Parametric Optimization on single objective Dry Turning using Taguchi Method

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ABSTRACT - The objective of this investigation is to obtain an optimal setting of process parameters in turning for maximizing the material removal rate of the manufactured component. The material removal rate has been investigated in this analysis while machining practically used components. As per Taguchi's "Design of Experiments", the number of experiments to be conducted in this analysis is calculated, and the turning operations are performed as per the machining conditions shown in the orthogonal array. The data for calculating material removal rate in all the test conditions are observed and recorded. The result of this analysis identifies the optimal values of process parameters for effective and efficient machining. ANOVA has been carried out to find the percentage of each process parameter on response characteristic i.e, MRR. .

Keywords : Machining, MRR, Taguchi Method, EN41B, ANOVA.

I. INTRODUCTION

Metal cutting is one of the important and commonly used manufacturing processes in any metal processing or business industries. By machining processes or manufacturing operations, attempts are made to make a particular product in several steps as of required dimensions and shapes to ensure the quality of machining products for the intended applications made for. The step-by-step machining is done on the material to reduce the machining costs thereby increasing the machining effectiveness. Every manufacturing Industry aims at producing a large number of products within relatively lesser time. It has long been recognized that conditions during cutting, such as feed rate, cutting speed and depth of cut, should be selected to optimize the economics of machining operations, as assessed by productivity, total manufacturing cost per component or some other suitable criterion. The optimization of cutting parameters during machining is a difficult task as it involves a number of aspects such as knowledge of machining, empirical equations of tool life, cutting forces, power consumed, material removal rate and machining surface finish etc. All these aspects should be considered during machining optimization to develop an effective optimization criterion[1]. Manufacturing industries have long depended on the skill and experience of shop-floor machine-tool operators for optimal selection of cutting conditions and cutting tools. Many authors have shown the optimization objective as specific cost from the beginning of the researches in this branch [2] to some of the most recent works [3], [4], [5], [6], and [7]. The present study is mainly focused on optimization of process parameters of dry turning operation considering maximization of material removal rate (MRR) as the objective function. Feed rate, spindle speed and cutting speed are considered as process parameters with specified ranges.

1.1 Taguchi method

Conventional methods for experimental design are of complex in nature and difficult to use. In addition to that, these methods also require a large number of experiments when the process parameters increases. In order to minimize the number of experiments, a powerful tool has been designed for high quality systems by Taguchi. Taguchi approach to design of experiments has got high adoptability and hence users can be applied with confined knowledge of statistics, hence gained wide popularity in Engineering application. Taguchi method uses a set of orthogonal arrays to investigate the effect of various process parameters on response characteristic to decide the optimal setting of process parameters. Taguchi method is especially suitable for industrial use, but can also be used for scientific research [8].

1.2 Analysis of variance (ANOVA)

Since there are a large number of variables controlling the process, some mathematical models are required to represent the process. However, these models are to be developed using only the significant parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the analysis of variance (ANOVA) [9] . ANOVA is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response.

II. EXPERIMENTATION

Turning plays a major role in metal cutting operation where in lathe is used to perform metal machining . It is a machining process in which a single point cutting tool removes unwanted material from the surface of a rotating cylindrical work piece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. In the present work , three levels, three factors and twenty seven experiments are identified. By using Taguchi design, L_{27} orthogonal array has been selected. Metal cutting operation are performed on PSG A141 lathe under dry cutting condition. Firstly, skinning operation has been performed on the work piece in order to remove the rust layer or hardened top layer from the out side surface of the work piece and to minimize the effect of in homogeneity on the experimental results. After that the skinned work piece is removed from the chuck of a lathe and weight is measured by a high precision digital balance meter. Then using different levels and with different factors tests are conducted. Each time the machined work piece is weighed by using digital balance meter and like wise weight is measure for all the experiments. Each time machining time is calculated and from which material removal rate (MRR) is calculated by using the formula.

MRR = (Initial Wt - Final Wt)/Time Taken.

Therefore three cutting parameters namely speed, feed and depth of cut need to be determined in a turning operation. The turning operations are accomplished using a cutting tool. The purpose of turning operation is to produce high material removal rate. Material removal rate is an important factor to evaluate cutting performance. Proper selection of cutting parameters and tool can produce longer tool life and high material removal rate. Hence, design of experiments by Taguchi method on cutting parameters was adopted to study the material removal rate. The cutting parameters chosen are shown in the Table 3.

