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Dam Length Optimization of Two Lobe Pressure Dam Bearing Using Genetic Algorithm

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Abstract

This paper attempts to find out the optimum length of pressure dams taking into account the various steady state characteristics of two lobe bearing. The length of the dam selected varies with eccentricity ratios of operation. Determination of Optimum performance is based on maximization of non-dimensional load, maximization of flow coefficient and minimization of friction variable using Genetic Algorithm. The result obtained gives an insight on how the performance of two lobe bearing can be enhanced using pressure dam. The data obtained from the above can be used conveniently in the optimum design of such bearings, as these are presented in dimensionless form.

Keywords: Steady state characteristics; Two lobe; Optimum dam length

Introduction

The performance of a two lobe bearing is enhanced by the use of pressure dams. The analysis of multi lobe bearings was first carried out by Pinkus [1]. A comparison of non-dimensional values of steady state and dynamic characteristics has been made with the published results of Lund et al. [2] for L/D=1 with two lobe bearing with 20° axial groove. Sihasan et al. [3] worked on various configurations of multi lobe bearings. Mehta et al. [4] analyzed three-lobe bearings with pressure dams and concluded that the stability of a three-lobe bearing can be increased by simply cutting pressure dams and a relief track. Mehta et al. [5] analyzed the static and dynamic characteristics of four lobe pressure dam bearing and concluded that the performance of four lobe bearing with pressure dams is superior to that of an ordinary four lobe bearing. Bhushan et al. [6] analysed the behaviour of four lobe pressure dam bearing operating under turbulence condition and concluded that values of eccentricity ratio, friction coefficient and oil flow coefficient increases with increase in turbulence. The attitude angle increases with increase in values of Sommerfeld number less than 1.8, it decreases for values greater than 1.8. Mehta et al. [7] carried out the stability analysis of plain circular hydrodynamic pressure dam bearing operating with couple stress fluid and concluded that the use of dams in plain circular bearings increases its stability as evident by the increase in the critical mass. Mehta and Rattan [8] studied the inverted three-lobe pressure dam bearing. The stability of inverted three-lobe pressure dam bearing is found to increase with the incorporation of a pressure dam and relief tracks. Batra et al. [9] conducted a study on the effect of L/D ratio on the performance of three-lobe pressure dam bearing and observed that the stability of an inverted three-lobe pressure dam bearing increased with the decrease in L/D ratio. Batra et al. [10] carried out the static and dynamic analysis of inverted three-lobe pressure dam bearing and compared its performance to that of three lobe journal bearing. Batra et al. [11] also carried out a study on the effect of various ellipticity ratio on the performance of an inverted three lobe pressure dam bearing. It was found that for a particular Sommerfeld number, as the ellipticity ratio increased, the value of minimum film thickness, oil flow coefficient, attitude angle and eccentricity ratio decreased whereas the value of friction coefficient slightly increased. The stability of inverted three lobe pressure dam bearing increased with the increase in ellipticity ratio. As the use of pressure dams have proved to be useful to enhance the performance of multi lobe bearings, a study has been carried out to determine the optimum dam length for two lobe bearing considering the steady state characteristics of two lobe bearings. It is found that the performance of ordinary circular bearings and multi-lobe bearings is not very satisfactory when it comes to application in these high speed turbo machine components. To improve the stability of these bearings, pressure dams are incorporated in these bearings. It has been found from analytical dynamic analysis that cylindrical pressure dam bearings are very stable. Also, using analytical and experimental stability analysis, it has been found that the stability of multi-lobe pressure dam bearing also increases. So it can be said that incorporating pressure dams in bearings help in improving the performance of the bearings.

With the advancement of technology, the requirements for various engineering elements are increasing. It is not only required by the machines to handle higher speeds and loads than before, but to do so without any drastic increase in cost of manufacturing and maintenance. This requires each element to have better performance and stability than before and bearings are no exception. Incorporating pressure dams in conventional hydrodynamic bearing could provide a solution to this increase in demand for better performance. So, a study has been carried out on the effect of pressure dam bearing on parameters like load capacity, friction variable and flow of lubricants.

