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CALCULATION OF STATIC EQUILIBRIUM POSITION OF HYDRODYNAMIC JOURNAL BEARINGS

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Abstract: *This paper deals with calculation of static equilibrium position of finite length hydrodynamic journal bearings. Cylindrical and lemon bore hydrodynamic bearings are considered. Investigating the static equilibrium position of the journal is very important for the correct determination of static and dynamic characteristics of the bearings. The solution to this problem depends on the hydrodynamic pressure in the bearing. The numerical solution of the Reynolds equation is used to calculate the pressure. The effect of variable viscosity and density of the lubricant due to temperature changes is considered. The results of static equilibrium position are shown for specific lemon bore bearing.*

Keywords: Journal bearing, Cylindrical and lemon bearing, Reynolds equation, Energy equation, Static equilibrium

1. Introduction

A specific power of rotational machines has been growing, thus the angular speed of their rotors has been increasing. Rotordynamic analyses are therefore needed to design these devices properly. However, rotordynamics is strongly influenced by the dynamic characteristics of rotors supports. They are spring and damping coefficients of used bearings. These coefficients can be determined computationally, but static equilibrium position of journal centre is there needed.

This paper describes the computing of static equilibrium position of journal hydrodynamic bearings. It is focused on cylindrical and lemon bore hydrodynamic bearings. For this purpose, an algorithm in numerical library NumPy has been created to find the equilibrium position for certain inputs of bearings dimensions, loads and angular speeds.

The static characteristics of hydrodynamic bearings depends mainly on hydrodynamic pressure in thin lubricating film. This film is formed between a rotating shaft and a bearing bush due to the hydrodynamic effect. Since the pressure in lubricating gap is described by Reynolds equation, the computational algorithm is based on its numerical solution. The solution of Reynolds equation depends, inter alia, on viscosity and density of the lubricant. The difficulty is that these quantities are temperature dependent and the temperature within lubricant film is concurrently dependent on the pressure in there. For this reason, energy equation is solved simultaneously with Reynolds equation.

Pressure and temperature field within lubrication film can only be solved for certain position of journal centre. However, this position is not known a priori, actually, the static load and the speed of the journal are known. The consequence is that static equilibrium position of the journal centre must be found. In other words, it is necessary to find a position of the journal in which the equilibrium between hydrodynamic forces and external load is achieved.

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2. Theory

2.1. Pressure distribution

Pressure distribution in the hydrodynamic bearing is described by Reynolds equation. Scheme of the cylindrical bearing with the used coordinate system is depicted in Fig. 1. (Harnoy, 2003)

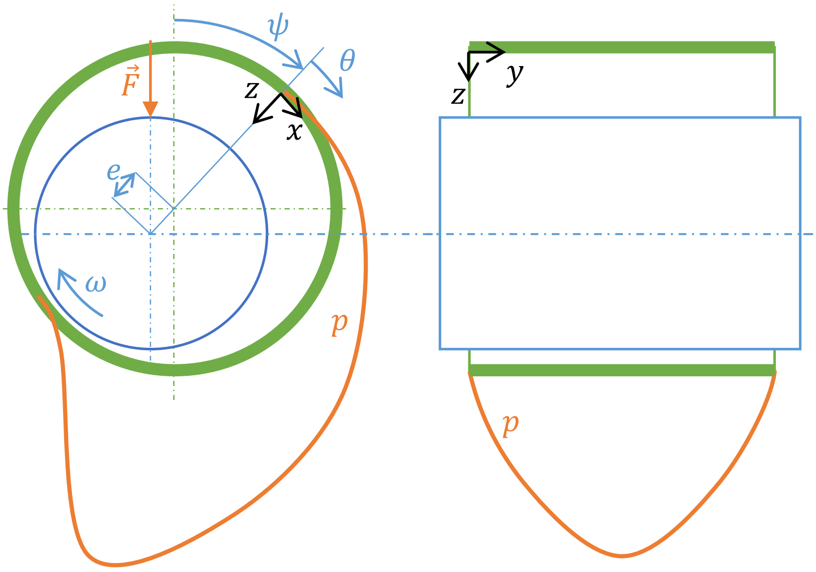

Fig. 1 *Pressure wave in cylindrical hydrodynamic bearing, used coordinate system.*