Fig. 1 View of cutting zone

The experiment was conducted for dry turning operation of EN 41-B alloy steel with cermet tool. The tests were carried for a length of 200 mm in a PSG A141 lathe. The control factors and their levels are illustrated in Table 1.

The cutting parameters ranges were selected based on machining guidelines provided by manufacturer of cutting tools manufacturers Kayocera. The different alloying elements present in a work piece are shown in the Table 2.

Table 1 Control factors and levels

Code	Control factors	Levels		
		1	2	3
A	speed, s (rpm)	360	450	580
B	feed, f (mm/rev)	0.05	0.07	0.09
C	Depth of cut, d (mm)	0.05	0.1	0.15

Table 2 Chemical composition of En 41B Alloy Steel

C	Mn	Si	S	P	Cr	Ni	Mo
0.35 - 0.45	0.60 MAX	0.10 - 0.45	0.04	0.04	1.50 - 1.80	0.40 MAX	0.10 -0.25

The dependent variable is Material removal rate. Table 3. shows standard L27 orthogonal array designed by Taguchi with experimental results. The left side of the Table 3 includes coding values of control factors and real values of cutting parameters. The right side of the Table 3 includes the results of the calculated values of the material removal rate and S/N ratio. The different units used here are: speed – rpm, feed mm/ rev, depth of cut – mm and material removal rate gm/sec . Design – MINTAB version 16 software was used for Taguchi's method and for analysis of variance (ANOVA).

Table 3. Plan of experiments with results

Experiment No.	Control Factors			Parameters			Material Removal Rate(MRR) gm/sec	S/N Ratio
	A	B	C	Speed s -rpm	Feed(f) mm/rev	DOC d -mm		
	s	f	d					
1	1	1	1	360	0.05	0.05	0.028	-30.97
2	1	1	2	360	0.05	0.1	0.029	-30.88
3	1	1	3	360	0.05	0.15	0.085	-21.38
4	1	2	1	360	0.07	0.05	0.038	-28.45
5	1	2	2	360	0.07	0.1	0.077	-22.30
6	1	2	3	360	0.07	0.15	0.076	-22.40
7	1	3	1	360	0.09	0.05	0.103	-19.76
8	1	3	2	360	0.09	0.1	0.097	-20.28
9	1	3	3	360	0.09	0.15	0.108	-19.35
10	2	1	1	450	0.05	0.05	0.072	-22.89
11	2	1	2	450	0.05	0.1	0.035	-29.04
12	2	1	3	450	0.05	0.15	0.035	-29.02
13	2	2	1	450	0.07	0.05	0.047	-26.49
14	2	2	2	450	0.07	0.1	0.095	-20.42
15	2	2	3	450	0.07	0.15	0.192	-14.34
16	2	3	1	450	0.09	0.05	0.064	-23.89
17	2	3	2	450	0.09	0.1	0.132	-17.59
18	2	3	3	450	0.09	0.15	0.066	-23.58
19	3	1	1	580	0.05	0.05	0.045	-26.87
20	3	1	2	580	0.05	0.1	0.045	-27.01

21	3	1	3	580	0.05	0.15	0.045	-26.85
22	3	2	1	580	0.07	0.05	0.060	-24.51
23	3	2	2	580	0.07	0.1	0.120	-18.43
24	3	2	3	580	0.07	0.15	0.119	-18.49
25	3	3	1	580	0.09	0.05	0.163	-15.74
26	3	3	2	580	0.09	0.1	0.164	-15.71
27	3	3	3	580	0.09	0.15	0.163	-15.74

2.1 Material Removal Rate

The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better". The S/N ratio for the larger-the-better is:
S/N = -10*log (mean square deviation)

$$\frac{S}{N} = -10\log_{10}\frac{1}{n}\sum 1/y^2 \text{ - - - (1)}$$

Where n is the number of measurements in a trial, in this case, n=1 and y is the measured value in a run. The S/N ratio values are calculated by taking into consideration Eqn. 1. The obtained results are analyzed using Minitab software and all the values are shown in the Table 4.

