range of each parameter was set at three different levels namely low, medium and high based on industrial practice. Different settings of control factor is used in the experimentation are summarized in Table IV. The level of each factor was selected based on the machining data hand book [11].

TABLE IVV
LEVEL OF CONTROL FACTORS

Factor Symbol	**Factor**	**Level 1 (Low)**	**Level 2 (Medium)**	**Level 3 (High)**
V	Cutting Speed (m/min)	40	70	100
F	mm/rev	0.10	0.15	0.20
D	Depth of Cut	0.25	0.50	0.75

TABLE V
MACHINE READINGS OF ROUGHNESS

Exp. No	V	F	D	Surface Roughness
1	-1	-1	-1	2.378253
2	-1	-1	0	2.948527
3	-1	-1	1	2.378253
4	-1	0	-1	4.181174
5	-1	0	0	4.677735
6	-1	0	1	4.181174
7	-1	1	-1	5.457342
8	-1	1	0	5.463032
9	-1	1	1	5.457342
10	0	-1	-1	0.848185
11	0	-1	0	1.428701
12	0	-1	1	0.848185
13	0	0	-1	2.385137
14	0	0	0	2.95532
15	0	0	1	2.385137
16	0	1	-1	3.873664
17	0	1	0	4.395165
18	0	1	1	3.873664
19	1	-1	-1	1.555542
20	1	-1	0	2.133174
21	1	-1	1	1.555542
22	1	0	-1	2.742841
23	1	0	0	3.307246
24	1	0	1	2.742841
25	1	1	-1	3.891168
26	1	1	0	4.411482
27	1	1	1	3.891168

Design of experimental techniques was used for the Execution of the plan of experiments. Experiments were as per central composite face centered (CCF) [12] for three factors. The CCF design consists of ns which include a 2^3 (8) fractional factorial portion, axial points and a centre point. Each experiment is replicated twice and a total of 30 experiments were need to analyze the influence of various factors on the surface roughness. The experimental layout along with the response (surface roughness) obtained is shown in table IV. In the table IV the values for the levels are given in coded form such as '-`1' indicates level 1 of the factor, '0' indicates level '2' of the factor, '+1' indicates level '3' of the factor. Experiments were conducted randomly to avoid bias.

III. DATA ANALYSIS AND DISCUSSION OF RESULTS

The plan of tests was developed aiming at determining the relation between the influence of cutting parameters and the surface roughness. The correlations were obtained by multiple linear regressions. CCF designs are best for fitting a second order model and accordingly second order models have been developed. The input data to SPSS software is provided in coded form of factors i.e. -1 to +1.

A. Surface Roughness Model

Applying backward linear regression, which eliminates the insignificant factors one at a time, option of SPSS is used to develop the models. The parameter estimates and analysis of variance for the model are given in table VI.

PE-Parameter estimates; SE-Standards error Analysis of variance for the model.

TABLE VI
THE PARAMETER ESTIMATES AND ANALYSIS OF VARIANCE FOR THE MODEL

Term	Coef	SECoef	T-Value	P-Value	VIF
Constant	2.9675	0.0557	53.29	0.000	5.00
v	-0.6423	0.0576	-11.14	0.000	5.00
f	1.4272	0.0576	24.76	0.000	5.00
d	0.0000	0.0576	0.00	1.000	5.00
v*v	0.9649	0.0447	21.61	0.000	1.00
f*f	-0.1294	0.0447	-2.90	0.016	1.00
d*d	-0.4897	0.0447	-10.97	0.000	1.00
v*f	-0.1436	0.0316	-4.55	0.001	1.00
v*d	-0.0000	0.0316	-0.00	1.000	1.00
f*d	0.0000	0.0316	0.00	1.000	1.00
v*v*f	-0.2011	0.0547	-3.68	0.004	3.00
v*v*d	-0.0000	0.0547	-0.00	1.000	3.00
v*f*f	0.1541	0.0547	2.82	0.018	3.00
v*f*d	0.0000	0.0387	0.00	1.000	1.00
v*d*d	-0.0983	0.0547	-1.80	0.102	3.00
f*f*d	-0.0000	0.0547	-0.00	1.000	3.00
f*d*d	0.1135	0.0547	2.08	0.065	3.00

df- degrees of freedom; SS-sum of squares; MS-mean squares;