The general 2D Reynolds equation for incompressible and static lubrication can be written as follows (Huang, 2013):

$$\frac{\partial}{R^2\partial\theta}\left(\frac{\rho h^3}{\eta}\frac{\partial p}{\partial\theta}\right)+\frac{\partial}{\partial y}\left(\frac{\rho h^3}{\eta}\frac{\partial p}{\partial y}\right)=6U\frac{\partial(\rho h)}{R\partial\theta} \tag{1}$$

The equation (1) consider variable viscosity and density of the lubricant in axes θ, y. For solving purposes dimensionless Reynolds equation is used (Pokorný, 2018):

$$\frac{\partial}{\partial\theta}\left(\frac{H^3\rho^*}{\eta^*}\frac{\partial P}{\partial\theta}\right)+\alpha\frac{\partial}{\partial Y}\left(\frac{H^3\rho^*}{\eta^*}\frac{\partial P}{\partial Y}\right)=\frac{\partial(\rho^* H)}{\partial\theta} \tag{2}$$

where R is the journal radius, $Y = y/b$ is the axial dimensionless coordinate, b is the bearing width, coefficient $\alpha = (R/b)^2$, the dimensionless pressure $P = pc^2/6U\eta_0 R$, c is the radial clearance, U is the sliding velocity, $H = h/c$ is the dimensionless film thickness, h is the film thickness, $\eta^* = \eta/\eta_0$ is the dimensionless dynamic viscosity, $\rho^* = \rho/\rho_0$ is the dimensionless density.

2.2. Temperature distribution

Solution of temperature distribution in bearing is based on the energy equation. In a lubrication calculation, the energy equation can be written as (Huang, 2013):

$$q_\theta\frac{\partial T}{R\partial\theta}+q_y\frac{\partial T}{\partial y}=\frac{\eta U^2}{J\rho c_p h}+\frac{h^3}{12\eta J\rho c_p}\left[\left(\frac{\partial p}{R\partial\theta}\right)^2+\left(\frac{\partial p}{\partial y}\right)^2\right] \tag{3}$$

where flow rates $q_\theta = \frac{Uh}{2}-\frac{h^3}{12R\eta}\frac{\partial p}{\partial\theta}$ and $q_y = -\frac{h^3}{12\eta}\frac{\partial p}{\partial y}$, J is the mechanical equivalent of heat, c_p is the specific heat of the lubricant.

In the temperature calculation, the energy equation should be also dimensionless (Pokorný, 2018):

$$\frac{\partial T^*}{\partial\theta}=\frac{1}{Q_\theta}\left\{-Q_y\frac{\partial T^*}{\partial Y}+\frac{2\eta^*}{H\rho^*}+\frac{6H}{\eta^*\rho^*}\left[\left(\frac{\partial P}{\partial\theta}\right)^2+\alpha\left(\frac{\partial P}{\partial Y}\right)^2\right]\right\} \tag{4}$$

where dimensionless flow rates $Q_\theta = \frac{H}{2}-\frac{H^3}{2\eta^*}\frac{\partial P}{\partial\theta}$ and $Q_y = -\frac{H^3}{2\eta^*}\frac{R}{b}\frac{\partial P}{\partial Y}$, dimensionless temperature $T^* = \frac{2J\rho_0 c_p c^2}{Ul\eta_0}T$, ρ_0 is the initial density of the lubricant, η_0 is the initial dynamic viscosity of the lubricant.

2.3. Journal equilibrium position

For the calculation of static equilibrium position of the journal, it is necessary to solve the Reynolds equation (2) simultaneously with the energy equation (4). In the case of finite length journal bearings, these equations must be solved numerically, therefore finite difference method is used. (Tiwari, 2018) The solution domain is divided into a discrete node network. Owing to this, lubricant temperature can change in every single node and can affect viscosity and density of the lubricant. That is the reason why the coupled system of equations (2) and (4) is solved repeatedly until the steady state is reached.

