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Process Parametric Optimization of CNC Vertical Milling Machine Using ANOVA Method in Mild Steel – A Review

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Abstract

In this paper we are approaching to the effective approach for the optimization of milling machine using MINITAB 17 and Taguchi Technique in varying condition. The information about machining of difficult cutting materials is inadequate and complicated. Therefore an experimental study has to be conducted to come out with an optimum outcome. In this study, the machining parameters namely Depth of Cut, Cutting Speed, Feed Rate and Tool Diameter are optimized with multiple performance characteristics, such as maximum material removal rate and maximum surface finish. Moreover we have to demonstrate a systematic procedure of using Taguchi Parameter Design in process control of individual milling machine and to identify the optimum Material Removal Rate and Surface Roughness performance with particular combination of cutting parameters in an end milling process.

Keywords: Depth of cut, feed rate, tool diameter, cutting speed, Mini Tab17.

Introduction

This experimental study presents an effective approach for the optimization of milling machine using MINITAB 17 and Taguchi Technique in depth of cut, feed rate, tool diameter, cutting speed. The information about machining of difficult cutting materials is inadequate and complicated. Therefore an experimental study has to be conducted to come out with an optimum outcome. In this study, the machining parameters namely Depth of Cut, Cutting Speed, Feed Rate and Tool Diameter are optimized with multiple performance characteristics, such as maximum material removal rate and maximum surface finish. Moreover we have to demonstrate a systematic procedure of using Taguchi Parameter Design in process control of individual milling machine and to identify the optimum Material Removal Rate and Surface Roughness performance with particular combination of cutting parameters in an end milling process. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the *t*-test to more than two groups. As doing multiple two-sample t-tests would result in an increased chance of committing a statistical type I error, ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance. ANOVA is a particular form of statistical hypothesis testing heavily used in the analysis of experimental data. A statistical hypothesis test is a method of making decisions using data. A test result (calculated from the null hypothesis and the sample) is called statistically significant if it is deemed unlikely to have occurred by chance, assuming the truth of the null hypothesis. A statistically significant result, when a probability (p-value) is less than a threshold (significance level), justifies the rejection of the null hypothesis, but only if the a priori probability of the null hypothesis is not high.

By construction, hypothesis testing limits the rate of Type I errors (false positives leading to false scientific claims) to a significance level. Experimenters also wish to limit Type II errors (false negatives resulting in missed scientific discoveries). The Type II error rate is a function of several things including sample size (positively correlated with

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experiment cost), significance level (when the standard of proof is high, the chances of overlooking a discovery are also high) and effect size (when the effect is obvious to the casual observer, Type II error rates are low).
The terminology of ANOVA is largely from the statistical design of experiments. The experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the results. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially random error. [1]