Geometry

The geometry of a two-lobe pressure dam bearing is usually the same as two-lobe bearing with the exception of the slot cut in one of the bearing pads and a long groove cut in the other bearing pad. Figure 1 gives the geometry of a pressure dam bearing. The upper pad of the bearing has a slot cut into it. A rectangular dam of step depth S_d and width L_d is cut circumferentially in the upper lobe. The dam starts after the oil hole and subtends an arc of θ_S degrees at the centre. A circumferential relief track or groove is of depth and width L_t is also cut centrally in the other pad of the bearing. The relief track is assumed to be so deep that its hydrodynamic effects are neglected. The pocket

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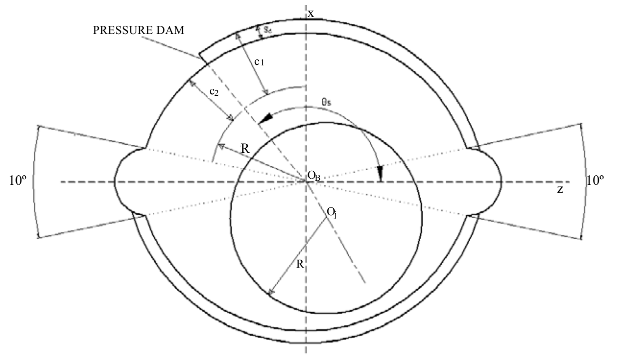

Figure 1: Geometry of a pressure dam bearing.

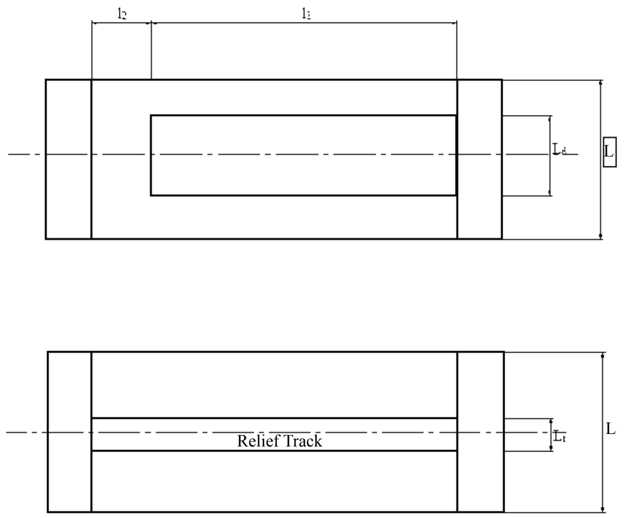

Figure 2: Top and bottom pad of pressure dam bearing.

clearance ratio K for the pressure dam is given by c_1/c_2 and the dam location is given by l_1/l_2 as shown in the Figure 2.

The pressure dam bearing is taken have two oil grooves at both the end of the two lobes. The groove angles being 10^0 each. The pressure dam is incorporated in the first lobe and a relief track is incorporated in the second lobe. The size of the pressure dam which is given in degrees is converted to be expressed in terms of the length of the arc subtended by the pressure dam. The geometry of the pressure dam and relief track can be expressed in terms of length instead of angle subtended at the centre. This helps in defining the geometry of the pressure dam and relief track in terms of discretized elements of ease of programming.

