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Effect of Load Orientation on the Stability of a Three-Lobe Bearing Supporting Rigid and Flexible Rotors

G. Bhushan

Abstract**—**Multilobe bearings are found to be more stable than circular bearings. A three lobe bearing also possesses good stability characteristics. Sometimes the line of action of the load does not pass through the axis of a bearing and is shifted on either side by a few degrees. Load orientation is one of the factors that affect the stability of a three lobe bearing. The effect of load orientation on the stability of a three-lobe has been discussed in this paper. The results show that stability of a three-lobe bearing supporting either rigid or flexible rotor is increased for the positive values of load orientation i.e. when the load line is shifted in the opposite direction of rotation.

Keywords**—**Thee-lobe bearing, load orientation, finite element method.

NOMENCLATURE

c	: radial clearance
c_m	: minimum film thickness for a centered shaft
$C_{xx}, C_{xy}, C_{yx}, C_{yy}$	: oil-film damping coefficients
$\bar{C}_{xx}, \bar{C}_{xy}, \bar{C}_{yx}, \bar{C}_{yy}$	: dimensionless oil-film damping coefficients, $\bar{C}_{xx} = C_{xx}(\omega c / W)$
C_0, C_1, C_2, C_3, C_4	: coefficients of the characteristic equation
D	: diameter
e	: eccentricity
F	: dimensionless shaft flexibility, W / ck
h	: oil-film thickness, $c(1 + \varepsilon \cos\theta)$
$\bar{h}$	: dimensionless oil-film thickness, $h / 2c$
$2k$	: shaft stiffness
$K_{xx}, K_{xy}, K_{yx}, K_{yy}$	: oil-film stiffness coefficients
$\bar{K}_{xx}, \bar{K}_{xy}, \bar{K}_{yx}, \bar{K}_{yy}$	: dimensionless oil-film stiffness coefficients, $\bar{K}_{xx} = K_{xx}(c / W)$
L	: bearing length
N	: journal rotational speed
O_i	: lobe center of lobe i (i = 1,2,3,4)
p	: oil-film pressure
R	: journal radius
S	:Sommerfeld number, $\frac{\mu NLD}{W}\left(\frac{R}{c}\right)^2$
V	: peripheral speed of journal
W	: bearing external load
x, z	: coordinates for bearing surface (x-peripheral, z-along shaft axis)
ϕ	: attitude angle
$\dot{\alpha}$	: whirl rate ratio, $\dot{\alpha} = \dot{\phi} / \omega$
$\dot{\beta}$	:squeeze rate ratio, $\dot{\beta} = \dot{\varepsilon} / \omega$
ε	: eccentricity ratio, e / c
δ	: ellipticity ratio, $(1 - c_m / c)$
θ	: angle measured from the line of centers in the direction of rotation
θ_g	: oil-groove angle
ρ	: fluid density
μ	: average fluid viscosity
ω	: rotational speed
v	: dimensionless threshold speed, $\omega(c / g)^{1/2}$
g	:gravitational acceleration constant

I. INTRODUCTION

The present trend in the industry is to run the turbomachines at high speeds. The ordinary circular bearings, which are the most common type of the bearings, are found to be unstable at high speeds. It is found that the stability of these bearings can be increased by the use of multilobes and the incorporation of pressure dams in the lobes. The analysis of multi-lobe bearings was first published by Pinkus [1]. It was followed by Lund and Thomson [2] and Malik et al. [3], who gave some design data which included both static and dynamic characteristics for laminar, as well as turbulent flow regimes.

G. Bhushan is with the National Institute of Technology, Kurukshetra, Haryana , India (e-mail: aroragian@yahoo.com)

The experimental stability analysis of such types of bearings [4]-[5] showed that the analytical stability analysis reflects the general trends in experimental data. The factors affecting the bearing stability are load, L/D ratio, viscosity of the fluid, clearance between the journal and the bearing, type of fluid (compressible or incompressible), rotor unbalance, flow regime (laminar or turbulent), ellipticity ratio, load orientation, friction, shaft and liner flexibility, groove angle etc.[6]-[7]. Load orientation is one of the parameters that affects the stability of a bearing. The present study is undertaken to investigate the effect of load orientation on the performance of a three-lobe bearing supporting rigid and flexible rotors.

II. ANALYSIS

The non-dimensionalised Reynolds Equation for the laminar flow is:

$$\frac{\partial}{\partial \bar{x}}\left(\frac{\bar{h}^3}{12}\frac{\partial \bar{p}}{\partial \bar{x}}\right) + \left(\frac{D}{L}\right)^2 \frac{\partial}{\partial \bar{z}}\left(\frac{\bar{h}^3}{12}\frac{\partial \bar{p}}{\partial \bar{z}}\right) = \frac{\pi}{2}\frac{\partial \bar{h}}{\partial \bar{x}} + \pi\varepsilon\dot{\alpha}\sin 2\bar{x} + \pi\dot{\beta}\cos 2\bar{x} \qquad (1)$$

The various assumptions made in the derivation of the Reynolds Equation are that the fluid is Newtonian, no slip occurs at the bearing surface, inertia terms are neglected, oil viscosity is constant and curvature is negligible. The Reynolds equation is analysed for a pressure profile using the finite element method [8]. The geometry of a three-lobe bearing is shown in Figure 1.

