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Analysis and Optimization of Parameters Affecting Surface Roughness in Boring Process

Pardeep Kumar[1], J. S. Oberoi[2], Charnjeet Singh[3,] Hitesh Dhiman[4]

[1]Mechanical Engg Department, Chd. College of Engg & Tech. Chandigarh, India
[21]Mechanical Engg Department, Baba Banda Singh Bahadur College of Engg & Tech., Fatehgarh Sahib, Punjab, India
[3]Mechanical Engg Department, Chd. College of Engg & Tech. Chandigarh, India
[4]UIET Hoshiarpur, India

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 Surface roughness (Ra) of engine crankcase tappet bore. It was found that with the increases of cutting speed and feed the Surface roughness decreases approximately 49.83% was observed. 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

Keywords: CNC, DOE, Ra, Full factorial with optimal design, cutting speed, feed, cutting allowance, ANOVA

INTRODUCTION

Machining industries continuously demanding for higher production rate and improved machineability 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. 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.

Harsimran Singh Sodhi and Dhiraj Prakash Dhiman et al [2] illustrated the role of Taguchi parameter optimization methodology for optimize cutting parameters in boring. The results of analysis show that feed rate and cutting speeds have present significant contribution on the surface roughness. Yogendra Tyagi and Vedansh Chaturvedi et al [3] illustrated optimal machining parameters i.e., spindle speed, depth of cut and feed rate) for drilling machine operations was investigated in order to minimize the surface roughness. Turgay Kıvak and Gurcan Samtas et al [4] investigated that optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra). Ajeet Kumar rai and Shalini yadav et al [6] applied Taguchi method 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 in dry condition. 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 surface roughness (Ra) of Engine crankcase bore was taken by Mitutoyo Surface Roughness Tester. 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).

2. EXPERIMENTAL METHODOLOGY

The aim of the experimental work was to optimize the cutting parameters to achieve good surface finish of the Crankcase made up of grade FG 260 of IS: 210-1978. 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 8.0. 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 surface roughness (Ra).

All data obtained was then used as input to the Design Expert software 8.0 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 2.1.

Table 2.1. Design Experimental data

Run	Factor 1 (A)	Factor 2 (B)	Factor 3 (C)	Response
	Cutting allowance (mm)	Cutting Speed (m/min)	Feed (mm/rev)	Surface Roughness Ra (μm)
1	0.3	120	0.1	4.9
2	0.5	120	0.1	4.84
3	0.3	140	0.1	4.53
4	0.5	140	0.1	4.78
5	0.3	160	0.1	2.88
6	0.5	160	0.1	3.44
7	0.3	120	0.2	4.53
8	0.5	120	0.2	4.68
9	0.3	140	0.2	4.48
10	0.5	140	0.2	4.6
11	0.3	160	0.2	2.61
12	0.5	160	0.2	3.31
13	0.3	120	0.3	4.58
14	0.5	120	0.3	4.84
15	0.3	140	0.3	4.54
16	0.5	140	0.3	4.66
17	0.3	160	0.3	2.87
18	0.5	160	0.3	3.06

3. 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.

3.1 Analysis Results for Surface roughness (Ra)

Surface roughness (Ra) in tappet bore processes is an important factor because it is main part of engine crankcase. Table 3.1 indicates the final analysis of ANOVA for Surface roughness (Ra).

Table 3.1: Sequential Model Sum of Squares

Source	Sum of Square	df	Mean Square	F-Value	Desirability
Mean vs Total	305.29	1	305.29		
Linear vs Mean	9.02	3	3.01	17.72	Suggested
2FI vs Linear	0.10	3	0.035	0.17	
Quadratic vs 2FI	2.14	2	1.07	71.29	Aliased
Residual	0.13	9	0.015		
Total	316.68	18	17.59		

3.2 Main effects plot for Ra

Regression analysis equation for Ra value:- The results obtained by this method were formed as regression analysis equation for Ra Value equation by the same software and given as equations.