Eccentricity Ratio is given by

For lobe 1 $$\varepsilon_1 = \sqrt{\varepsilon^2 + \delta^2 + 2\varepsilon\delta \cos\phi} \quad (1)$$

For lobe 2 $$\varepsilon_2 = \sqrt{\varepsilon^2 + \delta^2 2\varepsilon\delta \cos\varphi} \quad (2)$$

Attitude angle is given by

For lobe 1 $$\varphi_1 = \tan^{-1}\frac{e\sin\varphi}{\delta + e\cos\varphi} \quad (3)$$

For lobe 2 $$\phi_2 = \pi - \tan^{-1}\frac{\varepsilon\sin\phi}{\delta - \varepsilon\cos\phi} \quad (4)$$

The circumferential length of the pressure dam is given by

$$l \quad \pi R\theta \;\; /180 \quad (5)$$

Where θ_s is the angle subtended by pressure dam in degrees.

The fluid film thickness for the pressure dam bearing in the region where the pressure dam is present given as:

$$\bar{h} = 1 + S_d + € \cos\theta \quad (6)$$

Where S_d is the step depth €

And where the pressure dam is not present

$$\bar{h} = 1 + € \cos\theta \quad (7)$$

Theory

The Reynolds Equation has been derived from the Navier-Stokes equation and the continuity equation. The generalized Reynolds Equation is the differential equation originally developed by Reynolds restricted to incompressible flow. However, the equation can be formulated to include effects of compressibility. The simplified form of Reynolds Equation can be written as:

$$\frac{\partial}{\partial x}\left(\frac{\rho h^3}{\eta}\frac{\partial p}{\partial x}\right) + \frac{\partial}{\partial z}\left(\frac{\rho h^3}{\eta}\frac{\partial p}{\partial z}\right) = 6U\frac{\partial}{\partial x}(\rho h) + 12\frac{\partial}{\partial t}(\rho h) \quad (8)$$

Throughout this work, a consistent and meaningful set of parameters have been used. They can be termed as the geometric conditions. One of the important non-dimensional parameter used in this work is the slenderness ratio and is defined as the ratio of bearing's length to its diameter i.e. L/D ratio.

The "unwrapping" of the circumferential coordinate such as the fluid passage is expressed in a Cartesian frame implies another common assumption in bearing analyses: that the effect of curvature is negligible. This assumption is slightly more restrictive because the curvature terms are of order C/R that is also known as the clearance ratio. For most bearings, however, C/R is of the order of 1/1000.

Where, the various non-dimensional terms that has been used,

$$\theta = \frac{x}{R}, \bar{z} = \frac{z}{L/2}, \bar{h} = \frac{h}{C}, \bar{p} = \frac{pC^2}{6\eta UR}$$

By using the above substitutions, the non-dimensionalised form of the Reynolds Equation is obtained as:

$$\frac{\partial}{\partial\theta}(\bar{h}_0^{\,3}\frac{\partial\bar{p}_0}{\partial\theta}) + \left(\frac{D}{L}\right)^2 \frac{\partial}{\partial\bar{z}}(\bar{h}_0^{\,3}\frac{\partial\bar{p}_0}{\partial\bar{z}}) = \frac{\partial\bar{h}_0}{\partial\theta} \quad (9)$$

where, $\bar{h} = 1 + € \cos\theta$

The non-dimensional form of the Reynolds Equation is then can be used to determine the pressure at each point of a developed mesh of each side of the bearing thus giving us the pressure distribution on the bearing. The Reynolds Equation is solved using finite difference method with Gauss-Seidel method of iteration with successive over relaxation.

The Sommerfeld number is a dimensionless quantity that gives the characteristics of the bearing as it contains all the variables required to design a bearing.

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It is given by

$$S = \frac{\eta N}{P}\left(\frac{R}{C}\right)^2$$

The steady state characteristics for two lobe pressure dam bearing viz. non dimensional load, friction variable and flow coefficient are defined as follows

The non-dimensional load for journal bearing is given by

$$\overline{W}_{X_0} = \int_{\theta_1}^{\theta_2}\int_0^1 \overline{p}_0 \cos\theta \, d\theta \, d\overline{z}$$

$$\overline{W}_{Z_0} = \int_{\theta_1}^{\theta_2}\int_0^1 \overline{p}_0 \sin\theta \, d\theta \, d\overline{z}$$

