Integrated Fluid-Structure Interaction Simulations of Gas Foil Bearing Performance

Ibrohim Rustamov#, Zixi Wang*, Yuming Wang
Department of Mechanical Engineering , Tsinghua University, Beijing 100084, China
Email: ibrohimru@yahoo.com, zxwang@tsinghua.edu.cn*.
#The presenting author, a Ph. D. candidate from Tsinghua University, researches in the gas foil bearing applications.

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Introduction

Gas foil bearing (GFB) is a type of fluid film bearings that use the ambient gas to form the hydrodynamic wedge between the journal and a compliant foil structure.

Advantages over conventional bearings: operate at extreme temperatures and rotational speeds, offer improved damping and stability characteristics, require very little maintenance and offer powerful weight reduction due to the lack of dependence on external components.



Fig. 1 Oil-free turbocharger

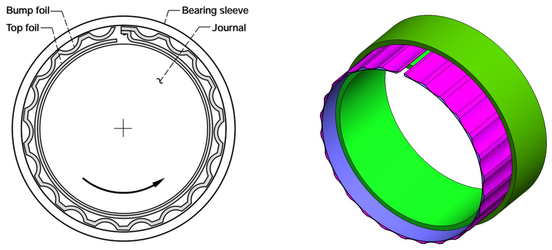


Fig. 2 Gas foil bearing assembly

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.

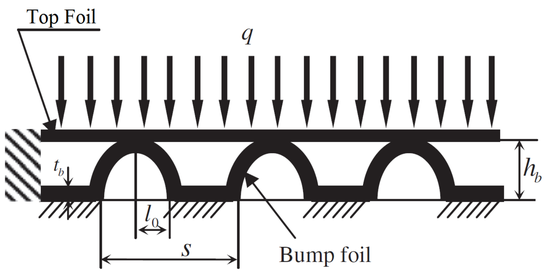


Fig. 3 Configuration of bump foil

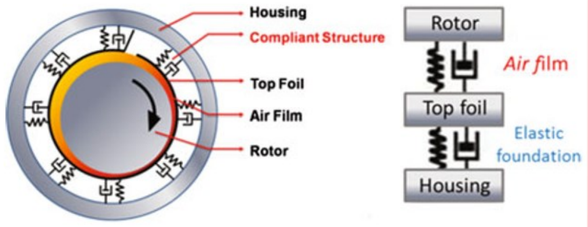


Fig. 4 Gas film and bump foil interaction

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, assuming:
a. Top foil as a shell structure between gas film and elastic foundation;
b. Bump foil as an elastic foundation which supports top foil;
c. Gas film as a laminar and isothermal flow;
d. Journal and bearing sleeve as a rigid moving and stationary wall, respectively.

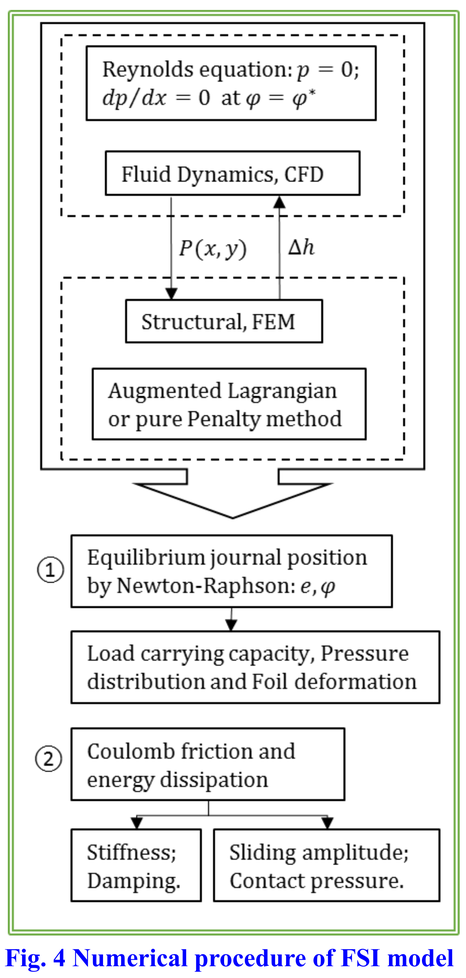


Fig. 4 Numerical procedure of FSI model

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:

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

In Reynolds boundary condition the film pressure cannot be lower than the ambient pressure (p_a), and the subambient pressure is equated to zero without violating the continuity of mass flow at the outlet end. Hence, the appropriate boundary conditions are:

$$p = \frac{dp}{dx} = 0 \quad \text{at} \quad \theta = \theta^*,\ \pi < \theta^* \le 2\pi$$

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.

