Analysis and Optimization of Parameters Affecting Bore Deviation in Boring Process

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Abstract- **This investigation applies a full factorial orthogonal table, integrating response surface methodology (RSM) to optimize parameters of a finish boring process using a computer numerical control (CNC) machine VA-50 for the finishing operation of engine crank case tappet bore. The main scope of this research work is to study the effects of various operational parameters like cutting speed, feed rate and cutting allowance on bore diameter of engine crankcase tappet bore. It is found that with the increases of cutting speed and feed the bore deviation (BD) decreases. The result of the experiment then was analyzed using DESIGN EXPERT (DOE) 9.0 software. This was done by using the FULL FACTORIAL technique with optimal (custom) design and ANOVA analysis. In this study, randomization of the run order to be carried out and analysis sequences were carried out according to the run order by Design Expert software. Full factorial with optimal design of three factors with two factor have three levels and one factor has two level was conducted which consist of 18 runs. The machining responses that were analyzed is Bore deviation (BD).All data obtained were then used as input to the Design Expert software for further analysis, according to steps outline for full factorial design. As speed and feed increased a decrement of Bore deviation approximately 40 % was observed. By applying RSM analysis, the predictive mathematical model of the bore deviation average was developed in terms of the cutting speed, feed rate, and cutting allowance. The error analysis and experimental results indicate that the proposed predictive mathematical models could adequately describe the performance indicators within the limits of the factors that are being investigated. In addition, the analysis of variance (ANOVA) was implemented to identify the significant factors and the response surface contours were constructed for determining the optimum conditions of finish boring processes using CNC machine operations.**

Keywords: ***CNC; DOE; Bore deviation; Full factorial with optimal design; cutting speed, feed; Cutting allowance; ANOVA***

I. INTRODUCTION

Machining industries continuously demanding for higher production rate and improved machine ability as quality and productivity play significant role in today's manufacturing market. The extent of quality of the procured item (or product) influences the degree of satisfaction of the consumers during the usage of the procured goods. Therefore, every manufacturing or production unit should concern about the quality of the product. Apart from the quality, there exists another criterion, called productivity which is directly related to the profit level and also goodwill of the organization. Higher production rate can be achieved at high cutting speed, feed, depth of cut which is limited by tool wear, capability of tooling, surface finish and accuracy required selection of cutting parameters is generally a compromise between several variables and it can be easily possible to determine by using Response Surface Methodology.

This study of application of RSM to improve machining processes has been conducted in machining of Tractor engine crankcase. Full factorial with optimal design under RSM with

Design Expert 9.0 software has been selected for optimizing the machining parameters for minimum bore deviation. Efficient boring of Gray cast iron of grade FG 260 material can be achieved through proper selection of boring process parameters to minimize tappet bore deviation

In this paper an experimental study to optimize and study the effects of process parameters in CNC boring on tappet bore deviation of Gray cast iron of grade FG 260 work material in dry environment conditions using triangular carbide inserts is to be done. The full factorial method with optimal condition and analysis of variance are employed to study the performance characteristics in CNC boring operation. Three machining parameters are chosen as process parameters: Cutting Speed, Feed rate and Cutting allowance. The experimentation plan is designed using design of experiment, 18 experiments and Design Expert 9.0 statistical software is used.

Ihsan Korkut and Yilmaz Kucuk [1] are study, the effects of cutting parameters, boring tool material and the overhang ratio of boring tool (tool clamping length) on the deviation from circularity of a bored hole were examined experimentally. Pantawane. P.D and Ahuja. B.B [2] [2011] investigated the 26 different conditions to drill holes in AISI 1015 sheet material 1 mm thick using friction drilling. Mathematical models were developed to find the relationship among commonly used input variables and their interaction on the quality of the hole produced in form drilling process. J.Pradeep Kumar and P.Packiaraj [3] are utilize taguchi method to investigate the effects of drilling parameters such as cutting speed (5, 6.5, 8 m/min), feed (0.15, 0.20, 0.25mm/rev) and drill tool diameter (10, 12, 15mm) on surface roughness, tool wear by weight, material removal rate and hole diameter error in drilling of OHNS material using HSS spiral drill. Orthogonal arrays of taguchi, the Signal–to- Noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis are employed to analyze the effect of drilling parameters on the quality of drilled holes. Adem Çiçek and Turgay Kıvak et al [4] [2012] investigated that the optimization of drilling parameters were carried out by the Taguchi method to obtain optimum surface roughness and roundness error values in the drilling of AISI 316 austenitic stainless steel with untreated and treated drills. In the performed experimental trials using Taguchi orthogonal arrays, it was found that the cutting speed (78.11%) had a significant effect on the surface roughness and that the cutting speed (35.352%) and feed rate (35.352%) had significant effects on the roundness error. Rong-Tai Yang and Hsin-Te Liao et al [5] investigate and applies a Taguchi orthogonal table, integrating response surface methodology (RSM) to optimize parameters of a precise boring process using a computer numerical control (CNC) machine operation for the production of aluminum alloy 6061T6 components. Ajeet Kumar rai and Shalini yadav et al [6] investigated Taguchi method to find optimum process parameters in the boring operation of a cast iron work piece. A L27 orthogonal array, signal-to-noise ratio and analysis of variances are applied to study the performance characteristics of machining parameters (cutting speed, feed rate and depth of cut) with consideration of surface finish.