It is also important to consider the mixing of hot and cold lubricant supplied from the oil grooves. Journal bearings with the oil grooves are actually made up of a number of pads arranged in tandem. (Heshmat and Pinkus, 1986) Hot oil emerges from an upstream pad and mixes with the cold supplied oil and then continues to the leading edge of downstream pad.

As soon as the solution of the steady state is obtained, temperature influenced pressure field is integrated over the solution domain to gain force resultant $\vec{W}$ as depicted in Fig. 2.

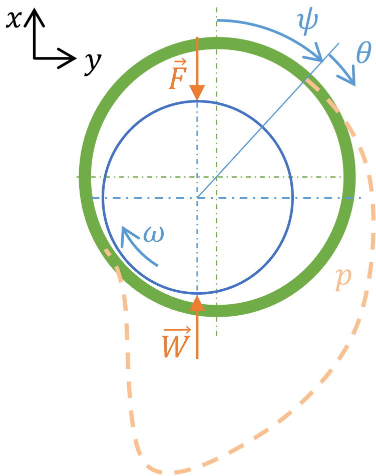

Fig. 2 *Static equilibrium position of cylindrical bearing, equilibrium between $\vec{F}$ and $\vec{W}$*

The static equilibrium position of the journal is determined clearly by the eccentricity and attitude angle magnitude. For this purpose, the bisection method can be used. (Pokorný, 2018) In case of cylindrical bearing, only one eccentricity bisection procedure is needed for determining the correct magnitude of force resultant W. Attitude angle is then assessed from the direction of force resultant. In other cases, e.g. lemon bore bearings, more bisection procedures for eccentricity and attitude angle must be done consecutively.

3. Results

Results are presented on specific lemon bore bearing because this bearing type is used in practice more often than the less stable cylindrical bearing. It has the following properties: $R = 45mm$, $b = 63mm$, $c = 0.075mm$, preload $\delta = 0.7$, $T_0 = 45°C$, $\eta_0 = 0.035Pa\ s$, $\rho_0 = 856kg/m^3$, specific load $p = 1MPa$.

Pressure and temperature profiles for this hydrodynamic bearing are depicted in Fig. 3:

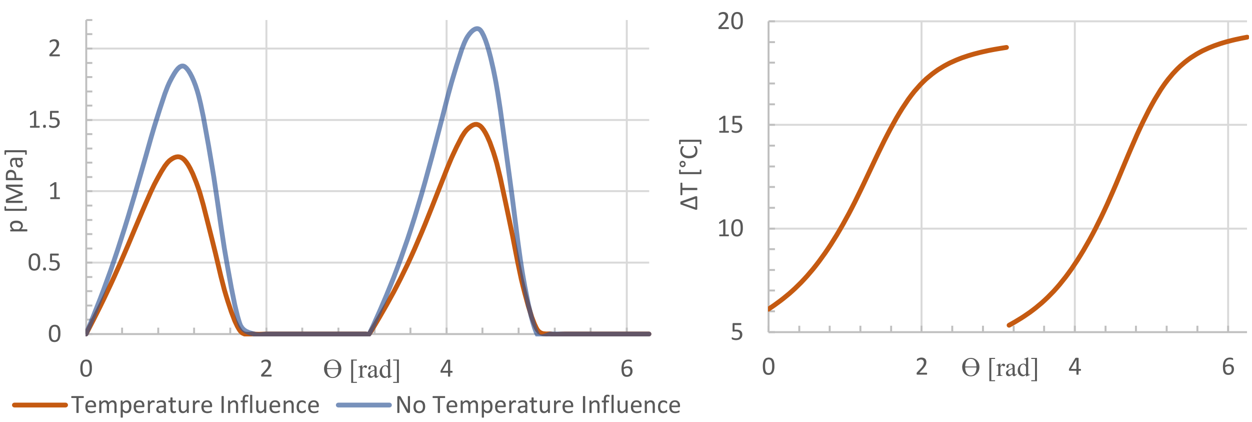

Fig. 3 *Pressure in centre plane (left), temperature change in centre plane (right), 45 000rpm*

In Fig. 3 it can be seen how the temperature changes affect the magnitude of the hydrodynamic pressure. It is worth noting that these results of pressure were not obtained for the same position of the journal but for two different equilibrium positions.