Table 4. ANOVA table for Material removal rate

Source	**DOF**	**S.S**	**M.S**	**F Value**	**C%**
Speed(s)	2	0.00462	0.00231	0.8088	8.09
Feed (f)	2	0.00232	0.00116	4.0738	40.78
Depth of cut (s)	2	0.00417	0.00208	0.7283	7.30
s X f	4	0.00083	0.00021	0.0072	1.45
s X d	4	0.00051	0.00013	0.0443	0.89
f X d	4	0.00083	0.00021	0.7249	1.45

DOF - Degrees of freedom , S.S - Sum of Squares M.S - Mean of Squares and C - Contribution
From the ANOVA Table 4, it is evident that the maximum contribution factor is feed having percentage contribution up to 40.78% . After that second main contribution is speed having percentage contribution up to 8.09% and depth of cut having 7.30% on Material removal rate . Hence the individual ranking of cutting parameters on the average value of mean on Material removal rate are shown in Table 5:

Table 5 : Ranking of cutting parameters

Level	**Speed**	**Feed**	**Depth of cut**
1	0.07113	0.04667	0.06889
2	0.08211	0.09148	0.08812
3	0.10269	0.11779	0.09892
Rank	**2**	**1**	**3**

2.2 Mathematical modeling

A regression model was developed for surface roughness using Minitab-16 software. The predictions are speed, feed and depth of cut. Regression equation for Material removal rate is
ln (MRR) = - 1.85 + 0.713 ln(s) + 1.61 ln (f) + 0.331 ln (doc)

2.3 Main effect plots analysis

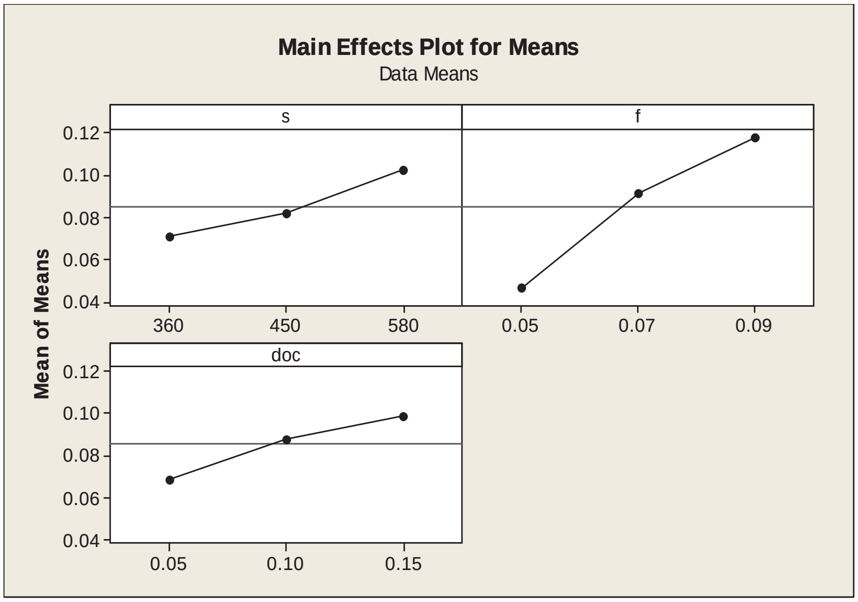

Fig 2: Effect of Turning parameters on Material removal rate

The analysis is made with the help of software package MINITAB-16. The main effect of plot is shown in Fig. 2. It shows the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal Material removal rate.

According to this main effect plot, the optimal conditions for maximum Material removal rate are speed at level 3 (580 RPM) , feed rate at level 3 (0.09 mm/rev) and depth of cut at level 3 (0.15mm).

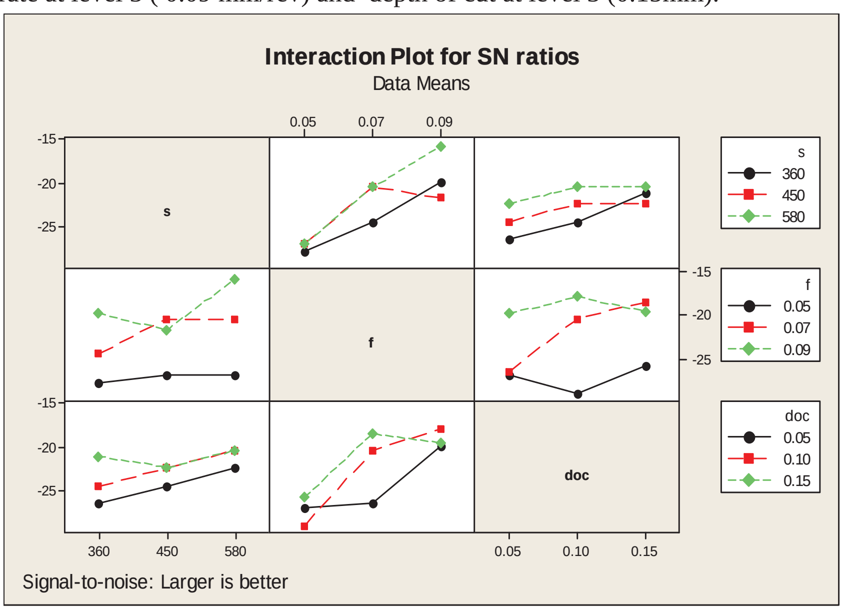

Fig 3. Interaction plot for S/N Ratios of the Material removal rate.

