Optimization of Hydrodynamic Journal Bearing Parameters Using Response Surface Methodology

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ABSTRACT

The hydrodynamic journal bearing is used extensively in rotating machines because of their low wear and good damping characteristics. Present work has been carried out to obtained the realistic performance characteristics of the journal bearing. The optimization approach which was applied to predict the optimal surface textured parameters to improve efficiency of journal bearing. After studied literatures, some parameters are considered as control parameters viz; groove location, groove width, groove height, number of groove and spacing between grooves for load carrying capacity (LCC) and Frictional Torque (FT) response. The effect various surface textured parameter is simulating for optimum response using the Response surface methodology has been applied. The response surface methodology tool re gives the robust design with respect to the control factors and their level. After the optimization method the comparison have been done with published good literature.

Keywords: *Journal Bearing, Hydrodynamic, LCC, FT, RSM, Optimization.*

1. Introduction

In a mechanical system bearing has an important role to play. The bearing is the system of machine elements whose function is to support an applied load by decreasing friction between the relatively moving surfaces. The load may be radial or axial or combination of these. Bearings are classified according to the direction of applied load. If the bearing supports radial loads, it is called radial or journal bearing. On other hand, a thrust bearing supports a thrust or axial load. Some bearing can support both radial as well as axial load and they are known as conical bearings.

Journal bearings with modified surface creating by surface texturing have attracted considerable interest as it is a promising way to enhance their hydrodynamic performance by reducing friction. A different bearing shape by creating texture leads to create a different flow pattern in the lubricant film. The Mostly texturing researchers were motivated by the idea that the surface texturing provides micro reservoirs to enhance lubricant retention or micro traps to capture wear debris.

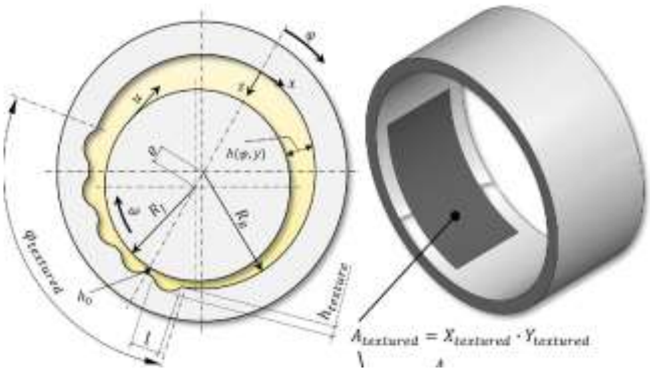

Figure 1. Surface textured journal bearing

2. Mathematical Formulation

The well-known Reynolds equation is used for finding the Pressure distribution in Journal Bearing. Reynolds equation for journal bearing considering Newtonian, laminar, incompressible fluid flow with no slip at boundaries and neglecting fluid inertia and curvature of bearing surfaces with pressure and viscosity assumed to be constant throughout the thickness of the film expressed as:

$$\frac{\partial}{\partial x}\left[h^3 \frac{\partial p}{\partial x}\right] + \frac{\partial}{\partial z}\left[h^3 \frac{\partial p}{\partial z}\right] = 6\mu U \frac{dh}{dx} \quad (1)$$

Where μ= relative viscosity
h= Fluid film thickness
The hydrodynamic theory as implemented to the journal bearing is mathematically explained by Reynold's equation. Using 3D Model, fluid film pressure distribution is:

2.1 Mathematical Model of RSM

The Response Surface Methods (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 influenced by several variables is to be optimized. It is useful to optimize the response variable when values of the factors are continuous.

$$Y_u = \beta_0 + \sum_{i=1}^{S} \beta_i X_i + \sum_{i=1}^{S} \beta_{ii} X_i^2 + \sum_{i>i}^{S} \beta_{ij} X_i X_j \ldots, \quad (2)$$

Where, Yu is the corresponding response, e.g. the LCC and FT etc. produced by the various process variables of injection molding and the X_i (1, 2,………,S) are coded levels of S quantitative process variables, the terms $\beta_0, \beta_i, \beta_{ii}$ and β_{ij} are the second order regression coefficients. The second term under the summation sign of this polynomial equation is attributable to linear effect, whereas the third term corresponds to the higher-order effects; the fourth term of the equation includes the interactive effects of the process parameters [18].