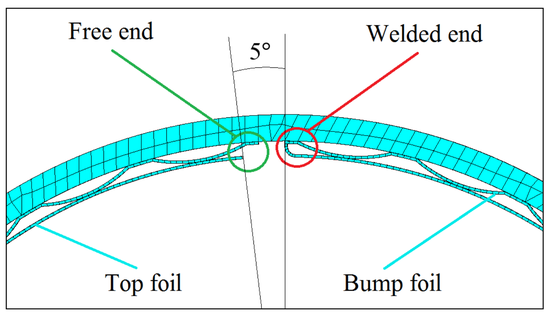


Fig. 5 Connection between foils and housing

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)

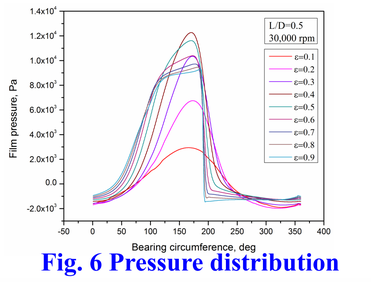


Fig. 6 Pressure distribution

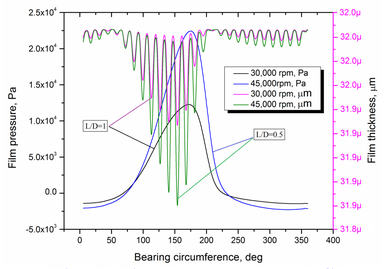


Fig. 7 Film pressure and film thicknesses for e/c=0.4

Comparative study (Fig. 9 - Fig. 12):
1. Ruscitto et al. 1978 - experimental data.
2. Strom, 1987 - experimental data.
3. Peng and Khonsari, 2004 - Theoretical.

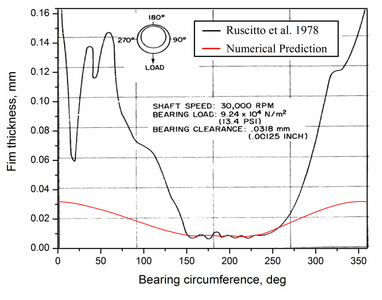


Fig. 9 Film thickness. Load is 134.1 N.

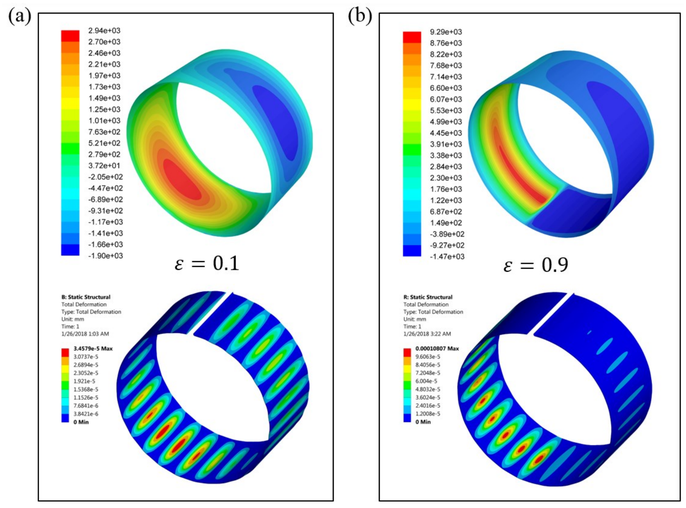


Fig. 8 Pressure Contours and top foil deformations at 30krpm

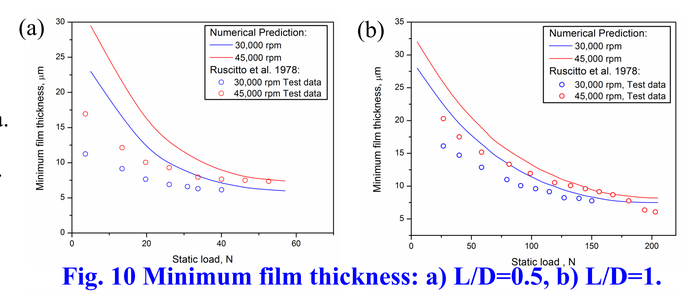


Fig. 10 Minimum film thickness: a) L/D=0.5, b) L/D=1.

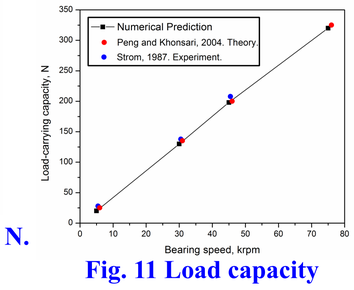


Fig. 11 Load capacity

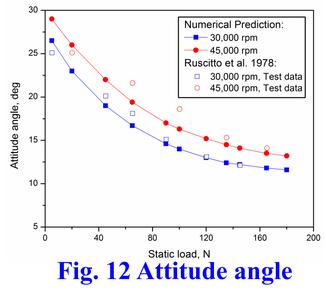


Fig. 12 Attitude angle

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.