Integrated Fluid-Structure Interaction Simulations of Gas Foil Bearing Performance

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#The presenting author, a Ph. D. candidate from Tsinghua University, researches in the gas foil bearing applications.

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Abstract

Oil-free gas foil bearings have always been attractive in the high-speed lightly-loaded applications because of its simple and effective design. Compliance of bump foil with the interaction of top foil triggers the rotor to levitate at the high rotational speeds separated by air pressure. Many researches established frameworks to simplify the relationship of foil structure reaction under an unequal pressure generation along the bearing circumference. However, there is a lack of evidence to evaluate the proper model with an appropriate parametric case studies. In this study, the connections between the hydrodynamic pressure in the bearing clearance and the foil assemblies are made by a coupled fluid-structure interaction (FSI) model to predict the optimum performance of the journal bearing. Input parameters such as eccentricity ratio and an attitude angle are applied to the initial journal position in order to capture the pressure distribution, foil deflection and load carrying capacities which were vital parameters in the performance of the rotor-bearing system. Case studies are carried out for different journal speeds and loading states to picture the bearing performance. The predicted values coincide with the published experimental data and indicate reasonable outcome.

Introduction

Gas foil bearing (GFB) is a type of fluid film bearings that use the ambient gas to form the hydrodynamic

Advantages over conventional bearings:

- Operate at extreme temperatures and rotational speeds;
- Offer improved damping and stability characteristics;
- Greater nominal film thicknesses for a given load;
- Require very little maintenance;
- Offer powerful weight reduction due to the lack of dependence on external components.
- And tolerance of foreign matter.

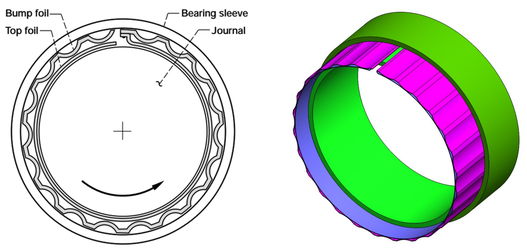


Fig. 1 Gas foil bearing assembly

GFB operate on two main principles: hydrodynamic lubrication and structural dynamics.

I. The principle of hydrodynamic lubrication in this case is where a lubricant is pulled into a converging geometry by the relative motion of two surfaces resulting in pressure generation;
II. The top foil is supported by a compliant bump foil which allows the top foil to deflect in response to the pressure profile in the fluid film.

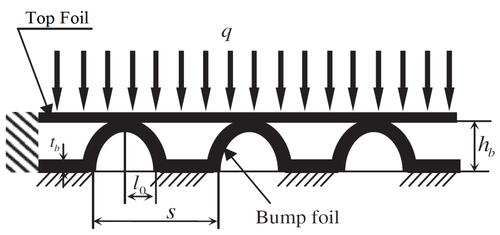


Fig. 2 Configuration of bump foil

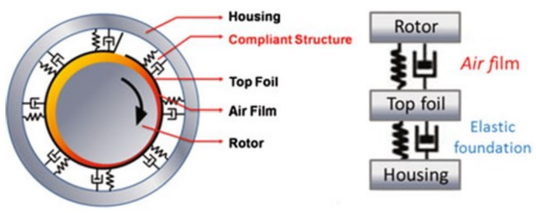


Fig. 3 Gas film and bump foil interaction

Fluid-Structure Interaction Model

Integrated model of GFB involves the coupled solution of hydrodynamic pressure in the radial clearance and foil deflections by the means of iterative scheme.

Fluid-Structure Interaction (FSI) model is widely used to predict a fully coupled solution of GFB, and are looped through repeatedly until overall equilibrium is reached between the structural FEM and fluid CFD solutions.

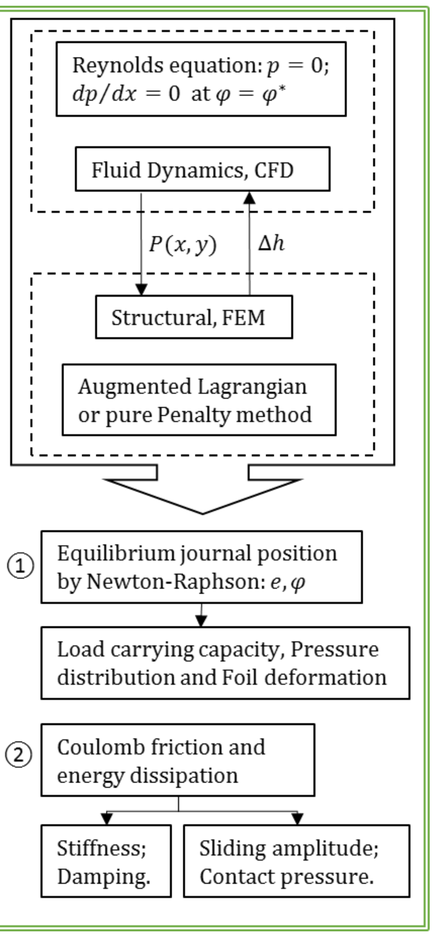


Fig. 4 Numerical procedure of FSI model

Governing Equations

- *Film pressure.* Assuming no slip at the fluid-surface interface, isothermal conditions, and time invariant lubrication, the compressible Reynolds equation in Cartesian coordinates can be written as:

$$\frac{\partial}{\partial x}\left(ph^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(ph^3\frac{\partial p}{\partial z}\right)=6\mu\omega R\frac{\partial(ph)}{dx}$$

- *Film thickness*. The film thickness h is given in the following:

$$h = c + x\cos\theta + y\sin\theta + w_D = c + e\cos(\theta-\varphi) + w_D$$

where

$$w_D = K_B(p - p_0)$$

Eccentricity ratio is defined as: ε=e/c. Elastic deformation of the foil structure is given as w_D, and φ is known as an attitude angle.

- *Bump stiffness.* K_B signifies the compliance or the structural rigidity of the bump foil, which is defined as:

$$K_B = \frac{2S}{E}\left(\frac{l}{t_B}\right)^3(1-\nu^2)$$

- *Load Capacity.* Resulting load components from the film pressure development parallel and perpendicular to the crossing line of bearing-journal centers are obtained by:

$$\begin{cases} W_x = 2\int_0^{\pi}\int_0^{L/2} pR\sin\theta\, d\theta dz \\ W_y = -2\int_0^{\pi}\int_0^{L/2} pR\cos\theta\, d\theta dz \end{cases}$$

Subsequently, total load-carrying capacity is generated by:

$$W = (W_x^2 + W_y^2)^{1/2}$$

Problem Definition

Description of GFB. Foils are welded from the one end to the bearing sleeve in the trailing edges while the leading edges remain free. Top foil covers the journal with a circumference of 355°. Equally positioned 26 corrugated bump strips support the top foil underneath, thus making the bearing fully compliant. Foil structure material is made of a thin Inconel X-750 nickel-chromium alloy which is used for its high strength in the elevated temperatures up to 704°C. Given parameters of GFB in Table 1 are obtained from the experimental work of Ruscitto et al. 1978.

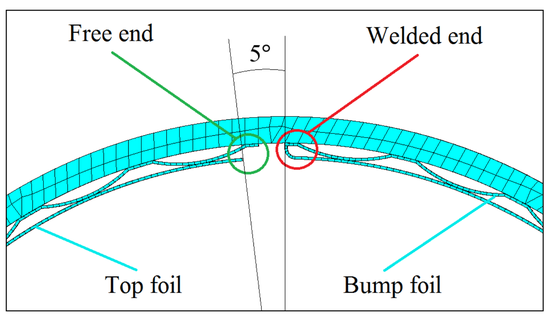


Fig. 5 Connection between foils and housing

Table 1. Design parameters of GFB

Parameters	Values
Bearing	
Radius, D=2R	38.1mm
Length to diameter ratio	L/D=0.5, 1
Radial clearance, c	31.8μm
Foils	
Top/Bump foil thickness, t_T, t_B	0.1016mm
Bump length, l_B	3.556mm
Bump pitch, S	4.572mm
Bump height, h_B	0.508mm
Young`s modulus, E	214GPa
Poisson's ratio	0.29

- Results are obtained for 3D fully coupled FSI model in the various length-to-diameter bearing ratio L/D=0.5, 1 and journal speeds at 30,000 rpm, 45,000rpm;
- A structured mesh with total number of nodes 3.96×10^5 is used for both fluid and solid domains;
- Initial parameters to start hydrodynamic process in the film thickness are taken by guessing eccentricity ratio and attitude angle and extracted loads are mapped to the structural domain;
- Pressure generations, film thicknesses and load-carrying capacities of the bearing are studied in different loading conditions (up to 200 N) and working operations.