The static equilibrium position of the journal depends besides other things on angular speed. The result of this dependence for the range of 5 000 - 45 000rpm is shown in Fig. 4.

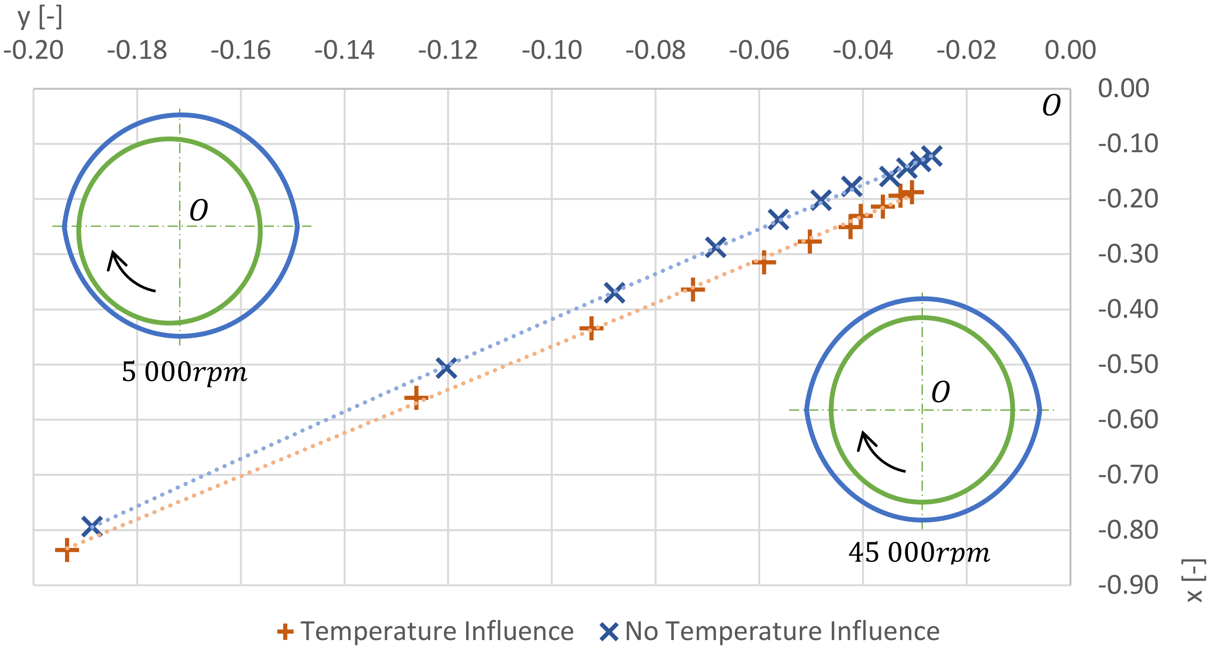

Fig. 4 *Static equilibrium position of lemon bearing, 5 – 45krpm, values divided by radial clearance*

As we can see in Fig. 4 with increasing speed the equilibrium position of the journal is closer to the bearing centre, i.e. eccentricity is reducing, while attitude angle is growing. Fig. 4 also demonstrates the difference due to considering the thermal effect. With increasing temperature, the dynamic viscosity goes down which leads to a decrease of hydrodynamic pressure. That is why the film thickness is reduced to achieve the same load carrying capacity.

4. Summary

Determination of static equilibrium position of the journal bearings is the most important part of the process of identifying its characteristics. But besides other things, it depends on the temperature changes, especially due to the exponential decrease of dynamic viscosity with temperature growth. That is the reason why thermal effects should be considered if conducting similar analyses.

In the presented paper it was considered varying viscosity and density of the lubricant in circumferential and axial direction owing to the implementation of dimensionless quantities η^* and ρ^* into Reynolds equation. These quantities were obtained using energy equation and process of mixing hot and cold lubricant. The bisection method was then used to find the static equilibrium position.

Future work will involve computing dynamic characteristics of mentioned hydrodynamic journal bearings and extending the computational algorithm to tilting-pad journal bearings geometries.

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