OPTIMIZING DESIGN OF COMPRESSOR BEARING USING DOE APPROACH

Engineering

KEYWORDS: Bearing, L9 orthogonal array, bearing modulus, optimize, regression

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ABSTRACT

This paper attempts to develop a simple and practical procedure to optimize coefficient of friction in journal bearing using Taguchi method. The three input parameters taken in the present paper are absolute viscosity(Z) of the lubricant, speed of journal(N) and maximum allowable pressure. The output parameter is coefficient of friction which has to be minimized. Taguchi L9 array is used to solve the problem in which set of nine input combinations of the three input parameters are given and the corresponding optimized value of the output which is coefficient of friction in present context is obtained with nine experiments instead of conducting twenty seven experiments thereby saving time and resources.

INTRODUCTION

A bearing is a machine part whose function is to support a moving element and to guide or confine its motion while preventing the motion in direction of applied load. They take up the radial and axial loads imposed on the shaft or axle they carry and transmit these to the casing or machine frame. Since there is relative motion between the bearing and journal so the layer of lubricant is applied between the contact surfaces to reduce wear and tear.

LITERATURE SURVEY

Asimov applied Newton Raphson method to determine the length and diameter of full circular journal bearing which optimizes the objective function defined as the sum of friction loss and shaft twist. Seireg and Ezzat applied the gradient search method to determine the optimized length, radial clearance and average viscosity of full circular journal bearing which minimizes the weighted sum of supply oil quantity and maximum average oil film temperature rise. Beightler treated the same problem as that of Asimov using geometric programming and including another parameter of temperature rise (ΔT). Rohde determined the minimum film thickness which optimizes the load carrying capacity of an infinite length full circular journal bearing by use of variational technique. Hashimoto and Kato minimizes a weighted sum of supply oil quantity and maximum oil film temperature rise using direct search method, GA and successive quadratic programming. H. Hashimoto and K. Matsumoto applied the hybrid optimization technique combining the direct search method and successive quadratic programming to minimize the objective function defined by weighted sum of maximum average oil film temperature rise, leakage flow rate and the inversion of whirl onset speed of journal.

In this study the approach to same interpretation has been done by statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods. Taguchi had envisaged a new method of conducting the design of experiments which are based on method which uses a special set of arrays called orthogonal arrays for conducting minimal number of experiments which could give the full information of all the factors that affect the performance parameter.

OBJECTIVE

In this study the objective function is to minimize coefficient of friction between journal and bearing. The use of low shear strength media to reduce friction of contacting surfaces was clearly intuitive right from the dawn of transportation. From the very early days, friction, wear and lubrication of contacting surfaces have been the main concerns in design bearings and gears.

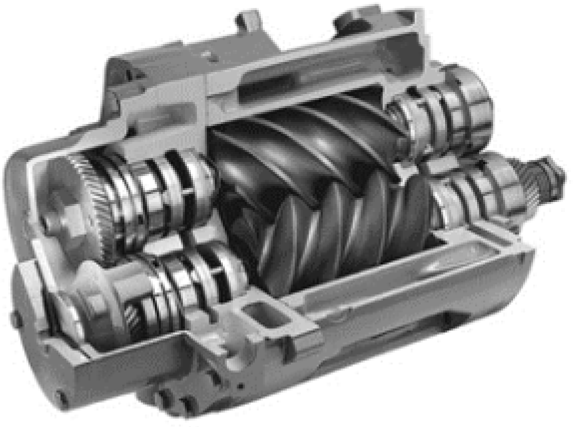


Fig 1.1 Compressor shaft supported with Bearings.

The design input variables are taken as the absolute viscosity (Z), speed of journal(N) and allowable maximum pressure (p).

