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Analysis on Effect of Machining Parameters in Oil Pump Back Plate using Response Surface Methodology

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Abstract: *Surface finish plays an important role in auto component manufacturing industries. Optimized machining parameters are very important to produce good quality of surface finish components with lesser lead time and cost. Purpose of this research is to analyze the effect of machining parameters on the quality of the surface finish of the oil pump backplate. Oil pump base plate is made up of alloy steel EN19. The machining parameters that have been chosen are feed rate, depth of cut and spindle speed. The radial depth of cut is kept as constant of 0.12mm because the thickness of the backplate is varying from 3 mm to 6 mm. Work holding is a problem in lesser thickness plates while using high radial depth of cut. Cutting tool in this research is solid carbide end mill. After the milling process, surface roughness tests have been conducted. The results of each test specimen are analyzed, and the optimized machining parameter for EN19 steel plate surface roughness is found. The results of this research will help manufacturing industries to improve the component surface roughness and reduce production time.*

Keywords: *Surface Roughness, Machining, Response Surface Methodology, EN19, Oil Pump*

I. INTRODUCTION

Surface finish is a critical quality parameter that could influence the performance of a product. Whenever two machined surfaces come in contact with one another the surface quality of the mating parts plays an important role in the implementation and wear of the mating parts. The surface roughness depends on workpiece hardness, tool geometry, and process parameters such as feed rate, depth of cut, cutting speed etc. To maximize the gain from machining, accurate predictive models for surface roughness must be constructed [1-3]. The experimental investigation used to study the relationship between the input factors and the response (output) of any system or a process [4-6]. The purpose is to optimize the response or to understand the system. If the input factors are quantitative and are few, Response Surface Methodology (RSM) can be used to study the relationship. The model for surface roughness using RSM to study the effects of various factors in surface roughness was developed [7-9]. The central composite design is used in DOE. They stated that the distribution area of the processing parameters could be quickly determined based on the ISO surfaces plot of surface roughness. Central composite rotatable second-order response surface methodology to create the mathematical model was used [10-12]. They have taken feed, spindle speed, radial depth of cut and axial depth of cut as parameters for the experiments. They stated that the main effect plot indicates that the feed rate is the most significant parameter on surface roughness. Taguchi optimization method with L16 orthogonal array was used [13-15]. In this work radial depth of cut and axial depth of cut has more influence on the surface roughness and their contributions of about 30% and 24%, respectively. Feed, cutting speed and depth of cut to analyzing the cutting force was taken [16, 17]. RSM model was further coupled with an established genetic algorithm to minimize the cutting force value. The author investigated that the cutting speed was the dominant factor in the second-order models, followed by the cutting feed rate and the axial depth of cut.

II. INDUSTRY OVERVIEW

M/s. Futurzcam is an industry which manufactures of the selected machining components. The company manufactures patterns, moulds and machined components for automotive industries. They have VMC and turning centres for production components. They are supplying oil pump backplates for auto component manufactures in Coimbatore and Pune.

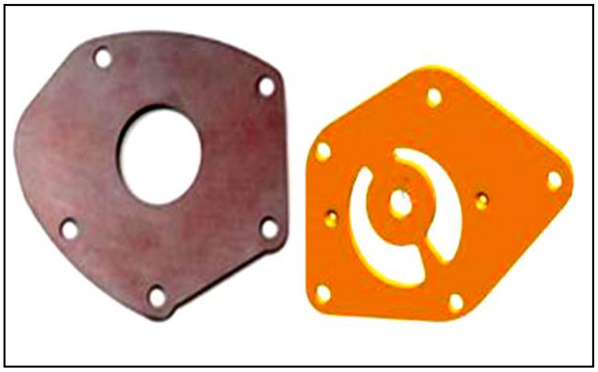

Fig.1: Oil Pump Back Plates

III. PROBLEM DEFINITION

Oil pump backplates are made up of aluminium, low carbon steel, cast iron and alloy steel based on its construction and oil pressure requirements. EN19 Backplate is used in high pressure and water pump integrated oil pumps. EN19 is an alloy steel material with case hardening properties. Figure 2 describes the methodology of manufacturing the backplates.