Table 1. Input variables and their levels [15]

Factor	Symbols	Code	Levels		
			-1	1	1
Groove location (deg)	$\theta_1 - \theta_2$	**A**	90-155	90-165	90-175
Groove width (mm)	*b*	**B**	2.4	2.5	2.6
Groove height (μm)	*Δh*	**C**	15	20	25
No. of grooves	*Ar*	**D**	7	9	11
Spacing between grooves (μm)	*Sp*	**E**	200	300	400

2.2 Analysis of variance (ANOVA)

In multi objectives optimization, the significant contribution of each input parameter on the responses in journal bearing parameters is studied by using analysis of variance. The results of the ANOVA are shown in next chapter. As in the ANOVA table, this indicates that the which input is the most contributing factor.

Table 2. Corresponding value of test run and their response

Test Run	A	B	C	D	E	LCC	FT
1	90-155	2.4	15	7	200	15.1659	1086.04
2	90-155	2.4	15	7	300	15.1514	1086
3	90-155	2.4	15	7	400	15.1365	1086.02
4	90-155	2.5	20	9	200	13.9181	1056.51
5	90-155	2.5	20	9	300	13.903	1056.5
6	90-155	2.5	20	9	400	13.887	1056.5
7	90-155	2.6	25	11	200	12.517	1021.9
8	90-155	2.6	25	11	300	12.4991	1021.8
9	90-155	2.6	25	11	400	12.4879	1021.91
10	90-165	2.4	20	11	200	13.8769	1013.82
11	90-165	2.4	20	11	300	15.0753	1013.8

12	90-165	2.4	20	11	400	15.0488	1013.8
13	90-165	2.5	25	7	200	14.2392	1054.62
14	90-165	2.5	25	7	300	14.2283	1054.6
15	90-165	2.5	25	7	400	14.2163	1054.6
16	90-165	2.6	15	9	200	16.3605	1049.62
17	90-165	2.6	15	9	300	16.3322	1049.6
18	90-165	2.6	15	9	400	16.3009	1049.6
19	90-175	2.4	25	9	200	4.8924	1021.16
20	90-175	2.4	25	9	300	14.874	1021.1
21	90-175	2.4	25	9	400	14.851	1021.11
22	90-175	2.5	15	11	200	16.9057	1018.88
23	90-175	2.5	15	11	300	16.851	1018.8
24	90-175	2.5	15	11	400	16.7904	1018.87
25	90-175	2.6	20	7	200	15.9933	1048.33
26	90-175	2.6	20	7	300	15.9771	1048.3
27	90-175	2.6	20	7	400	15.9558	1048.3

3. Results & Discussions

In this work, the data can be analyzed using Analysis of variance (ANOVA), which is used to investigate design parameters significantly affect the quality characteristics.

