Investigation of Journal Gas Foil Bearing Characteristics with Foils Prestress from Assembling Taken into Account

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Abstract. Investigation of journal gas foil bearing characteristics with foils prestress due to its installation into the bearing race with pretension is performed on the base of two-dimensional finite element model with contact interaction between bearing elements taken into account and verified versus static experimental data for nonrotating shaft taken from the open sources. Finite element simulation results show a good agreement with experimental and analytical data. Influence of top foil prestress due to its installation into the bearing race with pretension on bearing static elastic characteristics is demonstrated on the base of finite-element simulations considering light (top foil radius is close to the shaft journal radius) and strong (top foil radius is much greater than the shaft journal radius) top foil prestress.

Keywords: gas foil bearing · elastohydrodynamic contact

1 Introduction

Gas foil bearing (GFB) characteristics for constant gas film layer parameters and rotor rotational frequency are determined by shaft journal displacement with respect to the bearing race and foil deformations. Foil bearing structure comprises top foil, supported by the corrugated damper that is attached with one end to the bearing race (Fig. 1). Hence foil bearing structure comprises several elastic elements that affect its stiffness characteristics. Foil bearing elastic properties depend on its elastic element parameters (top foil and corrugated damper geometry, number of bumps and pads). Foils may be installed prestressed within the race to provide desired bearing load and proper foil-damper contact over the whole bearing with the peculiarities of the assembly process and foil-race attachment features taken into account. Herewith initial foil curvature may not be concentric with the race and shaft journal.

First models describing GFB elastic deformations have been proposed by H. Heshmat and R. Ku [1, 2] and I. Iordanoff. [3]. Both models were analytical (based on approximating equations) and considered top foil supported by the uniform [1, 2] or linearly non-uniform [3] elastic foundation. Later and R. Ku [4] and H. Heshmat [4, 5] studied flat bump strip and complete GFB static elastic characteristics experimentally

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and verified suggested analytical models with experimental data. Several GFB characteristic features were indicated as a result of those experimental investigations, such as elastic anisotropy and elastic hysteresis due to the friction produced in the contact zones between GFB elastic elements.

A decade later D. Rubio and L. San Andres [6], S. Le Lez and M. Arghir [7], K. Feng and S. Kaneko [8] and recently J. Viera and S. Diaz [9], J. Larsen and A. Varela [10] developed more accurate equivalent spring, link-spring and FE models for theoretical prediction of GFB static elastic characteristics and carried out similar experiments that proved suggested models accuracy. These studies indicated that bump interaction not taken into account by analytical models is of a considerable influence on GFB elastic properties.

Recently A. Fatu and M. Arghir [11] evaluated manufacturing errors impact on the GFB structural stiffness using 2D FE bearing model. The obtained results demonstrated another valuable aspect that affects GFB performance.

All these and many other studies made through the last half-a-century provided a wide range of theoretical and experimental data for GFB performance analysis. However there are still some problems remaining understudied. Influence of GFB elastic elements prestress on its elastic characteristics due to the top foil installation into the bearing race with pretention is one of them. M. Mahner et al. [12, 13] studied prestress effect in 3-pad air foil journal bearing using 1D beamshell model based on Reissner finite-strain beam theory. The obtained results demonstrated considerable influence of the prestress condition on bearing static elastic characteristics. Presented manuscript investigates preload effect in 1-pad 38.1 mm diameter air foil journal bearing, which is considered repeatedly in a number of studies [6–8, 14], using two-dimensional plane strain FE model.

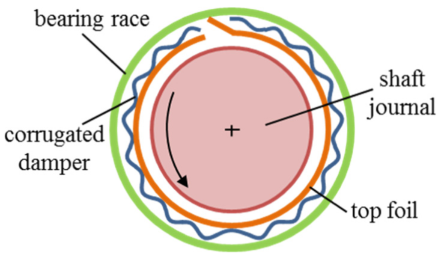


Fig. 1. Gas foil bearing

Gas foil bearing elastic properties are anisotropic and depend on shaft journal displacement direction. That anisotropy is provided not only by the foil attachment location with respect to the shaft journal displacement direction, but also by the foils prestress provided during its assembly process. That effect is confirmed by the results of the bearing static stiffness experimental investigations [4, 5, 11–13]. Foils deformation and contact interaction math model determine fluid film thickness accuracy during calculations and hence has an influence on the accuracy of bearing elastic characteristic calculations. Therefore verification of foil contact interaction models with their prestress determined by the foils geometry before and after shaft journal installation into the bearing is one of the relevant problems of gasdynamic bearing simulations. Foil bearing elastic characteristics are determined on the base of the GFB model schematically shown in Fig. 2 that considers static contact interaction between the shaft journal and GFB elastic elements.