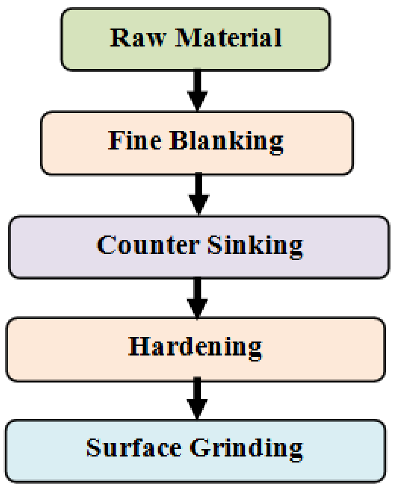

Fig. 2: Process Flow Chart

The present method of manufacturing the backplates are more time consuming due to surface grinding. Surface grinding takes more time and cost. Also, hardening is an in-house process for customer and surface grinding is a vendor process, so transport cannot be avoided. Backplates require surface roughness value 1.6 µm to 2.5 µm. It can be achieved in milling. The proposed manufacturing process, as shown in Figure 3, will reduce the process time and cost.

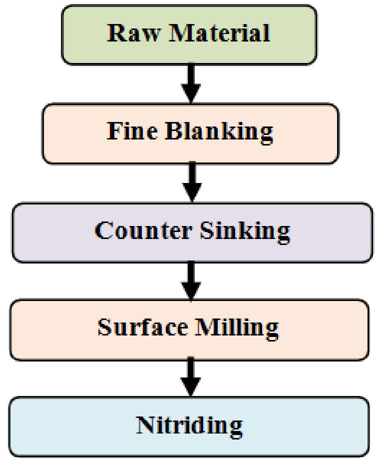

Fig. 3: Proposed Process Flow Chart

Consistency in producing the surface roughness is a serious problem in the milling operation. Arriving at an optimized parameter to achieve the surface roughness is the major requirement. Holding the workpiece on the machine table is also a major concern, because the thickness of the backplate is 5 mm. Magnetic chucks are used to hold the parts with less thickness, but the number of workpieces that can be held in a magnetic chuck is two. The cost of the magnetic chucks is more if more number of components needs to behold.

IV. OBJECTIVES

- To optimize the machining parameters in backplate milling.
- To eliminate the grinding operation in the backplate.
- To reduce the Process time.
- To reduce the Process cost.

V. EXPERIMENTAL DETAILS

EN19 is the backplate material, for experiments 300 mm x 150 mm x 20mm (thickness). EN19 plate is used for machining experiments. Chemical composition of the workpiece is given in Table 1.

A. Machining

The machine used for experimentation is cosmos vertical machining centre. Specification of the machine,

- Machine model = CVM-1060
- Table size = 1200mm x 550mm
- X travel = 1050mm
- Y travel = 610mm
- Z travel = 600mm
- Spindle speed = 8000 rpm (max)
- Cutting Feed rate = 10 m/min (max)

Table 1: EN19 Chemical Composition

Element	% Weight
C	0.36 – 0.44
Si	0.1 – 0.35
Mn	0.7 – 1
Cr	0.9 – 1.2
Mo	0.25 – 0.35
S	0.035
P	0.040