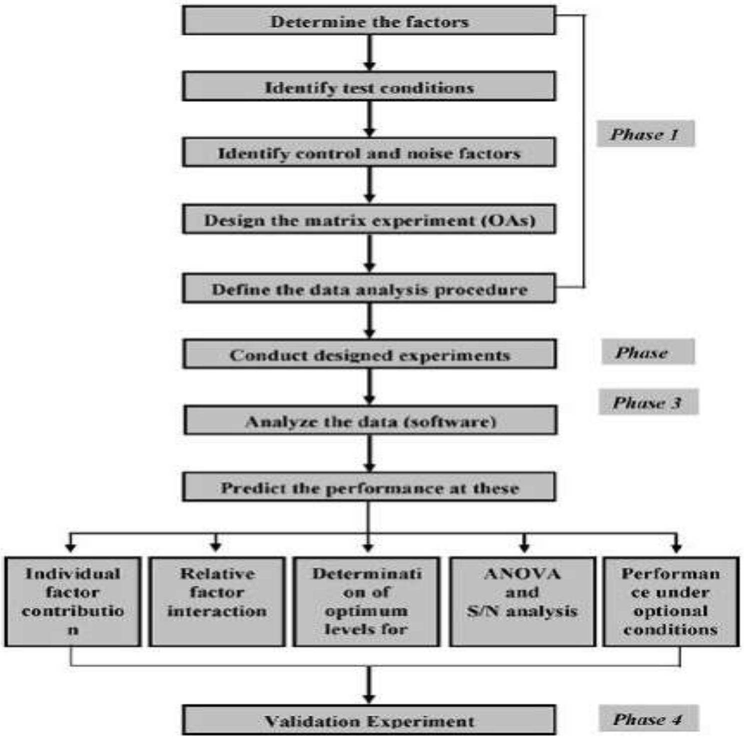

Fig 1:- Description of the execution of these steps

Literature review

B.Sidda Reddy.et.al.[5] is to optimization of surface roughness in CNC end milling using response surface methodology and genetic algorithm, pre- hardened steel is a widely used material in the production of moulds/ dies due to less wear resistance and used for large components.

Experiment setup

The AGNI BMV45 Vertical Milling Machine is comprised of CNC Function Such As Linear Interpolation, Circular Interpolation, Helical Interpolation, work piece co-ordinate system, cutter compensation, pitch error compensation, manual pulse generator & High Quality Balanced Spindle on large precision Bearing eliminates vibration & offers accurate machining under Heavy loads.24 pocket Tool Magazine with arm reduces the non cutting time.

Table.1 Table for Depth of Cut

Depth of cut (mm)	0.5	0.6	0.7

Table.2 Table for Feed Rate

Feed Rate (mm/min)	110	120	130

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Table.3 Table for Cutting Speed

Cutting Speed (rpm)	700	800	1100

Tool Diameter		
I	**II**	**III**
8 mm	10mm	12mm

Fig.2:- Milling machine used for experimental work

Experiment value

MRR (SECTION)

1. Average effect response table for MRR

Table 4 Average Effect Response Table for MRR

LEVELS	A	B	C	D	E
1	0.089	0.127	0.099	0.186	0.124
2	0.198	0.042	0.205	0.157	0.178
3	0.149	0.271	0.141	0.123	--
MAX - MIN	0.101	0.229	0.107	0.073	0.06
RANK	3	1	2	4	5

2. Average effect response table for S/N ratios (MRR)

Table 5 Average Effect Response Table for S/N Ratios (MRR)

LEVELS	A	B	C	D	E
1	-26.82	-20.84	-24.60	-18.90	-24.343
2	-16.70	-27.24	-9.95	-20.89	-18.455
3	-20.70	-12.43	-20.90	-24.40	--
MAX-MIN	10.12	14.81	14.65	5.50	5.888
RANK	3	1	2	5	4

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SR (SECTION)

1. Average effect Response table for SR

Table 6 Average Effect Response Table for SR

LEVELS	A	B	C	D	E
1	1.16	1.44	1.24	1.40	1.445
2	1.49	1.49	1.66	1.50	1.662
3	2.00	1.72	1.41	1.75	--
MAX-MIN	0.84	0.28	0.42	0.35	0.217
RANK	1	4	2	3	5

1. Average effect response table for S/N ratios (SR)

Table 7 Average Effect Response Table for S/N Ratios (SR)

LEVELS	A	B	C	D	E
1	-1.20	-2.95	-3.40	-2.62	-2.927
2	-3.28	-3.07	-4.11	-3.34	-3.973
3	-5.58	-4.31	-2.28	-4.23	---
MAX-MIN	4.38	1.36	1.83	1.61	1.046
RANK	1	4	2	3	5

Analysis of variance (ANOVA)

ANOVA is a statistically based, objective decision- making tool for detecting any differences in average performance of groups of items tested. It is elaborated in that ANOVA is performed to identify the process parameters of CNC Milling that significantly affect the multiple performance characteristics. An ANOVA table consists of sums of squares, corresponding degree of freedom, the F-ratio corresponding to the ratios of two mean squares, and the contribution proportions from each of the control factors. Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables.