Current investigation on boring process is a Response Surface Methodology applied on the most effective process parameters i.e. feed, cutting speed and cutting allowance while machining Gray cast iron of work pieces with Carbide cutting tool. The main effects (independent parameters), quadratic effects (square of the independent variables), and interaction effects of the variables have been considered separately to build best subset of the model. Three levels of the feed, three levels of speed, and two level of cutting allowance have been used. After having the data from the experiments, the performance measures bore deviation is calculated by dial bore gauge. To analyze the data set, statistical tool DESIGN EXPERT-9 (Software) has been used to reduce the manipulation and help to arrive at proper improvement plan of the Manufacturing process & Techniques. Hypothesis testing was also done to check the goodness of fit of the data. A comparison between the observed and predicted data was made, which shows a close relationship. The experimentation plan is designed using design of experiment, 18 experiments and Design Expert 9.0 statistical software is used. Optimal values of process parameters for desired performance characteristics are obtained by analysis of variance (ANOVA).

II. EXPERIMENTAL METHODOLOGY

The aim of the experimental work was to optimize the cutting parameters to achieve minimum bore deviation of the Crankcase made up of grade FG 260 of IS: 210-1978. For this purpose, a systematic methodology was adopted as outlined in the form of a flowchart in fig 2.1.

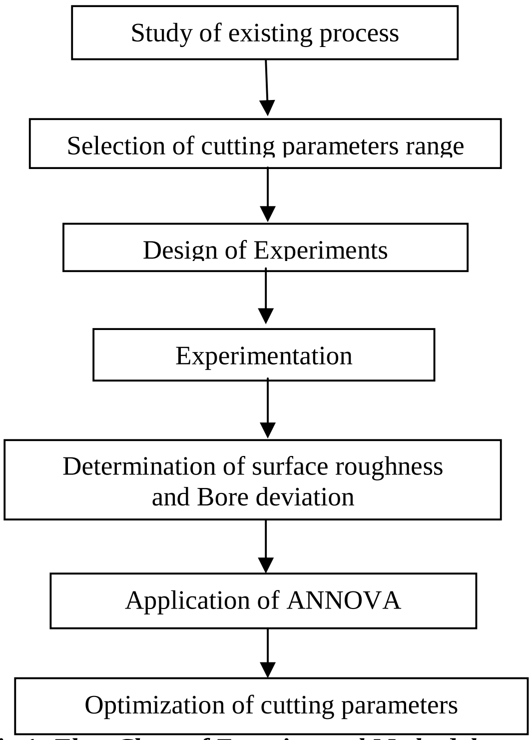

Fig 1: Flow Chart of Experimental Methodology

In this study, randomization of the run order to be carried out and analysis sequences were carried out according to the run order by Design Expert software 9.0. Full factorial design of three factors with two have three levels and one factor have two levels was conducted which consist of 18 runs. The machining response that was analyzed was bore deviation (BD).

All data obtained was then used as input to the Design Expert software 9.0 for further analysis, according to steps outline for full factorial with optimal design. The overall experimental results corresponding to each run generated by the software are shown below Table I.