Final Equation in Terms of Coded Factors:

Surface Roughness (Ra) = +4.12+0.13*A-0.85*B-0.068*C

Final Equation in Terms of Actual Factors:

Surface Roughness (Ra) = +9.69611+1.27222*CA- 0.042500*CS-0.68333*FR

The formed equation was validated by the tests. Moreover the formed equation of Regression Analysis was also plotted as Diagnostic Plots between actual and predicted values of response.

The graph between actual and predicted values is shown in Figure 3.1. The plot shows scattered points a little bit deviated from fitted line. The low range values of Surface roughness are shown in blue color points and high range values in red color. It indicates that lowest value of Ra i.e. 2.61(blue) and the value 4.9 (red) are most deviated experimental values.

The graph shows relationship between Ra value and cutting speed. The cutting speed is represented on X-axis where as Ra values on Y-axis. Main effect graph Figure 3.2 between CS and Ra indicates as cutting speed increases Ra value decreases which validate the experimental results with classical theory of machining process parameters.

Main Effect Graph between cutting allowance and Ra Value interprets that at minimum value of cutting speed and feed there was increased value of Ra if cutting allowance is increased its minimum to maximum value. At maximum value of cutting speed and minimum feed it predicted increased value of Ra if cutting allowance is increased from its minimum to maximum value.. At maximum value of cutting speed and maximum feed it predicted the increased value of Ra by increasing cutting allowance from its minimum to maximum value. Whereas at minimum value of cutting speed and maximum feed, it predicts the increased value of Ra by increasing cutting allowance from its minimum to maximum value.