R-square=0.963; Based on the above results, the surface roughness (S.R) model developed is given by:

$$S.R= 2.985 - 0.762\, v + 1.55\, f + 1.127\, v^2 - 0.5833\, d^2 -0.346\, vf$$

Surface roughness model in terms of actual factors can be expressed as:

1.55 feed +1.127 2 -.346 (cutting S.R = 2.985 -0.762 cutting speed + (cutting speed) 2 -0.583 (depth of cut) speed x feed) The R-square value of 0.963 indicates that 96.30% of the variability in surface roughness was explained by the model. It can be observed that the cutting speed and feed are affecting on surface roughness. The presence of square terms of cutting speed and depth of cut indicates the non-linear behavior on surface roughness. Further, interaction term of cutting speed and feed is also available into the model.

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A. *Effect of Process Parameters on Surface Roughness*

The effects of cutting parameters according to the experiments conducted can be summarized as follows: As seen from model equation and Figures 1-3, the feed has the greatest effect on surface roughness followed by cutting speed. It can be observed that an increase in cutting speed decreases surface roughness from its lower level to middle level and then slightly increases from middle level to higher level. But the better surface roughness is noticed at middle level of cutting speed irrespective of feed and depth of cut levels.From the figure 2, it can be observed that at lower level of feed value the minimum value of surface roughness occurs at a cutting speed of 75 m/min (the medium value). At higher level of feed, the minimum value of surface roughness occurs at medium and/or higher levels of cutting speed. When the depth of cut is at its lower and higher level there is no change in surface roughness value.

A. *Taguchi Analysis: strength versus v, f, d*

Response Table for Signal to Noise Ratios Smaller is better

Level	v	f	d
1	-11.880	-4.326	-8.553
2	-6.793	-10.076	-10.308
3	-8.741	-13.012	-8.553
Delta	5.088	8.686	1.755
Rank	2	1	3

Response Table for Means

Level	v	f	d
1	4.125	1.786	3.035
2	2.555	3.284	3.524
3	2.915	4.524	3.035
Delta	1.570	2.738	0.490
Rank	2	1	3