Therefore the load carrying capacity and attitude angle are:

$$\overline{w} = \sqrt{(\overline{w}_{x_0}{}^2 + \overline{w}_{z_0}{}^2)} \tag{10}$$

$$\varphi = \tan^{-1}\left(\frac{\overline{w}_z}{\overline{w}_x}\right)$$

Flow coefficient which is given by [1]

$$\overline{\mu} = \mu(R/C) = \frac{\int_0^{2\pi}\left(3\overline{h}\frac{\partial \overline{p}}{\partial \theta} + \frac{1}{\overline{h}}\right)\partial\theta}{6\overline{W}} \tag{11}$$

And friction variable which is given by

$$\overline{q}_z = \frac{1}{2}\left(\frac{D}{L}\right)^2 \int_0^{2\pi} \overline{h}_L^{\,3} \frac{\partial \overline{p_L}}{\partial z_L} d\theta_L \tag{12}$$

To determine the optimum dam length of two lobe pressure dam bearing by taking into consideration all the steady state characteristics of two lobe pressure dam bearing, single and multi-objective functions are defined. The single and multi-objective function is then optimized to find out the optimum dam length. The multi objective function is defined as

$$f = w_1\left(\frac{\overline{\mu}}{\overline{\mu}_{\max} - \overline{\mu}_{\min}}\right) + w_2\left(1 - \frac{\overline{q}_z}{\overline{q}_{\max} - \overline{q}_{\min}}\right) + w_3\left(1 - \frac{\overline{w}}{\overline{w}_{\max} - \overline{w}_{\min}}\right) \tag{13}$$

Where, w_1, w_2 & w_3 are the equal weight of the functions and is taken to be 0.33

The objective functions are minimized using the Genetic Algorithm toolbox in MATLAB. The angle subtended by the pressure dam at the centre of the bearing which is θ_s is the input parameter which is finally obtained using the GA toolbox. The optimization calls the Reynolds equation solver (Gauss-Seidel Method with over-relaxation in a Finite Difference Grid then numerical integration by Simpson's rule) to estimate the required parameter. Minimization of the multi objective function using the values generated for θ_s which give us the best value for the pressure dam.

Results and Discussions

Before the analysis of results of two-lobe pressure dam bearings, the steady state result of two-lobe bearing is compared with [2]. From the Table 1 it has been observed that present results agrees well with previously published results [2]

The results for two lobe pressure dam bearing has been obtained for single objective functions for steady state characteristics of pressure dam bearing viz friction variable ($\overline{\mu}$), flow coefficient ($\overline{q}_z$) and non-dimensional load carrying capacity ($\overline{W}$). Codes were developed for single and multi-objective function for these three steady state characteristics and the optimum dam length for two lobe pressure dam bearing was determined forming single (minimization of friction variable($\overline{\mu}$), maximization of flow coefficient ($\overline{q}_z$) and maximization of non-dimensional load carrying capacity ($\overline{W}$) and multi-objective function (formed by minimization of objective function formed by combination of all the objectives as stated above). The optimum dam length for two lobe pressure dam bearing was determined for different eccentricity ratios. The optimization of dam length for the two lobe pressure dam bearing for both single and multi objective function has been done using genetic algorithm. The optimum values obtained for friction variable, flow coefficient and non dimensional load are all in non dimensional form so that they can be used for practical purposes. Manufacturers and designers will be immensely benefitted if such dam locations can be determined by some method (Figures 3-11).