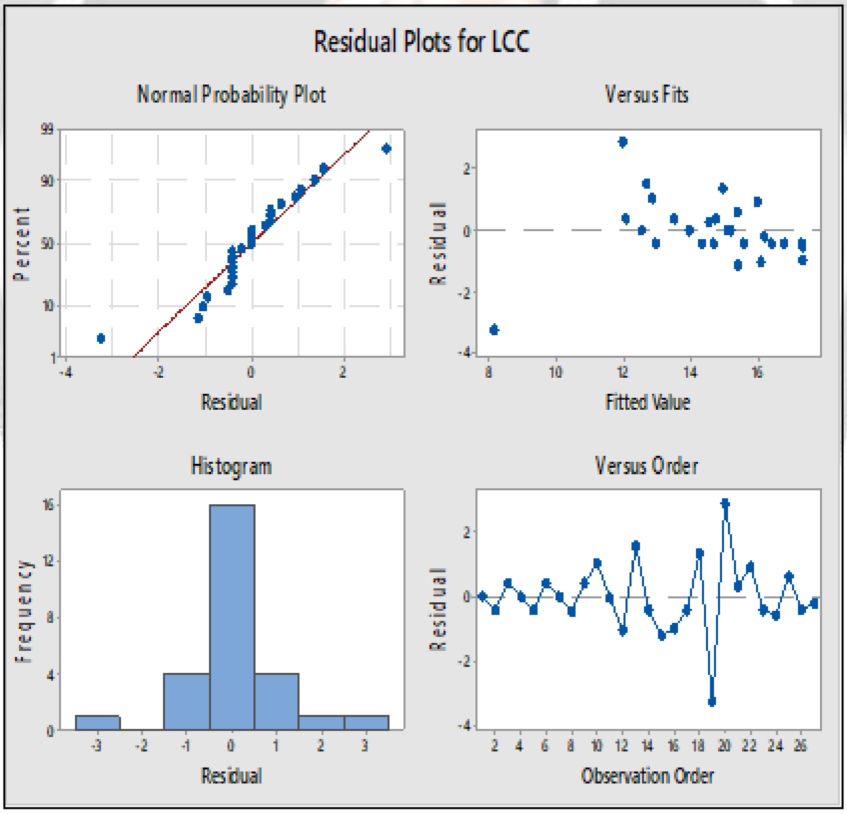

Figure 2. Residual plot for load carrying capacity of journal bearing

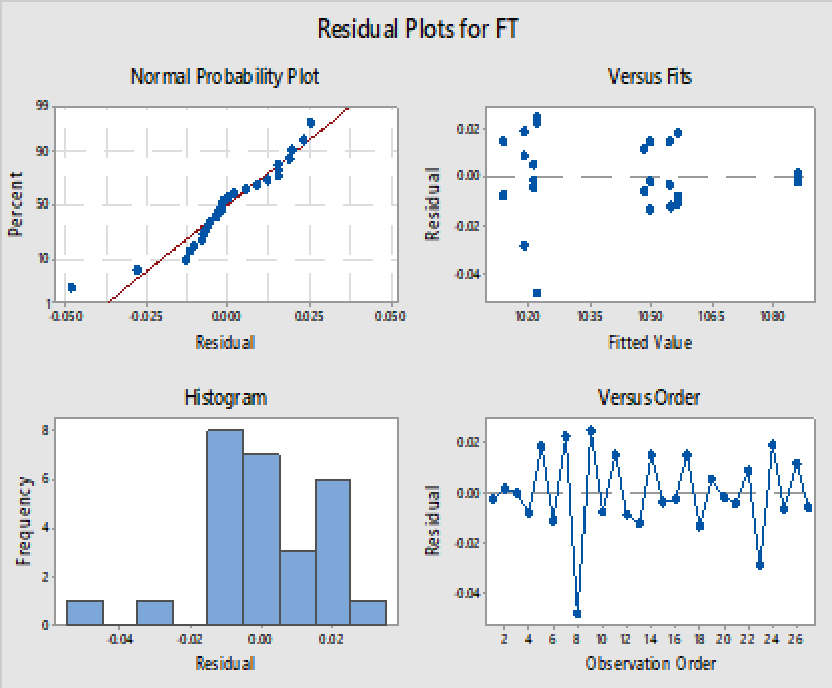

Figure 3. Residual plot for frictional torque of journal bearing

Figure 2 and Figure 3 are the residual plot for load carrying capacity and frictional torque. The figure shows the normal probability which is shown the points falling on the straight line means probability is more significant. The histogram shows that data are good-to-fit and the versus order and observation order has been shows the normal plot of residuals to verify the assumption that the residuals are normally distributed.