Defining the design constraint:- The variation between the coefficient of friction and bearing modulus is shown in Figure1.2

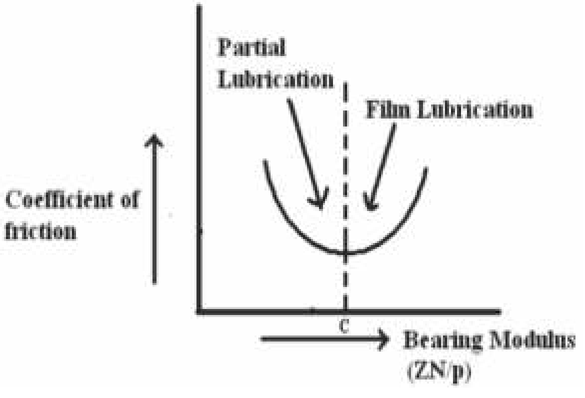


Fig 1.2 Variation of bearing modulus with coefficient of friction

The value of bearing modulus at which coefficient of friction is minimum is denoted by C. For bearing to operate in film lubrication region the value of bearing modulus should be greater than C. For safe design :

$$ZN/p>3C$$

If the value of bearing modulus is less than critical value then bearing will operate in partial lubrication conditions and there will be wear and tear of the bearing and the performance of the bearing will drop and its life will decrease.

METHODOLOGY

Experimental design strategy, using Taguchi orthogonal arrays concept as used. The following L-9 orthogonal array was applied:

Table 1.1 L-9 Orthogonal array with actual values

Absolute Viscosity(Z) kg/m-s	Speed (rpm)	Max. Allowable pressure (N/mm^2)	Coefficient of friction μ
0.017	900	0.7	0.007548352
0.017	1100	1	0.006746923
0.017	1500	1.3	0.00697929
0.06	900	1	0.015707692
0.06	1100	1.3	0.014887574
0.06	1500	0.7	0.034637363
0.12	900	1.3	0.023088757
0.12	1100	0.7	0.035507692
0.12	1500	1	0.035507692

Observations in Taguchi Analysis: Coefficient of friction μ versus Absolute Viscosity, Speed in rpm, Max. Allowable pressure (N/mm^2)

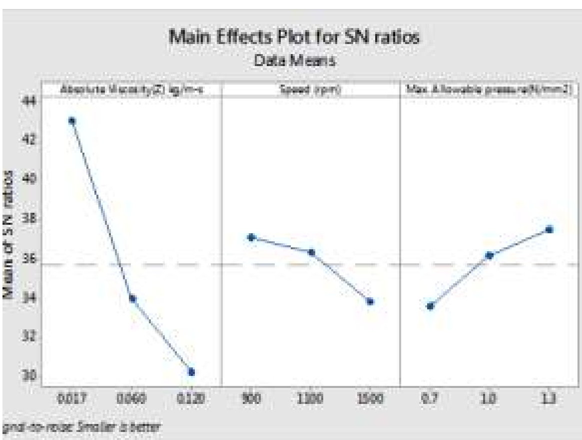


Figure 1.3 Main effects plot for S/N Ratio (μ)

The above SN ratio graph was made using 3 variables i.e. Absolute Viscosity, Speed in rpm, maximum allowable pressure (N/mm^2). As observed from graph, it is clear that at 0.017 absolute viscosity (Z) kg/m-s, 900 speed in rpm and 1.3 max. allowable pressure (N/mm^2) gives the best output in terms of coefficient of friction μ ie. it will be minimum.

Table 1.2 General linear Model (ANOVA) for μ

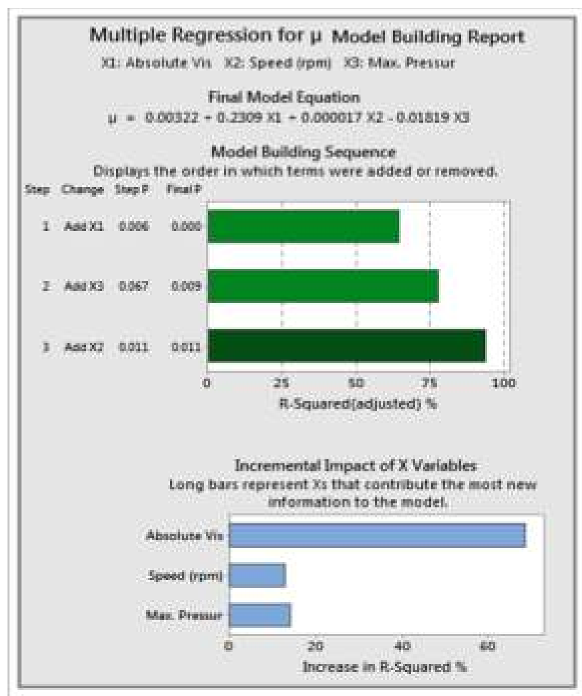
Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution
Absolute Viscosity kg/m-s	2	258.340	258.340	129.170	155.42	0.006	85.57%
Speed (rpm)	2	18.001	18.001	9.000	10.83	0.085	5.96%
Max. Allowable pressure (N/mm^2)	2	23.884	23.884	11.942	14.37	0.065	7.91%
Residual Error	2	1.662	1.662	0.831			0.55%
Total	8	301.888					