Simulated results and discussion

Solver: ANSYS Workbench System Coupling environment (ANSYS Mechanical + FLUENT)

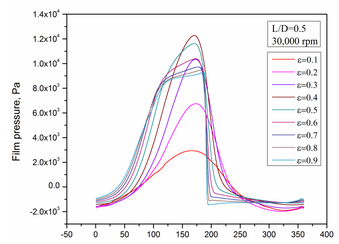


Fig. 6 Pressure distribution

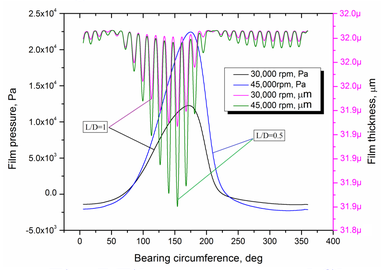


Fig. 7 Film pressure and film thicknesses for e/c=0.4

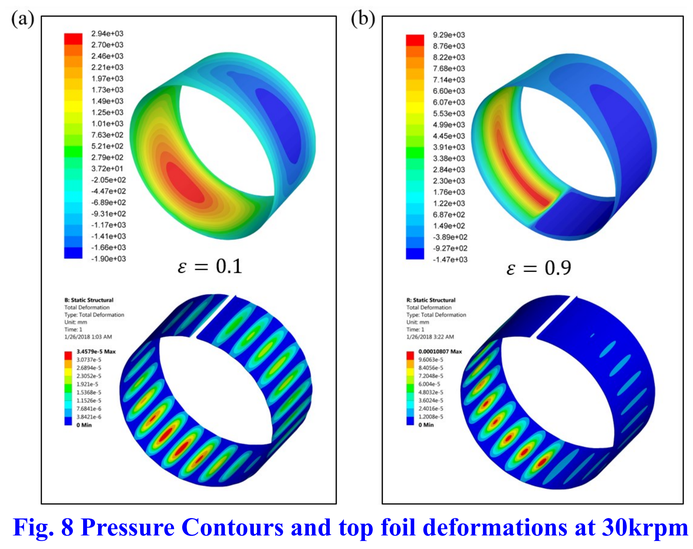


Fig. 8 Pressure Contours and top foil deformations at 30krpm

Comparative study (Fig. 9 - Fig. 12):

1. Ruscitto et al. 1978 - experimental data.
2. Strom, 1987 - experimental data.
3. Peng and Khonsari, 2004 - Theoretical.

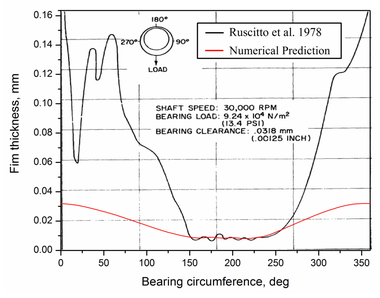


Fig. 9 Film thickness. Load is 134.1 N.

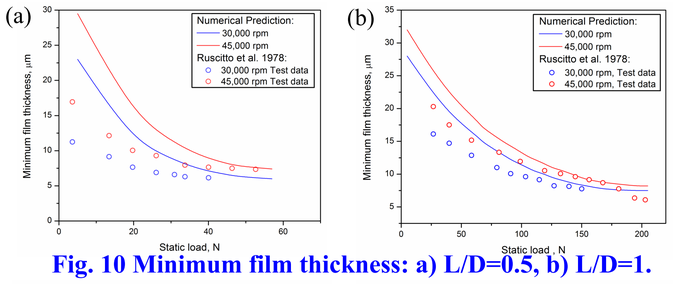


Fig. 10 Minimum film thickness: a) L/D=0.5, b) L/D=1.

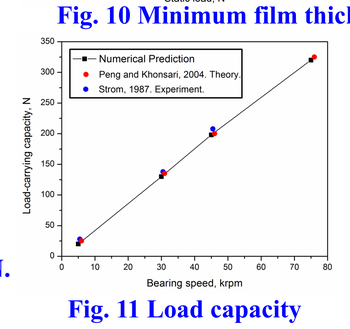


Fig. 11 Load capacity

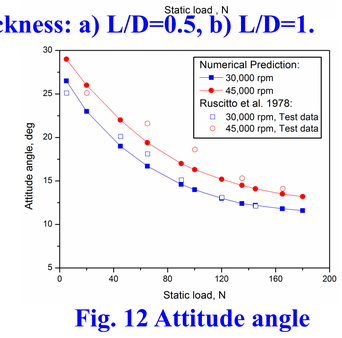


Fig. 12 Attitude angle

Conclusions

- Integrated coupled model of the gas foil bearing is developed by utilizing sophisticated FSI technique through the iterative solving method for the Reynolds equation and structural deformation;
- The steady-state analysis is conducted for the different parametric cases accounting for the film pressure distributions, film thicknesses, load-carrying capacity and an attitude angle;
- The validation of the simulations is carried out to certify the reliability of the numerical codes by examining with the published experimental data in Ruscitto et al. 1978, and results are in good agreement with slight differences due to the simplifications in the computational process;
- It is clearly observed that the film pressure and load-carrying capacity of the bearing is influenced by the eccentricity ratio, angular velocity and L/D ratio of the bearing;
- Greater load-carrying capacity is due to the higher values of the eccentricity ratio at the higher speeds;
- As the load and speed increased the film thickness is increased with the relatively small attitude angle.