Table I. Design Experimental data

Run	Factor 1 (A)	Factor 2 (B)	Factor 3 (C)	Response
	Cutting allowance (mm)	**Cutting Speed (m/min)**	**Feed (mm/rev)**	**Bore deviation (µ)**
1	0.3	120	0.1	0.017
2	0.5	120	0.1	0.022
3	0.3	140	0.1	0.02
4	0.5	140	0.1	0.019
5	0.3	160	0.1	0.018
6	0.5	160	0.1	0.02
7	0.3	120	0.2	0.021
8	0.5	120	0.2	0.021
9	0.3	140	0.2	0.02
10	0.5	140	0.2	0.021
11	0.3	160	0.2	0.016
12	0.5	160	0.2	0.019
13	0.3	120	0.3	0.023
14	0.5	120	0.3	0.022
15	0.3	140	0.3	0.021
16	0.5	140	0.3	0.021
17	0.3	160	0.3	0.014
18	0.5	160	0.3	0.015

III. RESULTS & DISCUSSION

As mentioned earlier, Design Expert software was used to analyze the results obtained in order to identify the significant factors and interactions between the factors under studied. Analysis of variance (ANOVA) table is commonly used to summarize the experimental results. These tables conclude information of analysis of variance and case statistics for further interpretation. In this section, all the analysis was presented in normal probability plot, main effect plot and interaction plot for the dependent parameters that significant to the responses.

A. Analysis Results for Bore deviation (BD)

Bore deviation (BD) in tappet bore processes is an important factor because it is main part of engine crankcase. Table II indicates the final analysis of ANOVA for Bore deviation (BD).

Table II: Sequential Model Sum of Squares

Sourcee	**Sum of Square**	**df**	**Mean Square**	**F-Value**	**Desirability**
Mean vs Total	6.806E -003	1	6.806E -003		
Linear vs Mean	5.356E -005	3	1.785E -005	4.55	
2FI vs Linear	**3.146E -005**	**3**	**1.049E -005**	**4.92**	**Suggested**
Quadratic vs 2FI	7.556E -006	2	3.778E -006	2.14	Aliased
Residual	1.587E -005	9	1.764E -006		
Total	6.9 14E-	18	17.59		

B. Main effects plot for BD

Regression Analysis Model

Moreover the regression analysis has also been provided by Design Expert by giving the Regression Equation for BD in coded and actual values. The equation in both form are given below.

(i) Final Equation in Terms of Coded Factors:

BD=+0.019+5.556E-004*A-2.000E-003*B-2.519E-018*C+1.667E-004*AB-5.000E-004*AC-1.875E-003*BC

(ii) Final Equation in Terms of Actual Factors:

BD=+5.63889E-003+3.88889E-003*CA+5.41667E-005*CS+0.15125*FR+8.33333E-005*CA*CS- 0.050000*CA*FR-9.37500E-004*CS*FR

This regression equation for BD gives the predicted values within the range of input process parameters. The actual and predicted values of BD are further compared graphically (Fig 2).

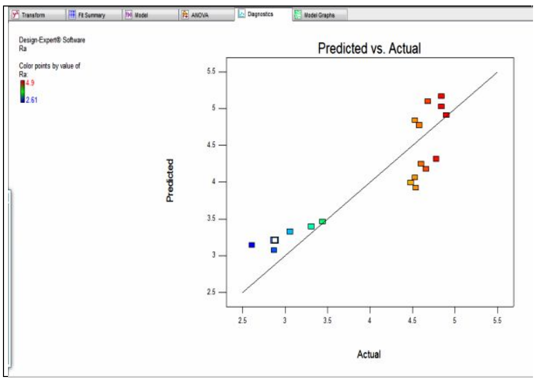

Fig 2: Actual and Predicted Values of Ra

The graph further shows that model is significant as values are well fitted on the line. Graph, showing the relationship between BD and input parameters for both the prediction methods and for the experimental values show that the trend shown by these graph for both the prediction techniques and the experimental values is increasing. These graphs can help in indirect measurement of the BD. Lower, middle and higher values are displayed with blue, green and red color respectively.

The main Effects of Input parameter on BD were further analyzed graphically by Main Effect perturbation and model graph as shown in the Figure 3, 4 and 5 All the main effect plots shows that there is increase in value of BD with increase in value of cutting speed, feed and cutting allowance individually.