From the ANOVA model for the above experimentation, the calculations are done at 95% confidence level. In an analysis of variance table, the P value determines the most significant factor. The factor whose P value is less than 0.05 will be most effective factor. The ANOVA table clearly indicates that speed in rpm and maximum allowable pressure (N/mm2) are not significant parameter for optimizing the coefficient of friction μ. Absolute Viscosity (kg/m-s), is the significant term that influence the model to a great extent. Absolute Viscosity (kg/m-s) has the greatest effect on optimizing coefficient of friction μ and is followed by maximum allowable pressure (N/mm2) and speed in rpm.

General Regression equation for Coefficient of friction μ, Absolute Viscosity, Speed in rpm, maximum allowable pressure (N/mm^2).

The following equation has been formed with the help of software MINITAB version 17:

Coefficient of friction = 0.00322 + 0.2309 Absolute Viscosity + 0.000017 Speed - 0.01819 maximum allowable pressure.



OPTIMIZED PARAMETERS COMBINATION

As Coefficient of friction μ is the "smaller is better: type quality type characteristic, from the figure 1.3 it can be seen that the third level of maximum allowable pressure, first level of speed and first level of absolute viscosity results in maximum value of coefficient of friction μ.

Table 1.3 Optimal value of μ.(optimization report)

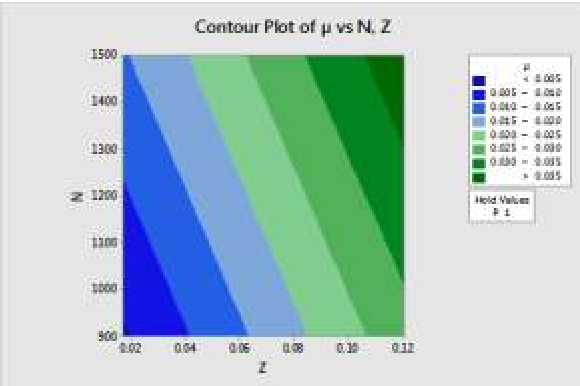
Sr. no.	Absolute Viscosity kg/m-s	Speed rpm	Max. Allowable pressure (N/mm2)	Coefficient of friction μ
1	0.017	900	1.3	0.00117

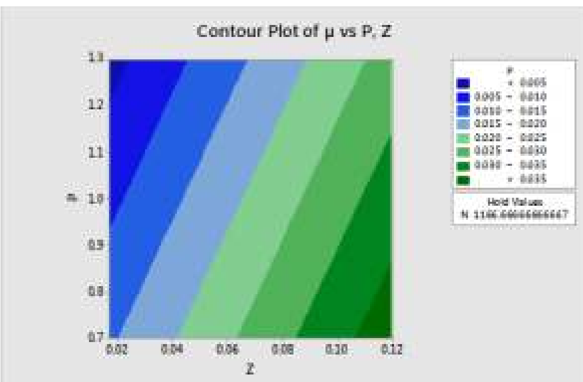
Contour plots for coefficient of friction