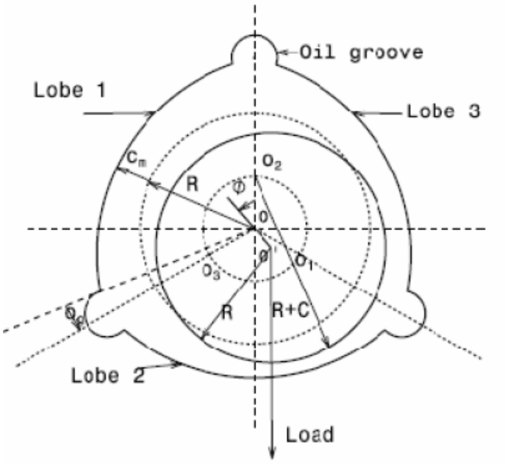

Fig. 1 A three-lobe bearing

Each lobe of the bearing is analysed separately. Since the pressure profile has to be symmetrical about the bearing centre line, only half of the lobe is taken for analysis. Fluid pressures at nodal points are taken by applying the Reynolds boundary conditions. The resulting matrix is stored in a banded form. Then it is solved by the Gauss-elimination method. Stiffness and damping coefficients are determined separately for each lobe and then added. The values of these stiffness and damping coefficients, shaft flexibility, and dimensionless speed are then used to evaluate the coefficients of the characteristic equation[9], which is a polynomial of the 6th order for flexible rotors.

For a rigid rotor, the value of F (dimensionless flexibility) is taken as zero. The value of F for most of the practical rotors varies from 0.5 to 4.0 and the same has been considered for the case of the flexible rotors. The system is considered as stable if the real part of all roots is negative. For a particular bearing geometry and eccentricity ratio, the values of dimensionless speed are increased until the system becomes unstable. The maximum value of speed for which the bearing is stable is then adopted as the dimensionless threshold speed.The present analysis has been done for the bearing with L/D = 1.0 and ellipticity ratio (δ) = 0.5.The values of load orientation angle (γ)considered are 0°, -5°, -10°, +5° , +10° and the bearing is investigated for its stability characteristics.

$$\begin{aligned} & s^6F^2v^4C_0 + s^5v^4\left(F^2C_1 + FC_2\right) + \\ & s^4v^2\left(v^2F^2C_3 + 2FC_0 + v^2 + v^2FC_4\right) \\ & + s^3v^2\left(2FC_1 + C_2\right) + s^2\left(2Fv^3C_3 + v^2C_4 + C_0\right) + \\ & sC_1 + C_3 = 0 \end{aligned} \qquad (4)$$

III. RESULTS AND DISCUSSION

The effect of load orientation on the stability of a three-lobe bearing is shown in Figures 2 to 6. The stability threshold curve divides any figure in two major zones. The zone above the curve is unstable, whereas, the zone below the curve is stable. The minimum value of this curve is termed as minimum threshold speed. The bearing is stable at all speeds towards the left side of the curve, which is called as zone of infinite stability.

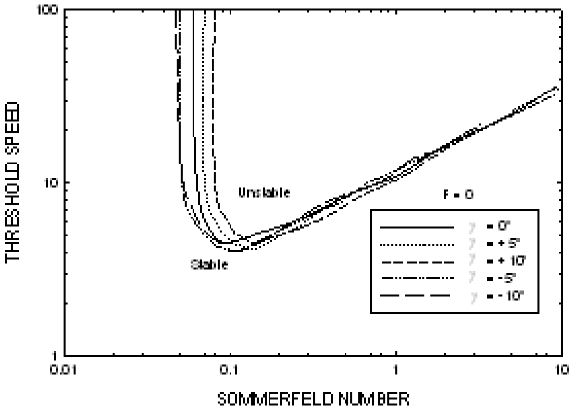

Fig. 2 Effect of load orientation on the stability of a three-lobe bearing supporting a rigid rotor (F=0)

Figure 2 shows the effect of load orientation on the stability of a three-lobe bearing supporting a rigid rotor (F = 0). It is observed from the Figure that negative values (-5°, -10°) of load orientation adversely affect the stability of the bearing. The plots show that both, the minimum threshold speed and the zone of infinite stability decrease with the increase in negative values of load orientation angle. The values of the minimum threshold speed at load orientation angles of 0°, -5°, -15° are 4.5, 4.1, & 4.05 respectively. The zone of infinite stability decreases at load orientation of -10° (up to S = 0.047) from the value at 0° (up to S = 0.06). The positive values of the load orientation have favourable effect on the stability of the bearing in the considered range. There is increase in the value of zone of infinite stability (up to S = 0.06 to S = 0.08) when the angle of load orientation increases from 0° to +10°. There is almost no change in the value of minimum threshold speed and it remains at about 4.5.