There are three conceptual classes of such models:

1. Fixed-effects models assume that the data came from normal populations which may differ only in their means. (Model 1)
2. Random effects models assume that the data describe a hierarchy of different populations whose differences are constrained by the hierarchy. (Model 2)
3. Mixed-effect models describe situations where both fixed and random effects are present. (Model 3).

The F-test

F-test is used for comparisons of the components of the total deviation. For example, in one-way or single-factor ANOVA, statistical significance is tested for by comparing the F test statistic.

$$F = \frac{\text{variance of the group means}}{\text{mean of the within-group variances}}$$

i.e.

$$F^* = \frac{\text{MSTR}}{\text{MSE}}$$

Where,

$$\text{MSTR} = \frac{\text{SSTR}}{I-1},$$

I = number of treatments

And

$$\text{MSE} = \frac{\text{SSE}}{n_T - I},$$

n_T = total number of cases to the F-distribution with $I - 1$

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$n_T - I$ degrees of freedom

T-Test

The t-test assesses whether the means of two groups are *statistically* different from each other. This analysis is appropriate whenever you want to compare the means of two groups, and especially appropriate as the analysis for the posttest-only two-group randomized experimental design.

In practice, there are several types of ANOVA depending on the number of treatments and the way they are applied to the subjects in the experiment:

1. One-way ANOVA is used to test for differences among two or more independent groups. However, the one-way ANOVA is used to test for differences among at least three groups. When there are only two means to compare, the t-test and the F-test are equivalent; the relation between ANOVA and *t* is given by $F = t^2$.
2. Factorial ANOVA is used when the experimenter wants to study the effects of two or more treatment variables. The most commonly used type of factorial ANOVA is the 2^2 (read "two by two") design, where there are two independent variables and each variable has two levels or distinct values.
3. Mixed-design ANOVA is used when one wishes to test two or more independent groups subjecting the subjects to repeated measures, one may perform a factorial mixed-design ANOVA, in which one factor is a between-subjects variable and the other is within-subjects variable.
4. Multivariate analysis of variance (MANOVA) is used when there is more than one dependent variable.

ANOVA table for response data (for MRR)

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARE	VARIANCE	F- VALUE	P- VALUE (%)
Depth of cut 'A'	2	312.32	156.16	3.76	11.84
Cutting Speed 'B'	2	936.11	468.05	11.28	44.05
Feed Rate 'C'	2	107.43	53.72	1.30	1.26
Tool Diameter 'D'	2	92.94	46.47	1.12	0.51
Type of milling 'E'	1	156.03	156.03	3.76	5.59
ERROR	8	331.83	41.48		36.75
TOTAL	17	1936.66			100

Table 8 ANOVA table for MRR

ANOVA table for response data (for SR)

SOURCE OF VARIATION	DEGREE OF FREEDOM	SUM OF SQUARE	MEAN OF SQUARE	F- VAUE	P- VALUE x100 (%)
Depth of cut	2	0.0305	0.0153	0.86	0.444
Cutting Speed	2	0.1595	0.0797	8.68	0.003
Feed Rate	2	0.0349	0.0174	1.00	0.392
Tool Diameter	2	0.0331	0.0166	0.94	0.413
Type of milling	1				
ERROR	8				
TOTAL	17				