Mastercam is NC programming software used for 2 axis to 5 axis machining. In this 3D model of the plate, the model is used in Mastercam software to generated NC codes and transferred to the machine to conduct the experiments. Experiment plates are divided into 24 segments; each set of experiment parameter are feed to specified segments. Identification has created using the chamfer in the right side corner of the plate. Both the sides of the plate has machined for trials. Response Surface Methodology (RSM) is a very powerful tool; it permits us to carry out the modelling and analysis of the influence of process parameters on the response variables. The response variable is an unknown function of the process variables, which are known as design factors. There are a large number of factors that can be considered for machining of a particular material in end milling. The central composite design (CCD) is one of the most commonly used response surface designs for fitting second-order models. A central composite design consists of F factorial points, 2k axial points (±α). The factorial points are formed from a complete 2k design or fractional factorial design, and the factorial portion is used to fit all linear and interaction terms. The axial ends provide additional levels of the factor for purposes of estimation of the quadratic terms. The choice of α depends upon the design region of interest. Second-order polynomial for CCD is equation 1.

$$Y = R_a - \varepsilon = a + bx_1 + cx_2 + dx_3 + ex_1x_2 + fx_1x_2 + gx_2x_3 + hx_1^2 + jx_2^2 + mx_3^2 \quad (1)$$

Y is the response test of error and is the process parameters and are the model parameters calculated with linear regression. Analysis of Variance (ANOVA) and regression analysis are used to validate the model. F-ratio test has been performed to check the adequacy of the models. It can be appreciated that the P-value is less than 0.05, which means that the model is significant at 95% confidence level. Table 2 shows the process parameters and their levels. 21, xx3x ..., cba

Table 2: Process Variables and their Levels

	Level				
	-1.682	**-1**	**0**	**1**	**1.682**
Feed xi (mm/min)	750	1400	2800	4200	4800
Spindle Speed x2 (rpm)	200	1000	2250	3500	4300
Depth of cut x3 (mm)	0.1	0.2	0.35	0.5	0.6

The program generated in Mastercam software is used for machining. All three parameters are given in the program itself. No change has made while machining. Mastercam programming screenshot is shown in Figure 4. Based on corner chamfer, the segments are identified, and process parameters are given to the software. Each segment is programmed separately and verified against Table 2. Simulation of the machining shows that no abnormal run. All the grooves are appropriately formed in the simulation, and they separate the segments clearly in the plate. Plate fixed on the table properly to avoid the vibration. As defined in the program, machining starts with the corner chamfer, Groove forming between the segments and surface milling. While machining coolant is used. Figure 5 shows the plate machining, and Figure 6 shows the machined plate.

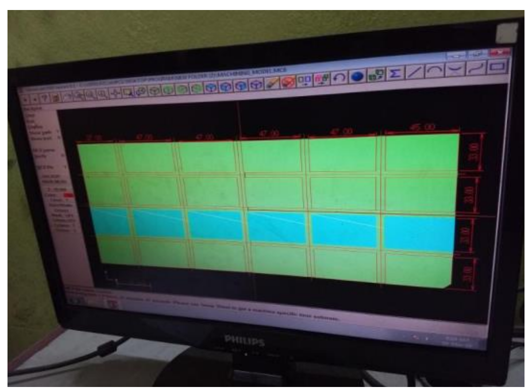

Fig. 4: Master CAM Programming

Fig. 5: Plate Machining

Fig. 6: Machined Plate

B. Surface roughness testing

Surface roughness measured using Mitutoyo SURFTEST SJ – 410. The measuring head is mounted on the vertical column, and the workpiece is fixed on the surface plate. The calibrated specimen is measured and ensured that the equipment is working correctly. Each segment is tested and recorded with segment identification and the Ra value displayed on the equipment screen. Figure 6 shows the surface roughness measurement setup with the test piece. Experimental surface roughness data collected for 20 nos of experiments, and those experiments are repeated three times. Surface roughness data along with the process parameter given in Table 3.