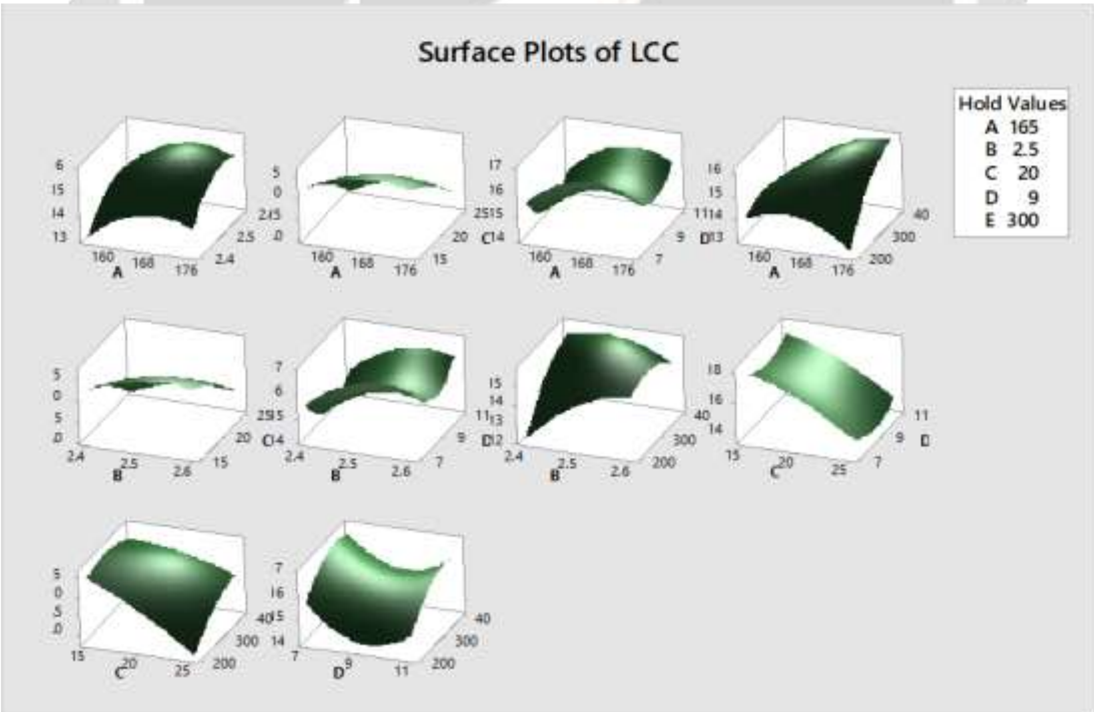

Figure 4. 3-D surface plot of LCC with respect to its control factors which significantly affected the response

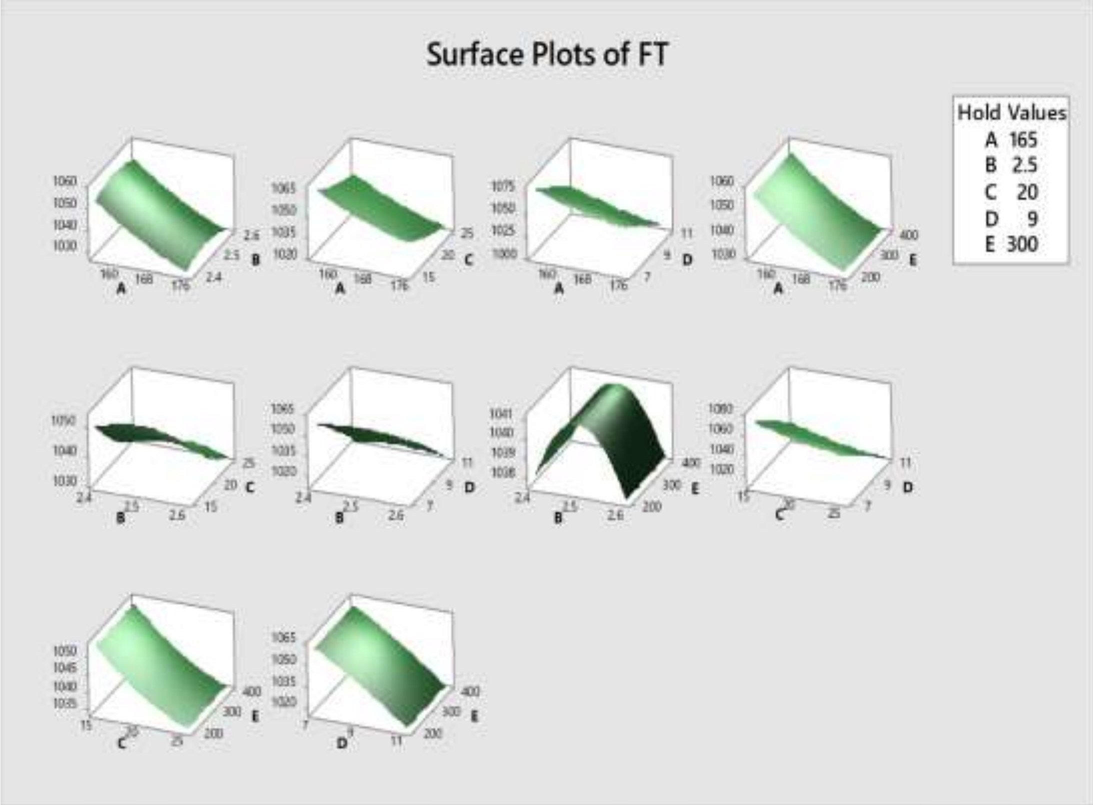

Figure 5. 3-D surface plot of FT with respect to its control factors which significantly affected the response