Table 9 ANOVA Table for SR

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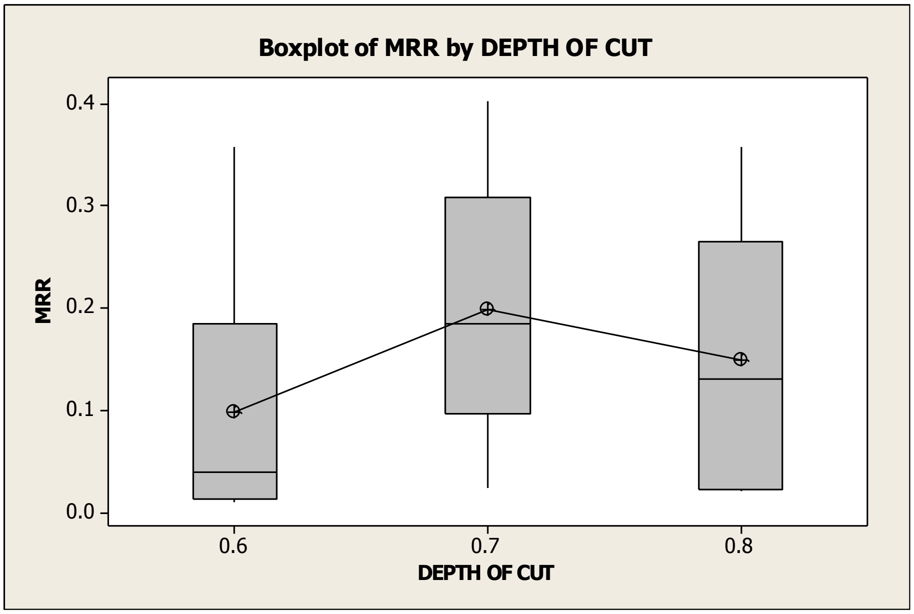