From Figure 3 it can be said that the optimum dam length of two lobe pressure dam bearing considering only friction variable as objective function increases with increasing eccentricity ratios. The angle subtended by dam varies between 104° to 341° for the variation of eccentricity ratio from 0.05 to 0.451. A convergence plot considering friction variable as objective function is shown in Figures 4 and 5 it can be said that the angle subtended by dam of two lobe pressure

Eccentricity ratio	Attitude angle (ϕ)	Sommerfeld Number (S)
(ε)	Present work [2]	Present work [2]
0.050	93.812 [93.75]	1.445 [1.463]
0.100	93.125 [93.15]	0.699 [0.709]
0.150	91.980 [92.00]	0.442 [0.447]
0.200	90.387 [90.40]	0.308 [0.312]
0.239	88.831 [88.85]	0.239 [0.243]
0.250	88.284 [88.35]	0.224 [0.227]
0.260	87.896 [87.85]	0.219 [0.213]
0.304	85.561 [85.25]	0.165 [0.163]
0.350	81.853 [82.00]	0.121 [0.122]
0.381	79.029 [78.77]	0.099 [0.098]
0.451	64.194 [63.80]	0.046 [0.045]

Table 1: Validation of results for two lobe bearing.

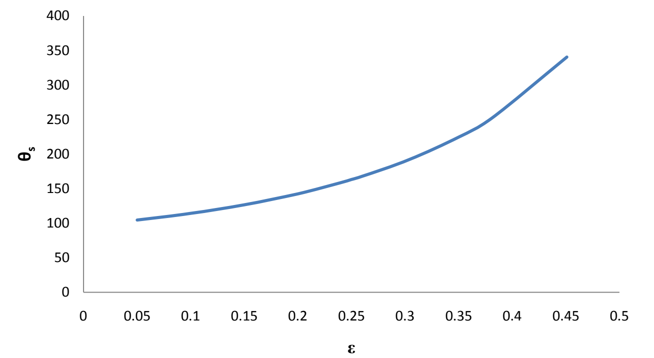

Figure 3: Variation of angle subtended by pressure dam (θ_s) with eccentricity ratio (ε) considering friction variable as objective function.

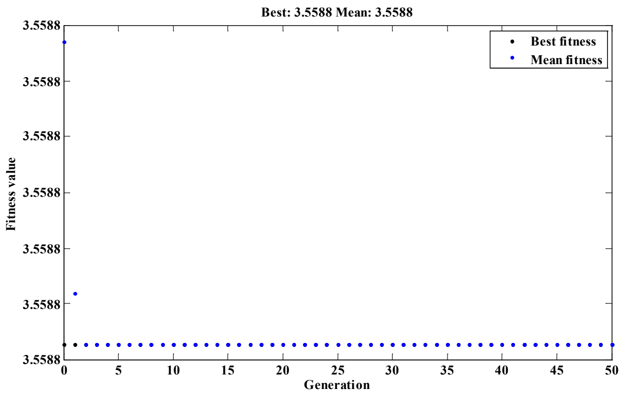

Figure 4: Convergence of best fitness value for friction variable considering eccentricity ratio 0.381.

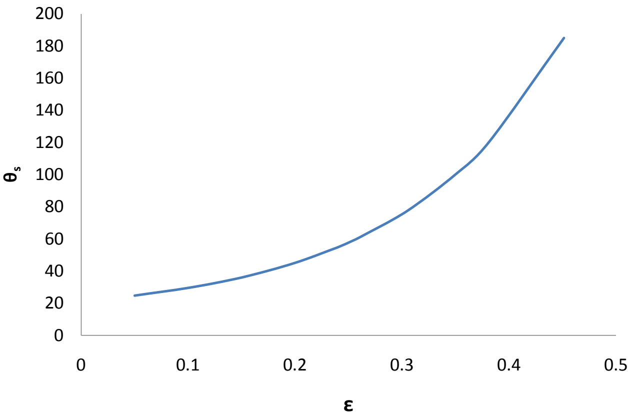

Figure 5: Variation of angle subtended by pressure dam θ_s with eccentricity ratio (ε) considering flow coefficient as objective function.