Interaction plot for S/N ratios of the Material removal rate for data means is shown in Fig .3 Signal-to-Noise ratio of common interest for optimization for Material removal rate is larger the better.

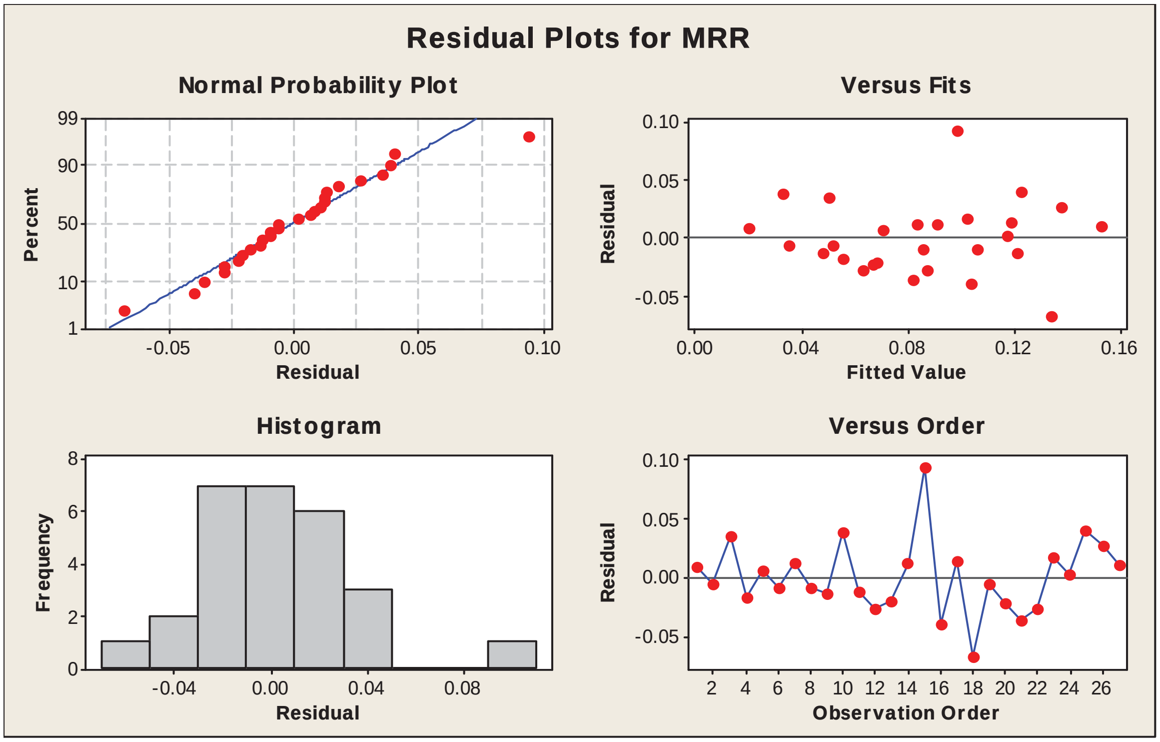

Fig 4. Residual analysis of Material removal rate

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for Material removal rate are shown in Fig. 4. These are generally fall on a straight line implying that errors are distributed normally. From Fig .4, it can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy. Hence these values yield better results in future predictions.

III. CONCLUSIONS

The following are conclusions drawn based on the experimental investigation conducted on turning EN 41-B alloy steel with cermet cutting tool at three levels by employing Taguchi technique to determine the optimal level of process parameters.

1. The ANOVA and F-test revealed that the feed is dominant parameter followed by speed and depth of cut for material removal rate.
2. The optimal combination process parameters for maximum material removal rate is obtained at 580 rpm, 0.09 mm/rev and 0.15mm.
3. A regression model is developed for material removal rate. The developed model is reasonably accurate and can be used for prediction within limits.
4. For the optimum operating conditions the Taguchi gives systematic simple approach and efficient method.

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