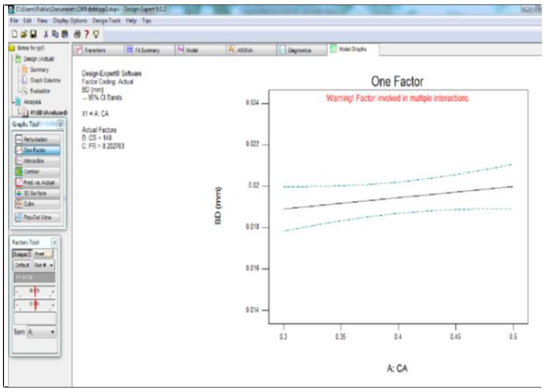

Fig 3: Main Effect Plot between BD and Cutting Allowance

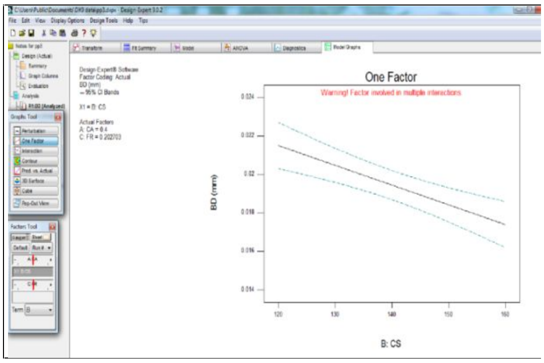

Fig 4: Main Effect Plot between BD and Cutting Speed (CS)

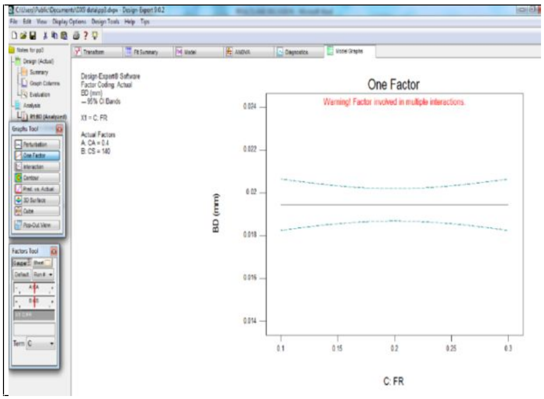

Fig 5: Main Effect Plot between BD and Feed (FR)

C. 3D Interaction graphs for Ra

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response surface for the Regression Equation of BD has been depicted in Fig 6 & 7 The figure clearly shows that the BD improves with the increase in cutting speed confirming the classical theory.

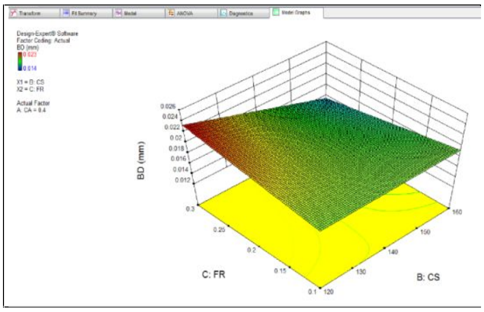

Fig 6: Response Surface Graph of CS and FR Verses BD

The interpretation of parameters with RSM actually shows the response with a surface rather than lines. This method alone can used to analysis as well as to visualize the changes occur in responses with varying the input parameters.

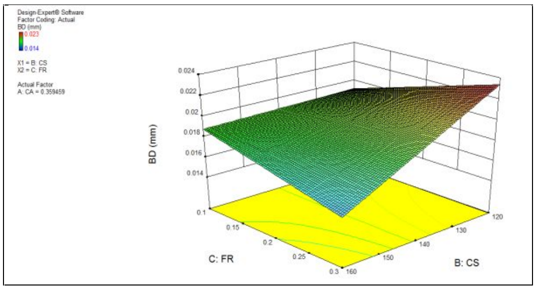

Fig 7: Response Surface Graph of CS and FR Verses BD

The graph shows as Cutting Speed and Feed increases from their lower to higher values. The BD decreases which again verifies the significance of Model & Regression Analysis equation.

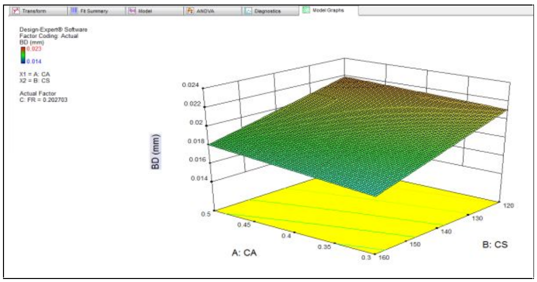

Fig 8: Response Surface Graph of CA and CS Verses BD

The graph shown in fig 8 and 9 further validates the model, as it shows the most significant effect of CA on BD. Moreover a low inclination with lowest BD value in the response surface can be seen in this graph fig 8. On analyzing this graph further, it can be observed that the minimum value of BD touches to 0.014 mm. approximately with maximum value of CA and CS (Cutting Speed) i.e. 0.3 mm and 160 m/min respectively and the value of BD decreases with decrease in the value of CA and CS.