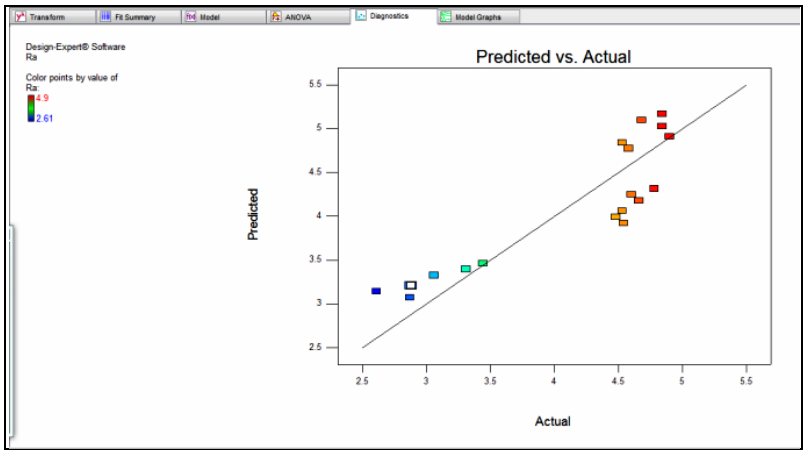

Fig 3.1: Actual and Predicted Values of Ra

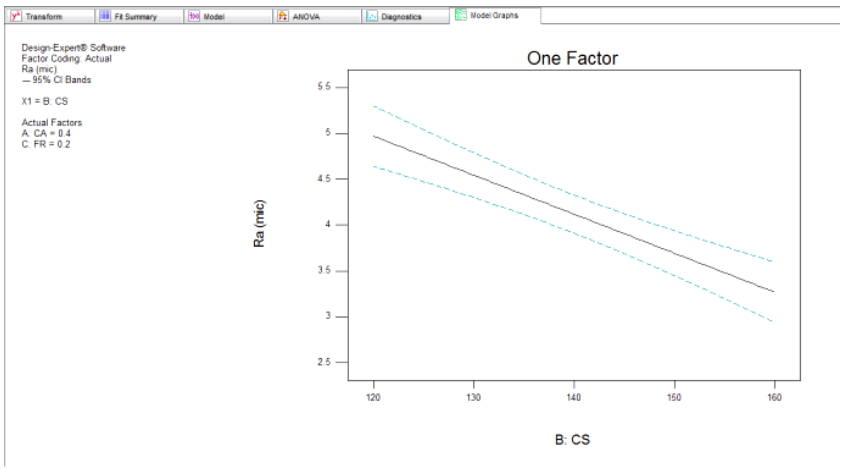

Fig 3.2 Main Effect Graph between Cutting Speed and Ra Value

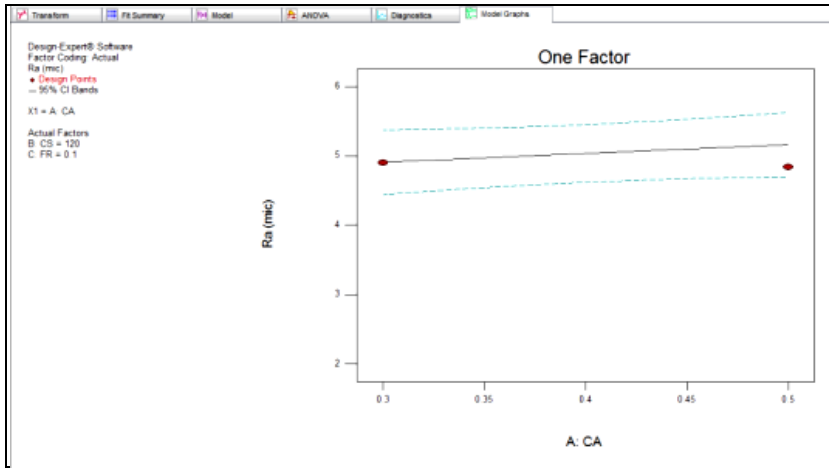

Fig 3.3: Main Effect Graph between CA and Ra Value

3.3 3D Interaction graphs for Ra

The interpretation of parameters with RSM actually shows the response with a surface rather than lines. The response surface graph shows the decrease in Ra value by combined effect of cutting speed CS and cutting allowance CA. The response surface graph Figure 3.4 and (b) shows the combined effect of cutting allowance and cutting speed on Ra value by varying the feed from minimum to maximum.

XI represents = A = CA, X2 represents = B = CS, Y represents = Ra value. It further indicates that as the cutting speed increases roughness decreases but at high level of CA i.e. of 0.5 mm the roughness increases. However at higher value of CA 0.5 Ra value increases. In Figure 3.6 and 3.7 the response surface shows combined effect of CA and FR on Ra value. Cutting allowance is represented on X1 axis, Feed rate on X2 axis and Ra is represented on Y-axis.

The response surface graph Figure 3.6 and 3.7 shows the combined effect of cutting allowance and Feed rate on Ra value by varying the cutting speed from minimum to maximum. XI represents = A = CA, X2 represents = C = FR, Y represents = Ra value. It further indicates that as the cutting speed decreases to120 m/min value of Ra increases but at high level of CS i.e. of 160 m/min the roughness decreases.