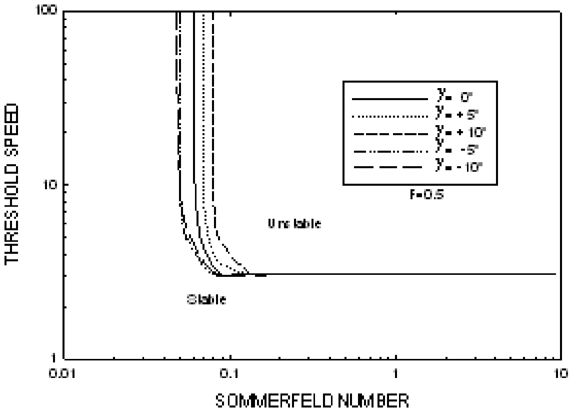

Fig. 3 Effect of load orientation on the stability of a three-lobe bearing supporting a rigid rotor (F=0.5)

Figures 3 to 6 show the effect of load orientation on the stability of a three-lobe pressure dam bearing supporting a flexible rotor. The effect of flexibility of a rotor on the stability of the bearing is considered by using non-zero values of *F* in the characteristic equation. The increase in the value of *F* indicates more flexibility of a rotor. The value of dimensionless flexibility *F* of most of the practical rotors may vary from 0.5 to 4 and the same range has been considered. Figure 3 shows the effect of load orientation on the stability of a three lobe bearing supporting a flexible rotor with F =0.5. It is observed from the figure that the zone of infinite stability increases with an increase in positive value of load orientation while there is no change in the value of minimum threshold speed. The zone of infinite stability decreases with an increase in negative value of load orientation in a similar manner as for the case of a rigid rotor and there is no change in the value of minimum threshold speed. The negative values of load orientation adversely affect the stability of the three-lobe pressure dam bearing while there is improvement in the stability for positive values of load orientation up to +10°.

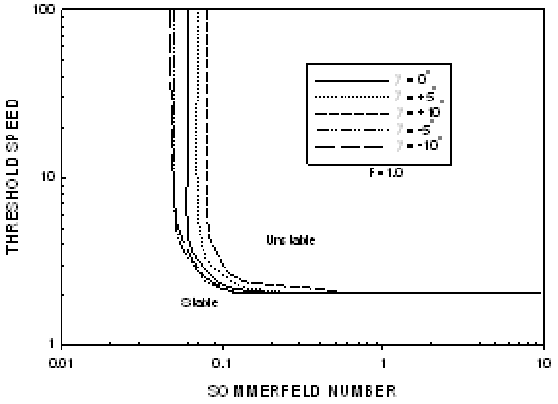

Fig. 4 Effect of load orientation on the stability of a three-lobe bearing supporting a rigid rotor (F=1.0)

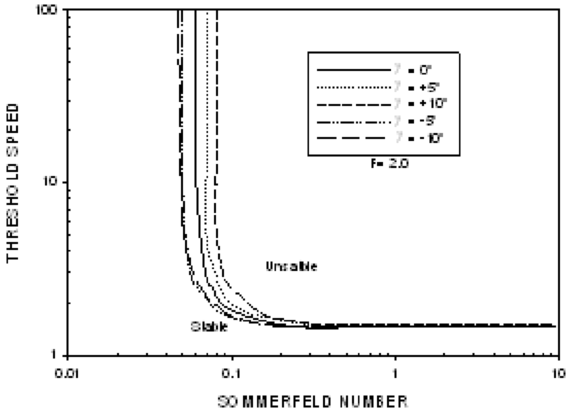

Fig. 5 Effect of load orientation on the stability of a three-lobe bearing supporting a rigid rotor (F=2.0)

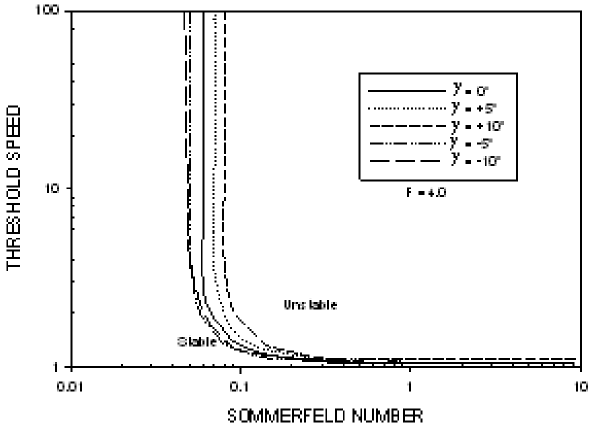

Fig. 6 Effect of load orientation on the stability of a three-lobe bearing supporting a rigid rotor (F=4.0)

The similar effects are also observed for other values of F (Figures 4 to 6). Another important observation from the Figures 3 to 6 is that for a particular value of load orientation angle, with an increase in the flexibility of the rotor the zone of infinite stability remains unchanged but there is decrease in the value of minimum threshold speed, thus reducing the stability of the bearing.

IV. CONCLUSIONS

1. The stability of a three-lobe bearing is affected by the load orientation. The negative values of the load orientation adversely affect the stability while there is improvement in the stability for the positive values of load orientation.
2. The increase in flexibility of the rotor decreases the stability of a three-lobe dam bearing for a particular value of load orientation.

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