Fig. 3 Box Plot for MRR by Depth of Cut

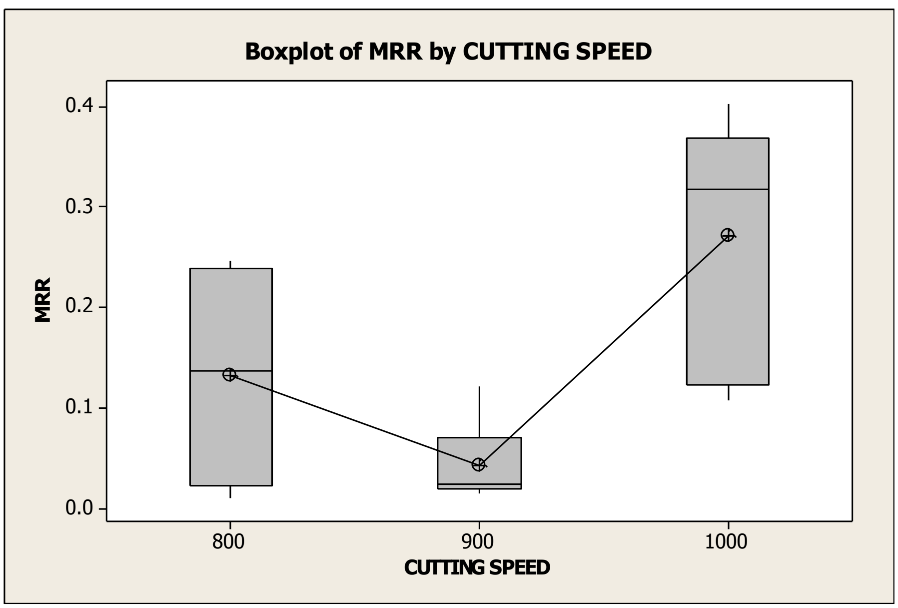

Fig. 4 Box Plot for MRR by Cutting Speed

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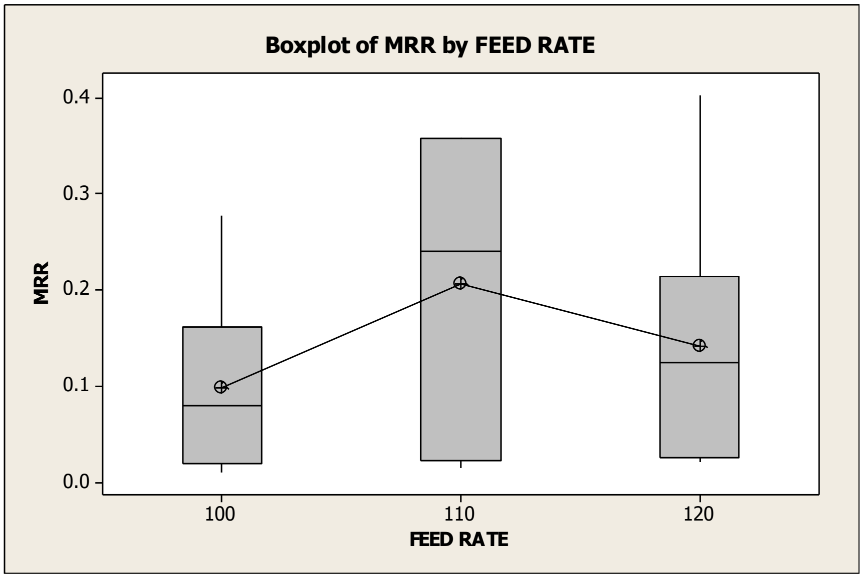

Fig. 5 Box Plot for MRR by Feed Rate

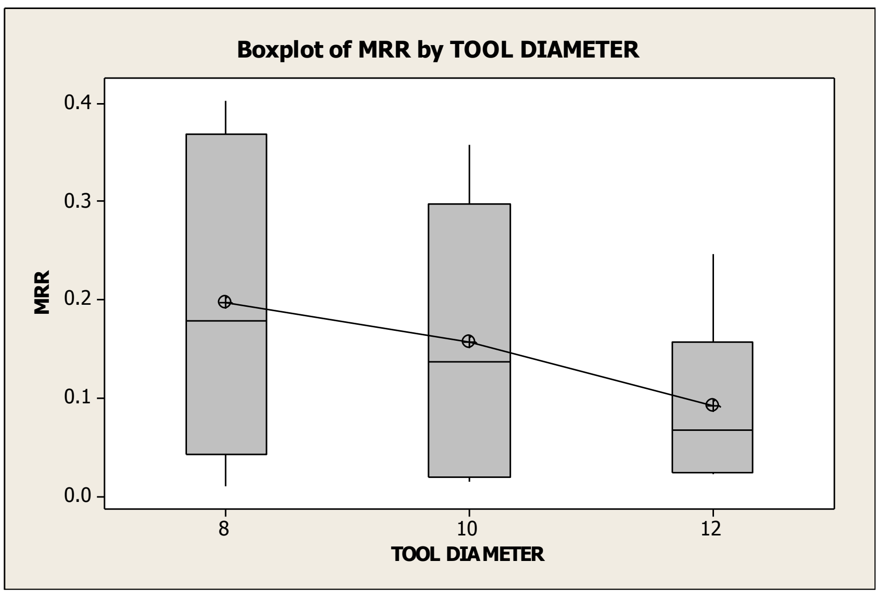

Fig. 6 Box Plot for MRR by Tool Diameter

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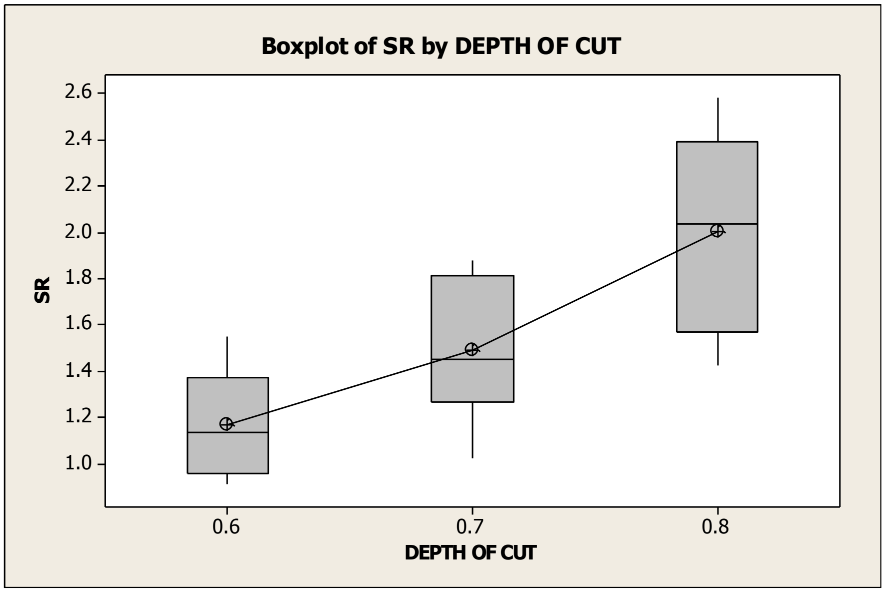