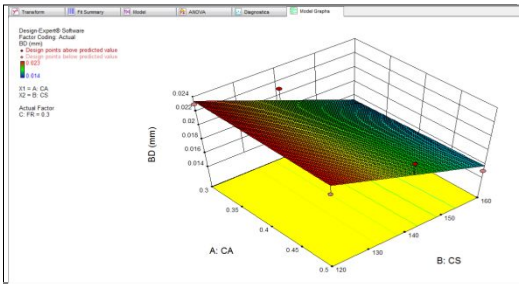

Fig 9: Response Surface Graph of CA and CS Verses BD

The fig 10 shows and verifies the significance of model by indicating the increase in BD with increasing values of FR (feed rate) and the effect of CA on BD is less significant. The maximum value of BD in fig 10 shows that feed has great significance as there is a decrease in cutting speed.

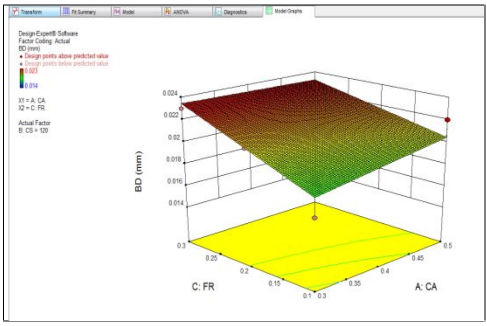

Fig 10: Response Surface Graph of Depth of Cut and Feed Verses BD

The Fig 11 shows and verifies the significance of model by indicating the decrease in BD with increasing values of FR (feed rate). The minimum value of BD in fig 11 shows that feed has great significance as there is an increase in cutting speed.

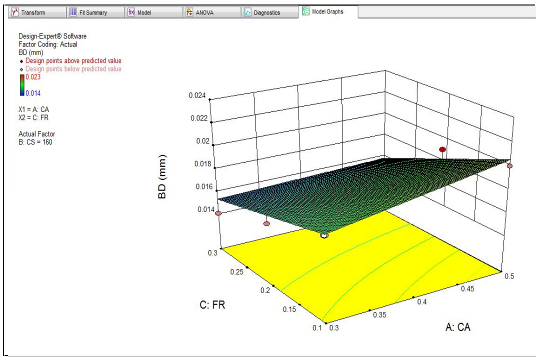

Fig 11: Response Surface Graph of CA and FR (Feed) Verses BD

IV. CONFIRMATION EXPERIMENT

The confirmation experiment was the final step of the design of the experiment process. The purpose of the confirmation experiment was to validate the conclusions drawn during the analysis phase. The confirmation experiment was performed by conducting a test with a specific combination of the factors and levels previously evaluated. The final step of the experimental work was to compare the results of the finish bore diameter process of different work pieces, bore with initial parameters and optimum parameters, to verify any improvement in the performance. The machining parameters and the results obtained in two cases i.e. Existing Conditions and Proposed Optimum Conditions are given in the Table 4.1.

Table III: Existing and Proposed Optimum Conditions

Parameters	Values for		%age Difference
	Existing Conditions	Proposed Optimum Conditions	
RPM of boring bar	137 m/min	160 m/min	14.37
Feed	0.1 mm/rev.	0.3 mm/rev.	66.66
Cutting Allowance	0.5 mm	0.3 mm	-(20.00)
Dry/wet machining	dry	dry	----------
Hardness of component	190 BHN	190 BHN	------
Insert nose radius	0.4 mm	0.4 mm	------
Room temp.	35°C	35°C	------
Bore deviation	0.021 µm	0.015	-(40.00)

V. CONCLUSION

After analyzing and comparing the results of experimental study on cutting parameters and subsequent values of responses, it has been observed that the existing parameters for finish tappet bore was cutting speed 137 m/min, feed 0.1 mm/rev, and cutting allowance was 0.5 mm, whereas for the same dimensions the optimum cutting parameters was cutting speed 160 m/min, feed 0.3 mm/rev, and cutting allowance was 0.3 mm. Further, on comparing the values of BD (Bore deviation) of existing and optimum parameters, the BD was 0.021mm when the experiments were performed with existing cutting parameters whereas BD obtained with optimum parameters is about 0.015mm. Therefore there is an approximately **40 %** of reduction in BD by employing the optimum parameters.

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