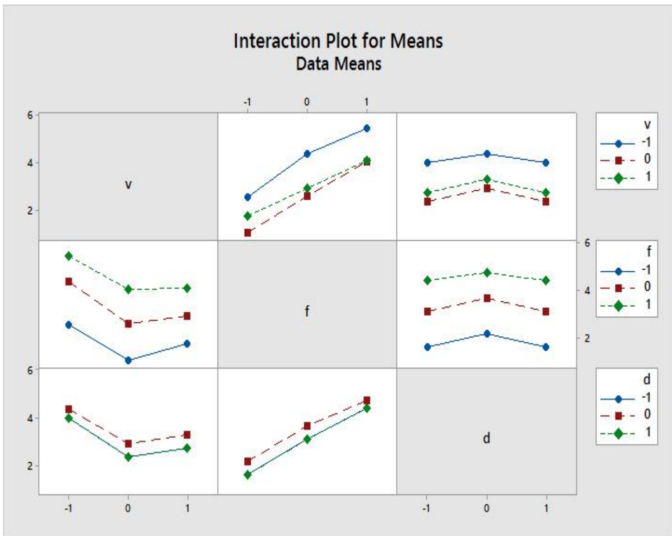

FIGURE NO.2 MAIN EFFECTS PLOT FOR MEANS

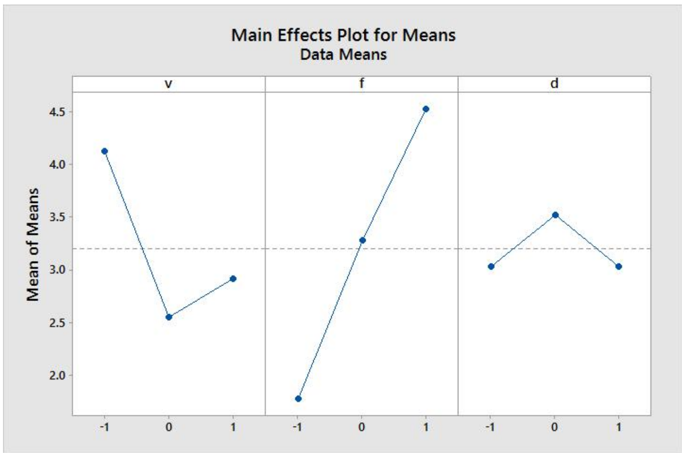

FIGURE NO.3 INTERACTION PLOT FOR MEANS

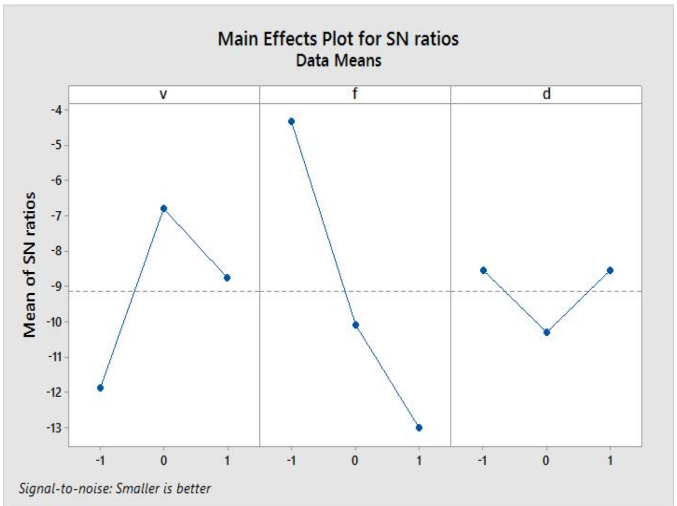

FIGURE NO.4 MAIN EFFECTS PLOT FOR SN RATIOS

Interaction plot for S/N ratios of the Surface roughness for data means is shown in Fig .5 Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

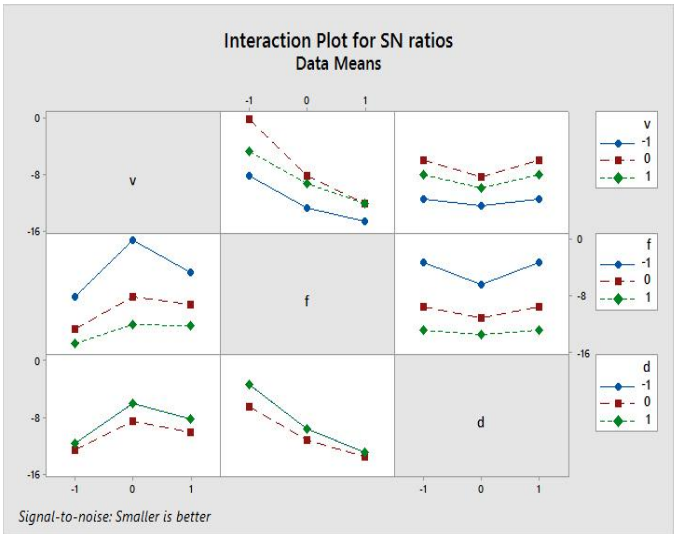

FIGURE NO.5 INTERACTION PLOT FOR SN RATIOS

A. Analysis of variance (anova)

Analysis of data variance with surface roughness was iadc with the objective of analyzing the influence of cutting speed (v), feed (f) and depth of cut (d) on the total variance of the results.