Table 3: Experimental Results

Sl. No.	x_2	X_2	X_2	Feed (mm/min)	Spindle Speed (rpm)	Depth of Cut (mm)	R_0 (μm)
1	0	0	0	2800	2250	0.35	2.68
2	-1	-1	1	1400	1000	0.5	2.88
3	0	-1.68	0	2800	200	0.35	3.21
4	1	-1	1	4200	1000	0.5	2.94
5	0	0	0	2800	2250	0.35	2.83
6	0	0	0	2800	2250	0.35	2.69
7	0	0	0	2800	2250	0.35	2.79
8	-1.68	0	0	750	2250	0.35	2.02
9	1	1	1	4200	3500	0.5	2.22
10	0	0	0	2800	2250	0.35	2.46
11	-1	1	1	1400	3500	0.5	2.22
12	1.68	0	0	4800	2250	0.35	2.66
13	0	0	1.68	2800	2250	0.6	3.26
14	1	-1	-1	4200	1000	0.2	3.32
15	1	1	-1	4200	3500	0.2	2.56
16	-1	1	-1	1400	3500	0.2	1.85
17	-1	-1	-1	1400	1000	0.2	2.97
18	0	0	-1.68	2800	2250	0.1	3.44
19	0	1.68	0	2800	4300	0.35	1.91
20	0	0	0	2800	2250	0.35	2.86

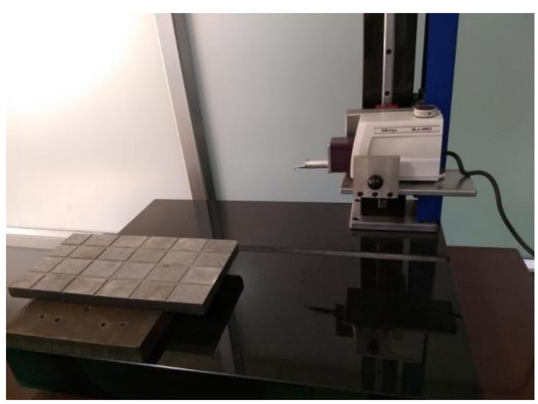

Fig. 7: Surface Roughness Measuring Setup

C. Analysis of experimental results

The second-order response surface equations have been fitted using Minitab software for surface roughness (Ra). The regression model is shown in equation 2. Response surfaces generated for roughness value against the Feed, Depth of cut and spindle speed. Equation 2 is used to create the following surfaces.

R_a = 3.13579 + 0.00869963 x_1 – 0.00027556 x_2 + 6.0229 x_3 + 2.18929 x $10^{-8}x_1x_2$ – 0.000589583 x_1x_3 + 0.000339 x_3 – $1.06411x10^{-7}x_1^2$ - 5.04927 x 10^{-8} x_2^2 + $9.34251x_3^2$ … (2)