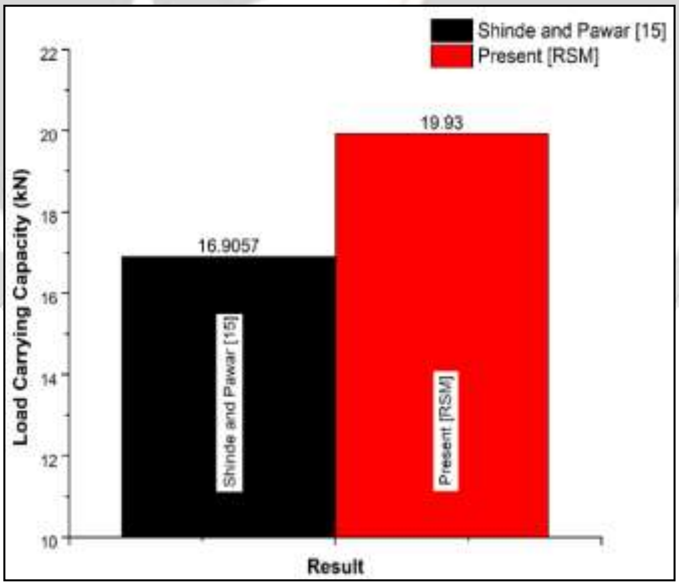

Figure 6. Comparison of load carrying capacity of literature results [15] and optimized results obtained from response surface model

The graph Figure 6 represents that the value of load carrying capacity (LCC) in previous work is less as compared to present work. The value of the LCC has been gives the maximum life due to improvement of LCC. In this work the LCC value is more useful than the literature results. The percentage improvement of the present work is 17.89%, as compared to literature [15].

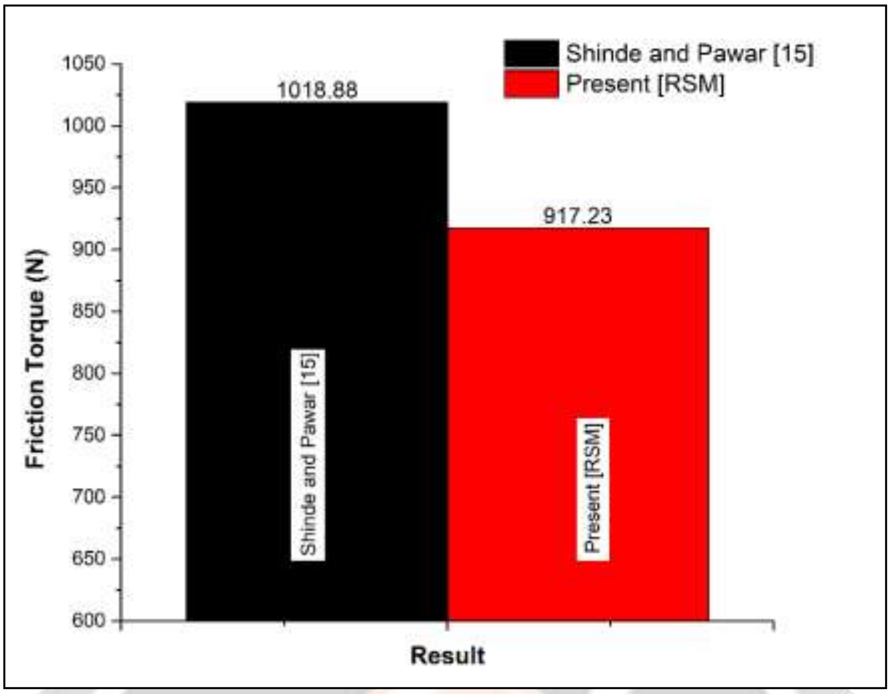

Figure 7. Comparison of frictional torque of literature results [15] and optimized results obtained from response surface model

The Figure 7, indicates that the value of the present results is gives less prediction value in this field. The percentage improvement of the present work is 9.98%, as compared to literature [15].

4. Conclusion

- A Response surface methodology of optimization method for journal bearing has been applied.
- The present work, used the five design variables and two response using response surface optimization.
- The effect of load carrying capacity and frictional torque improve the performance of the journal bearing. The results lead to the recommendation of using simultaneously maximizing and minimizing the LCC and FT respectively with least contribution factors i.e.; groove location 90-175, groove width 2.45mm, groove height 19μm, No. of grooves 11 and spacing between grooves 240 μm.
- The work is assumed the effect of thermal contribution in journal bearing has been constant. The work was performed, and the predicted value results were compared.
- The maximal variation between present predicted value and literature [15] are approx. 17.89% and 9.98%, indicating the regression model has high accuracy for predicting load carrying capacity (LCC) and friction torque.
- In this present work, it has been concluded that the Taguchi technique is normally used linear interactions only but RSM can help in visualizing the effect of parameters on response in the entire range specified.
- Taguchi technique gives the average value of response at given level of parameters but RSM is a promising analytical tool to predict the response which suits the range of parameters.

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