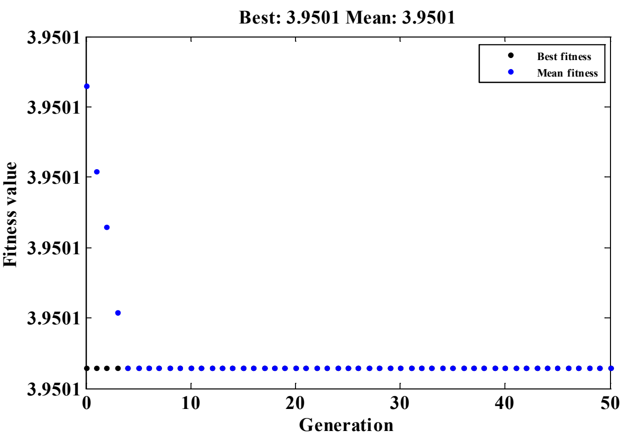

Figure 6: Convergence of best fitness value for flow coefficient considering eccentricity ratio 0.381.

dam bearing considering only flow coefficient also increases with increase in eccentricity ratio. The subtended angle varies between 24° to 185° for the variation of eccentricity ratio from 0.05 to 0.451. A convergence plot considering flow coefficient as objective function is shown in Figure 6. From Figure 7 it can be said that the optimum angle subtended by dam of two lobe pressure dam bearing considering only non-dimensional load also increases with eccentricity ratio. The dam angle varies between 19° to 37° for the variation of eccentricity ratio from 0.05 to 0.451. A convergence plot considering non dimensional load as objective function at a particular value of eccentricity ratio is shown in Figure 8. From Figure 9 it can be said that the optimum

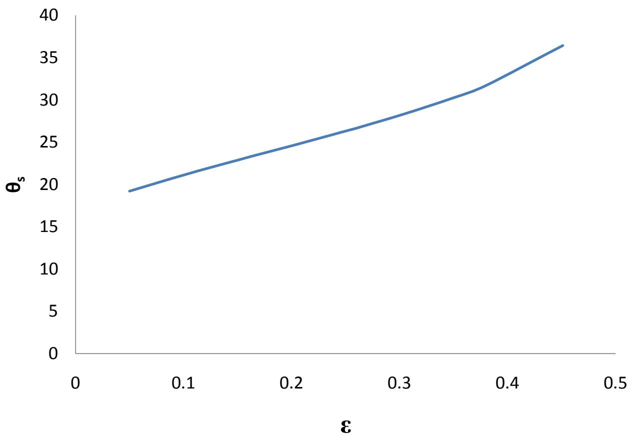

Figure 7: Variation of angle subtended by pressure dam θ_s with eccentricity ratio (ε) considering non dimensional load as objective function.

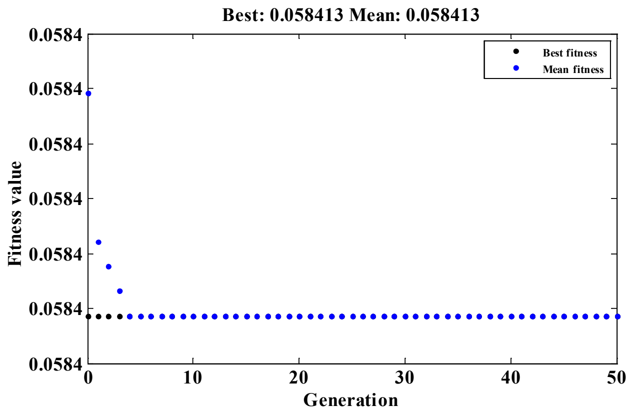

Figure 8: Convergence of best fitness value for non-dimensional load considering eccentricity ratio 0.381.