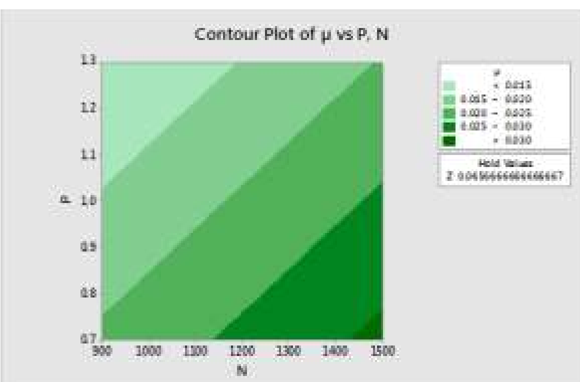
A contour plot is a graphic representation of the relationships among three numeric variables in two dimensions. Two variables are for X and Y axes, and a third variable Z is for contour levels. The contour levels are plotted as curves; the area between

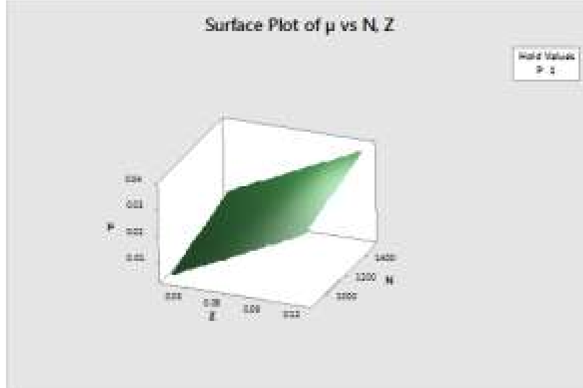
Volume : 4 | Issue : 10 | Special Issue Oct- 2015 • ISSN No 2277 - 8179

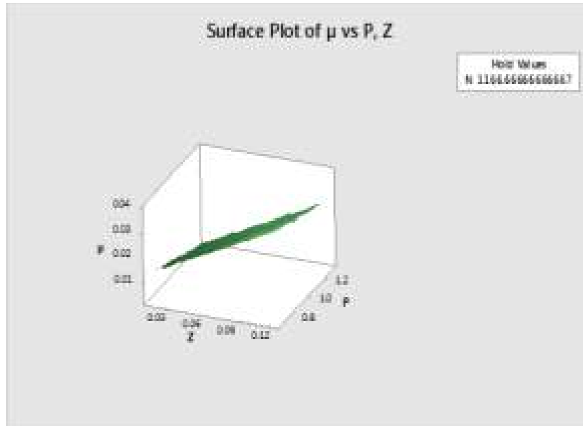
curves can be color coded to indicate interpolated values.You can interactively identify, label, color, and move contour levels, and change the resolutions of rectangular grids to get better contouring quality and performance. You can choose linear interpolation or thin-plat smoothing spline to fit contour surface functions. You can also toggle, identify and label observations in the contour plot, control the orientation of the plot, and control the information shown on the axes.











CONCLUSION

The optimized value of coefficient of friction comes out to be at absolute viscosity of 0.017 kg/m-s, speed of 900 rpm and allowable pressure of 1.3 N/mm2. Further from Table 1.2 it is evident that maximum contribution towards achieving the optimized output is of absolute viscosity(Z) which is 85.57%.The contribution of speed (N) and maximum allowable pressure is 5.96 percent and 7.91 percent respectively. The application of Taguchi L9 array provides the optimized result with 95 percent confidence level and by using only 9 input values rather than conducting 27 experiments. Hence this technique of optimizing is accurate ,fast and reliableand can be carried out conveniently with less effort and resources.

FUTURE SCOPE

The study presented in the paper is limited to hydrodynamic journal bearing of compressor with absolute viscosity, speed of journal and allowable pressure as design inputs. It can be extended to include radial clearance as design variable. Further Taguchi technique can be used to optimize heat generation and dissipation in bearing, temperature rise in bearing ,manufacturing cost , oil leakage flow rate, whirl onset velocity of shaft and shaft twist as design input variables which are to be optimized. The present study can be extended to improve the characteristics of elliptical journal bearings, roller bearings and thrust bearings. The bearings for pumps, turbines, generators, motors, railway, cars, gyroscope, gas and oil engines, machine tools, rolling mills etc can also be optimized.

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