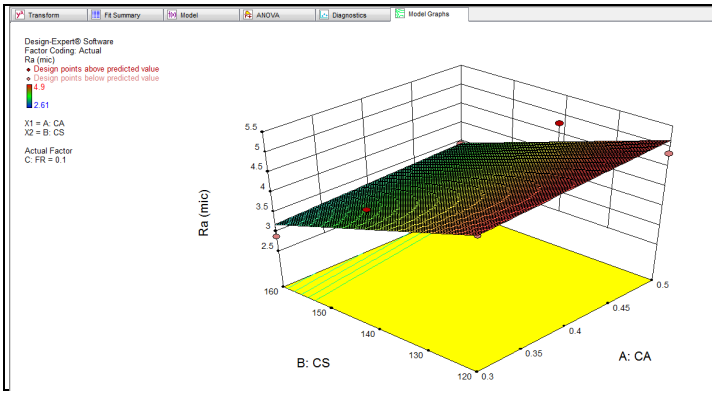

Fig 3.4: Response Surface Graph of CS and CA Verses Ra

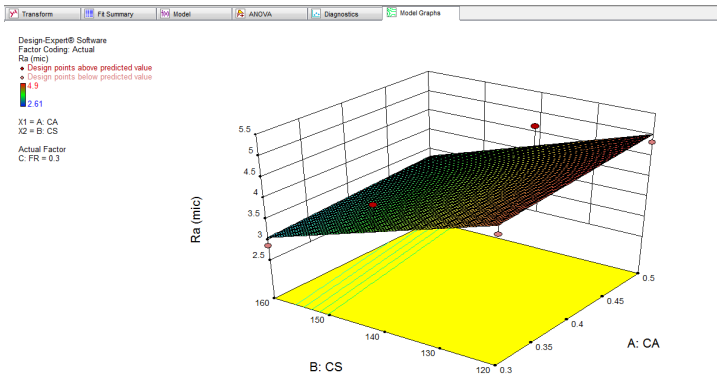

Fig 3.5: Response Surface Graph of CS and CA Verses Ra

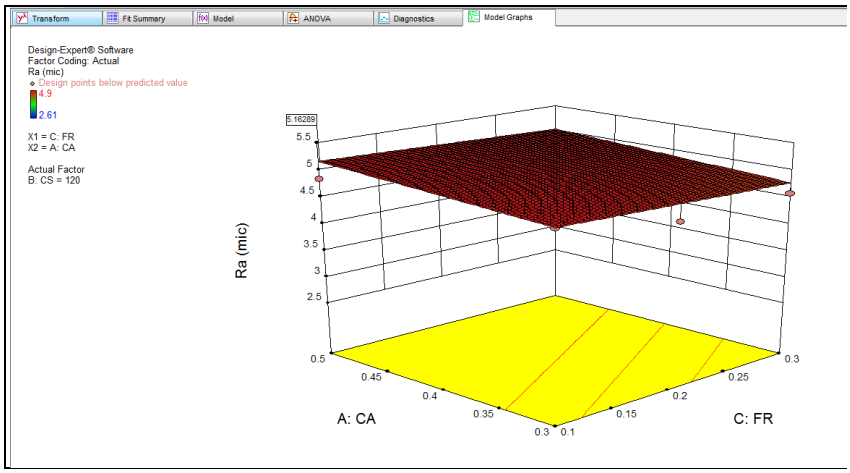

Fig 3.6: Response Surface Graph of CA and FR Verses Ra

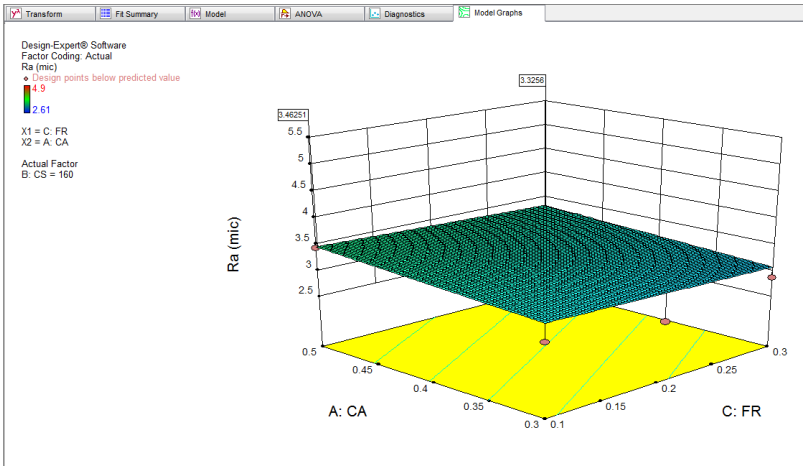

Fig 3.7: Response Surface Graph of CA and FR Verses Ra

4. 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 4.1: 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	------
Surface roughness	4.60	3.07	-(49.83)

5. 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. On examining the average values of surface roughness (Ra), its value with existing parameters was measured as 4.60 μm. On the other hand, the surface roughness obtained with optimum parameter is about 3.02 μm which shows the 49.83% reduction in surface roughness or improvement in surface finish.

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