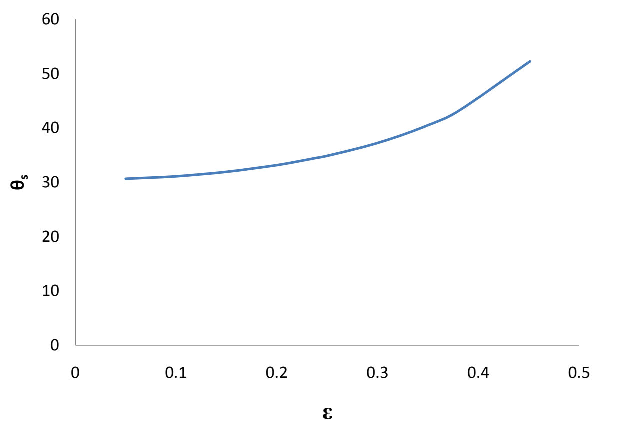

Figure 9: Variation of angle subtended by pressure dam θ_s with eccentricity ratio (ε)formed by minimization of objective function formed by combination of all the objectives.

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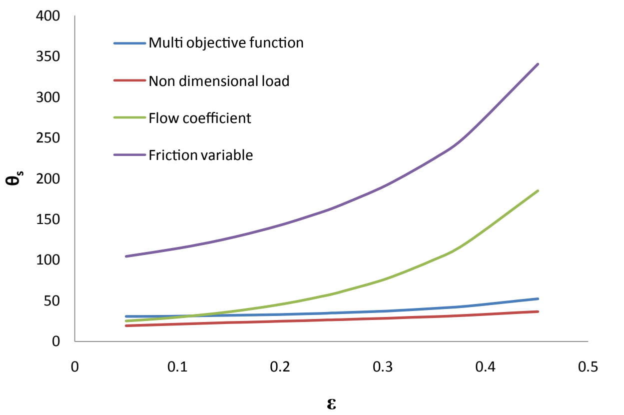

Figure10: Comparison of angle subtended by pressure dam θ_s for various objective functions.

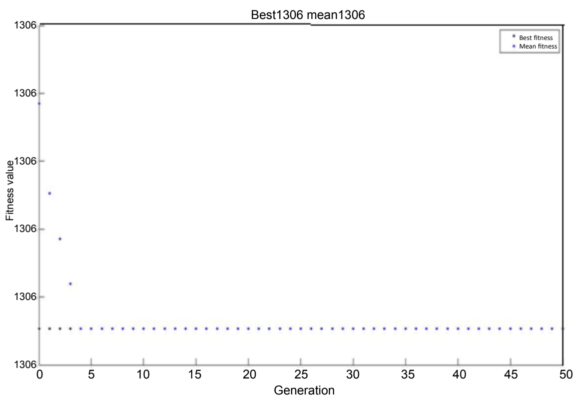

Figure 11: Convergence of best fitness value for multi objective function considering eccentricity ratio 0.304.

dam length of two lobe pressure dam bearing considering the multi objective function increases with increasing eccentricity ratio. The dam angle varies between 30° and 53° for eccentricity ratio from 0.05 to 0.451. From Figure 10 it can be said that the variation of dam length for two lobe pressure dam bearing is the highest for friction variable. The variation is less for flow coefficient and it is the least for non-dimensional load. The variation of dam length for two lobe pressure dam bearing considering multi objective function is very less and is only slightly more than the variation for non-dimensional load. A convergence plot considering multi objective function at a particular value of eccentricity ratios is shown in Figure 11.

Conclusions

In this work, optimization of dam length of two lobe pressure dam bearing is carried out using GA. Considering the different objective functions, genetic algorithm is able obtain a global solution of optimum design parameters such as friction variable, flow coefficient and non-dimensional load carrying capacity and multi objective function of the two lobe pressure dam bearing. From the discussion the following conclusions can be drawn.

In case of two lobe pressure dam bearing considering only friction variable as an objective function, the angle subtended by pressure dam comes out to be in the range of 104° to 341° for eccentricity ratio ranging from 0.05 to 0.451 respectively. The angle subtended by pressure dam for two lobe pressure dam bearing is found to increase with eccentricity ratio.