The Anova is shown in below.

Regression Analysis: strength versus v, f, d

```
The following terms cannot be estimated and
were removed:
   v*v*v, f*f*f, d*d*d
Analysis of Variance

Source  DF   Adj SS  Adj MS   F-Value P-Value
Regres. 16  48.0384 3.00240  250.98    0.000
  v      1   1.4853 1.48528  124.16    0.000
  f      1   7.3333 7.33332  613.02    0.000
  d      1   0.0000 0.00000    0.0     1.000
  v*v    1   5.5858 5.58575  466.94    0.000
  f*f    1   0.1004 0.10043    8.40    0.016
  d*d    1   1.4387 1.43869  120.27    0.000
  v*f    1   0.2474 0.24743   20.68    0.001
  v*d    1   0.0000 0.00000    0.00    1.000
  f*d    1   0.0000 0.00000    0.00    1.000
  v*v*f 1    0.1617 0.16169   13.52    0.004
  v*v*d 1    0.0000 0.00000    0.00    1.000
  v*f*f 1    0.0950 0.09503    7.94    0.018
  v*f*d 1    0.0000 0.00000    0.00    1.000
  v*d*d 1    0.0387 0.03865    3.23    0.102
  f*f*d 1    0.0000 0.00000    0.00    1.000
  f*d*d 1    0.0515 0.05152    4.31    0.065
Error       10   0.1196  0.01196
Total       26  48.1580

Model Summary

   S        R-sq     R-sq(adj)  R-sq(pred)
0.109373   99.75%      99.35%      97.93%

Regression Equation

Surface roughness = 2.9675 - 0.6423 v
+ 1.4272 f + 0.0000 d + 0.9649 v*v -
 0.1294 f*f - 0.4897 d*d
           - 0.1436 v*f -   + 0.1541 v*f*f
+ 0.0000 v*f*d - 0.0983 v*d*d - 0.0000 f*f*d
+ 0.1135 f*d*d

Fits and Diagnostics for Unusual Observations

Obs strength     Fit    Resid   Std Resid
  8     5.4630  5.6610  -0.1979      -2.94   R

  R  Large residual
```

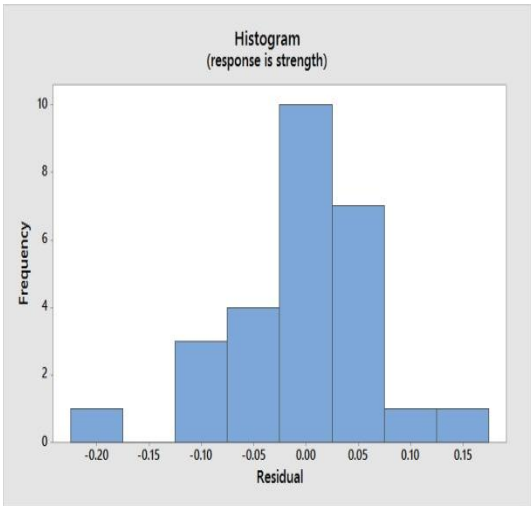

FIGURE NO.6 HISTOGRAM FOR SR

Degrees of freedom: SS-sum of squares: MS-mean squares

From the ANOVA table it can be observed that the feed k74.6%) has great influence on surface roughness followed by cutting speed (p=20.18%).

IV. CONCLUSIONS

The feed is observed to be most dominant factor followed by cutting speed on surface roughness within the ranges considered.Analysis shows that 74 % contribution is due to feed whereas 21 % contribution is due to speed. The depth of cut has no significant effect on surface roughness. The presence of square terms of cutting speed and depth of cut in model equations indicates the existence of non-linear relationship between the parameters and the response (surface roughness).The CCF design provides lot of information with minimum amount of experimentation. The low level of feed, middle level of cutting speed and high level of depth of cut are identified as optimum levels for achieving the better surface finish.

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