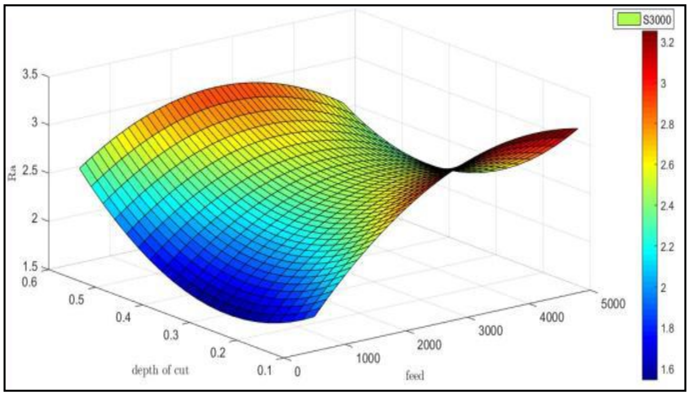

Fig. 8: Effect of Feed and Depth of Cut on Ra

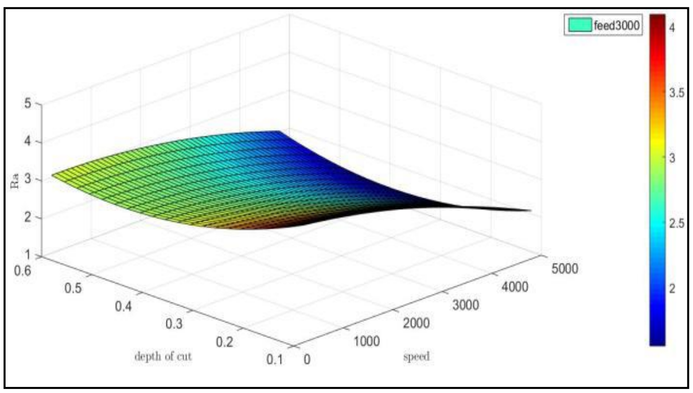

Fig. 9: Effect of Speed and Depth of Cut on Ra

Above response surface Figure 7 shows the effect of feed and depth of cut on Ra at feed 3000 mm/min. Figure 8 shows the effect of speed and depth of cut on Ra at feed 3000 mm/rev, and Figure 9 shows the effect of feed and speed on Ra at a depth of cut 0.1 mm.

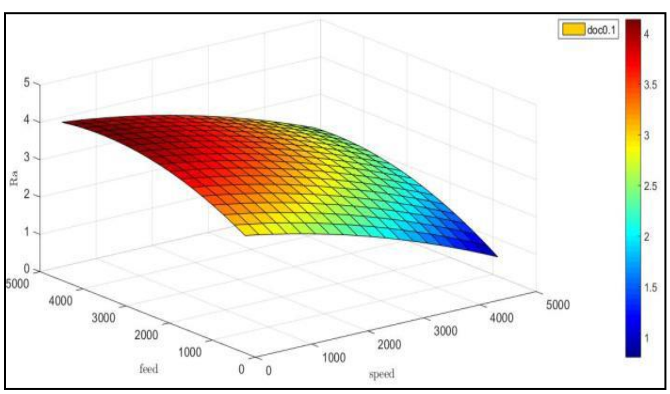

Fig. 10: Effect of Feed and Speed on Ra

ANOVA performed on these trials, and results are given in Table 4. F value of the model is more than the table value (Table F0.05 9, 10=3.02< 26.66). Also, the P-value is very small. It shows that the fitted model is accurate enough to predict the response.

Table 4: Process Parameter Effect on the Surface Roughness

Source	Sum of Square	DF	Mean Square	F-Value	P-Value Prob>F
Model	3.90	9	0.433	26.66	0.000008
Feed (F)	0.341	1	0.517	31.80	0.000216
Cutting Speed (S)	2.17	1	0.053	3.29	0.099920
Depth of Cut (D)	0.04	1	0.324	19.94	0.001206
F^2	0.423	1	0.405	24.96	0.000541
S^2	0.123	1	0.083	5.14	0.046749
D^2	0.625	1	0.625	38.46	0.000101
F X S	0.117	1	0.011	0.72	0.415314
F X D	0.1226	1	0.122	7.54	0.020609
S X D	0.03232	1	0.032	1.99	0.188911
Residual	0.162	10	0.016		
Lack of Fit	0.057	5	0.011	0.55	0.736038
Pure Error	0.104	5	0.104	0.02098	
Total	4.064	19			

VI. CONCLUSIONS

Response surface method is applied on milling of EN19 steel, and solid carbide end mill tool is used with coolant. The results of the research work are as follows,

- Surface roughness and cutting parameters (i.e. Speed, Feed and Depth of cut) have highly non - linear relationships among them.
- The model of the surface roughness was developed, and the effects of various factors were analyzed. It shows that the speed has the most important effect on surface roughness, followed by feed. The depth of cut has minimal effect.
- Based on response surfaces, Spindle speed (4000-5000 rpm), feed (750-1500 mm/min), and depth of cut (0.2 to 0.3mm) produce the minimum surface roughness between 1.7 to 1.9 μm.
- Spindle speed is the main contributing parameter to produce the minimum surface roughness. While increasing the speed along with decreasing feed, EN19 steel gives minimum surface roughness.

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