1. In case of two lobe pressure dam bearing considering only flow coefficient as an objective function, the angle subtended by pressure dam comes out to be in the range of 24° to 185° for eccentricity ratio ranging from 0.05 to 0.451 respectively. In this case also, the angle subtended by pressure dam for two lobe pressure dam bearing also increases with increase in eccentricity ratio.

2. In case of two lobe pressure dam bearing considering only non-dimensional load, the angle subtended by pressure dam is in the range of 19° to 37° for eccentricity ratio ranging from 0.05 to 0.451 respectively. The optimum dam length for two lobe pressure dam bearing increases with increase in eccentricity ratio.

3. In case of two lobe pressure dam bearing considering the multi objective function the optimized dam length comes out to be in the range of 30° to 53° for eccentricity ratio ranging from 0.05 to 0.451 respectively. In this case also, the angle subtended by pressure dam for two lobe pressure dam bearing increases with increase in eccentricity ratio.

4. The rate of increase in the angle subtended by pressure dam for two lobe pressure dam bearing is much higher while considering only friction variable as an objective function than the other cases. The rate of increase is the least while considering only non-dimensional load as an objective function. The rate of increase while considering flow coefficient is lower than that for friction variable but higher than the rest. The rate of increase for dam length for two lobe pressure dam bearing while considering the multi objective function is higher than that of non-dimensional load but lower than the rest. Dam at the top of the bearing it adds more to friction and flow than the load capacity.

5. The data obtained from the above analysis can be used conveniently in the design of such bearings, as these are presented in dimensionless form.

Identification of the optimum length of the dam is done so that the performance characteristics are near to the optimum for any loading condition (eccentricity ratio) and any objective function and will be much beneficial to the manufacturers and designers. Experimental verification of the present result may lead to a new approach of production of bearings with optimum groove locations, however, it is beyond the scope of the present work and hopefully experimentalists have a problem in hand.

References

1. Pinkus O (1959) Analysis and characteristics of three-lobe bearings. ASME J Basic Eng 81: 19.
2. Lund W, Thomson KK (1978) A Calculation Method and Data for the Dynamic Coefficients of Oil Lubricated Journal Bearings. Proceedings of the ASME Design and Engineering Conference, Minneapolis.
3. Sinhasan R, Malik M, Chandra M (1981) A Comparative study of some three-lobe bearing configurations. Elsevier Sequoia, Lausanne 72: 277-286.
4. Mehta NP, Rattan SS (1993) Stability analysis of three-lobe bearings with pressure dams. Elsevier, Sequoia, 167: 181-185.
5. Mehta NP, Rattan SS, Bhushan G (2003) Static and dynamic characteristics of a four-lobe pressure-dam bearings. Tribology Letters 15: 415-421.

6. Bhushan G, Rattan SS, Mehta NP (2007) Effect of turbulence on performance of four-lobe pressure dam bearing. IE(I) Journal-MC 87: 18-23.

7. Mehta NP, Rattan SS, Verma R (2010) Stability analysis of circular pressure dam hydrodynamic journal bearing with couple stress lubricant. Aprn J Eng Appl Sci 5: 26-33.

8. Mehta NP, Rattan SS, Bhusan G, Batra NK (2012) Stability analysis of an inverted three-lobe pressure dam bearing. J Mech Sci Technol, Springer 26: 2425-2430.

9. Batra NK, Bhushan G, Mehta NP (2012) Effect of L/D ratio on the performance of an inverted three-lobe pressure dam bearing. J Eng Technol 1: 94-99.

10. Batra NK, Bhushan G, Mehta NP (2012) Static and dynamic characteristics of an inverted three-lobe pressure dam bearing. Akademeia 2: 1523-1530.

11. Batra NK, Bhushan G, Mehta NP (2012) Effect of ellipticity ratio on the performance of an inverted three-lobe pressure dam bearing. Tribology Transactions 55: 798-804.