Fig. 7 Box Plot for SR by Depth of Cut

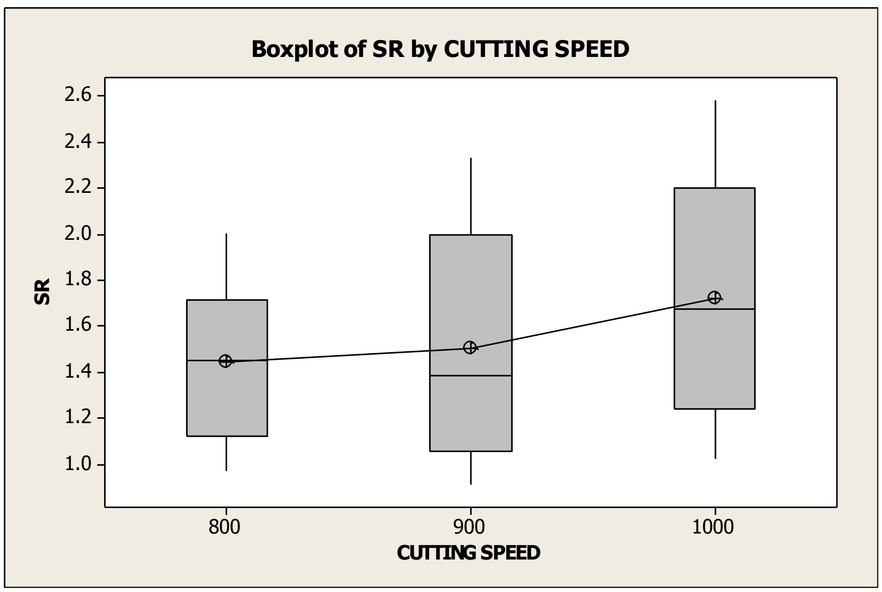

Fig. 8 Box Plot for SR by Cutting Speed

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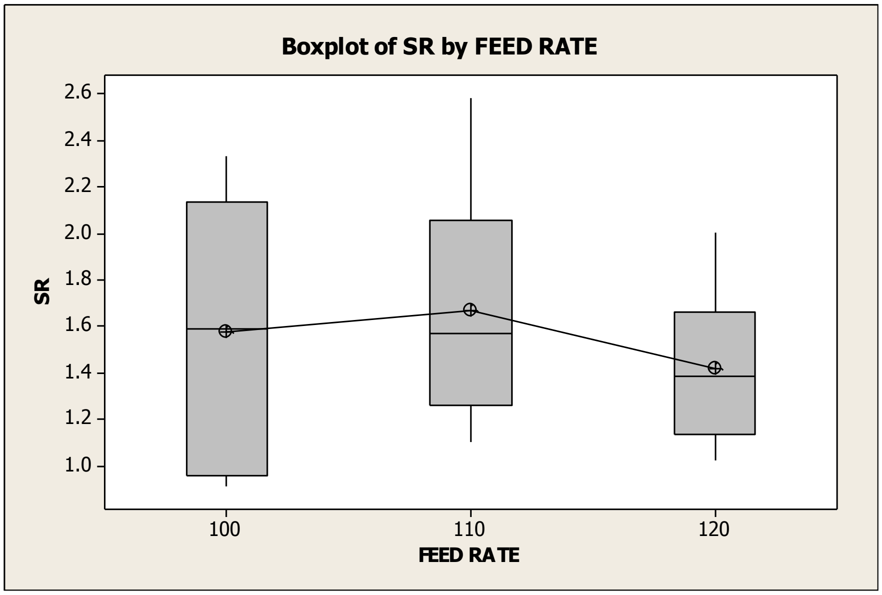

Fig. 9 Box Plot for SR by Feed Rate

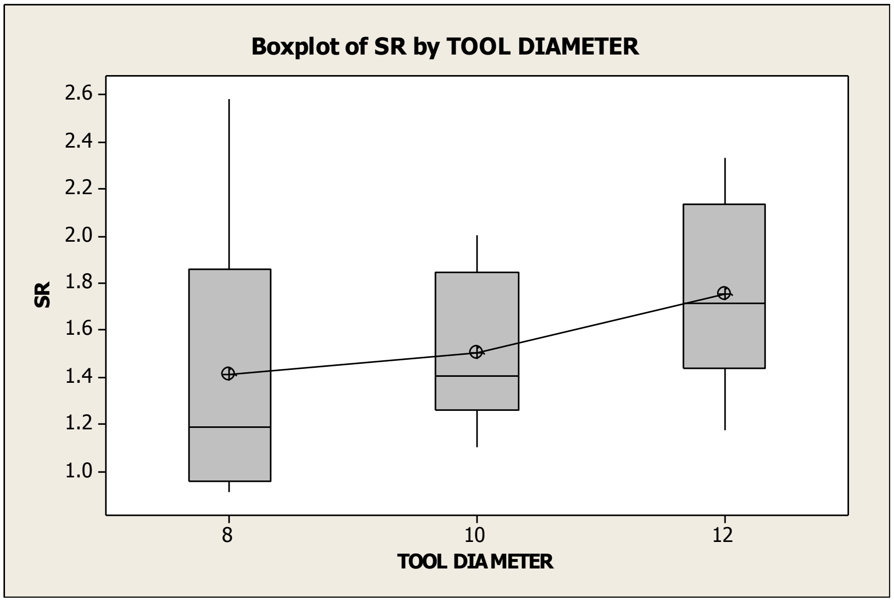

Fig.10 Box Plot for SR by Tool Diameter

Result/ Discussion

This experimental study described the development of process in terms of MRR and Surface finish, using Taguchi's L_{18} orthogonal array. It was fond that the S/N ratio with Taguchi's parameter design is a simple, systematic, reliable and more efficient tool for optimizing multiple performance characteristics of CNC milling process parameters. Factors like depth of cut, feed rate, cutting speed, tool diameter and their interactions have been found to play a significant role in rough cutting operations for maximization of MRR and surface finish. Interestingly, the optimal levels of the selected control factors for both objectives differ widely. In order to optimize for both objectives, mathematical

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models are developed using the non-linear regression method.

Analysis of variance (ANOVA) is also employed to identify the level of importance of the machining parameters on the multiple performance characteristics namely material removal rate and surface roughness. Assumptions of ANOVA are tested using residual analysis. After careful testing, none of the assumptions was violated. ANOVA results showed that CUTTING SPEED AND FEED RATE are the powerful control parameters for the material removal rate and DEPTH OF CUT AND FEED RATE calculated as powerful factors for controlling the surface finish of Mild Steel. In case of MRR analysis, percent contribution for residual error is 4.176% is very small (less than 12%), it is proved that no important factors were omitted during the experiment and there is no opportunity for the further improvement while surface roughness analysis result interprets that percent contribution of residual error is -3% is small (less than 50%), it is acceptable that no important factors were omitted during the experiment but there may be very small opportunity for the further improvement.

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