2 Model of Foil Deformations

Gasdynamic bearing design is a multidisciplinary problem that requires the coupled calculation of the gas film flow parameters in the gap and foil elastic deformations [1–11]. Multidisciplinary gas bearing model used for its elastic characteristics calculation was represented previously in [15–17]. Contact interaction between shaft journal and bearing through the gas film layer may be simulated with different models (2D, 3D) depending on elastic elements geometry and structure. Foil deformations are determined by plane (2D) foil bearing model based on the plane strain theory and taking contact interaction between shaft journal, top foil, corrugated damper and bearing race into account (contact zones 1, 2 and 3, respectively – see Fig. 2). Elastic Coulomb friction is assumed in both contact zones with 0.1 friction coefficient value [7].

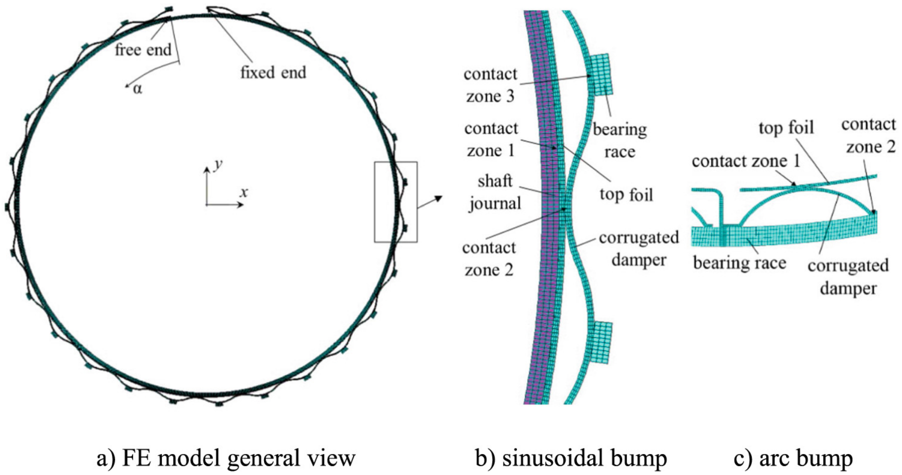


Fig. 2. Foil bearing finite element model

Bearing static elastic characteristics are determined for different shaft journal displacement directions. Calculations are carried out for two shapes of corrugated damper: arc bumps (the most widespread form of the bumps) [1–11] (Figs. 2c, 3a) and sinusoidal bumps [18] (form of the bump, that is easier for manufacturing – see Fig. 2b, 3b). GFB dimensions are taken from [7] and represented in Table 1. Sinusoidal bump parameters are taken with respect to the ones of the arc bump (See Fig. 3).

Foils prestress is provided by simulation of the bearing assembly process. At that radius of foil curvature is different from shaft journal and bearing radius. Foil prestress due to its installation into the bearing is modelled with special loading applied to the row of the top foil damper side elements (Fig. 4b). Two special loading cases are considered

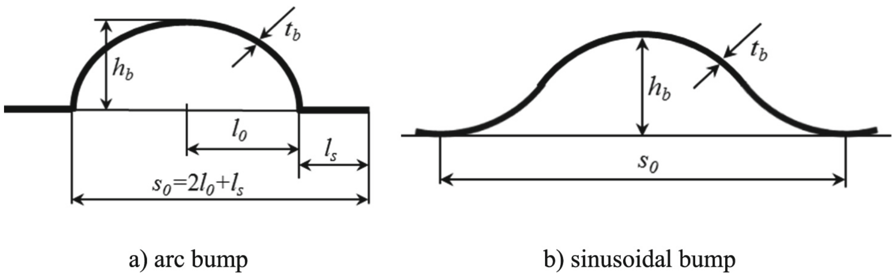


Fig. 3. Bump geometry

Table 1. GFB parameters

Bearing axial length, mm	38.1
Shaft journal diameter, mm	38.1
Nominal radial gap, μm	31.8
Number of bumps	26
Top foil thickness, mm	0.1016
Corrugated damper thickness t_b, mm	0.1016
Bump height h_b, mm	0.508
Bump pitch s_0, mm*	4.572
Arc bump half-length l_0, mm	1.778
Distance between adjacent arc bumps l_s, mm	1.016

* - bump pitch for particular damper type is determined as per Fig. 3a, b.

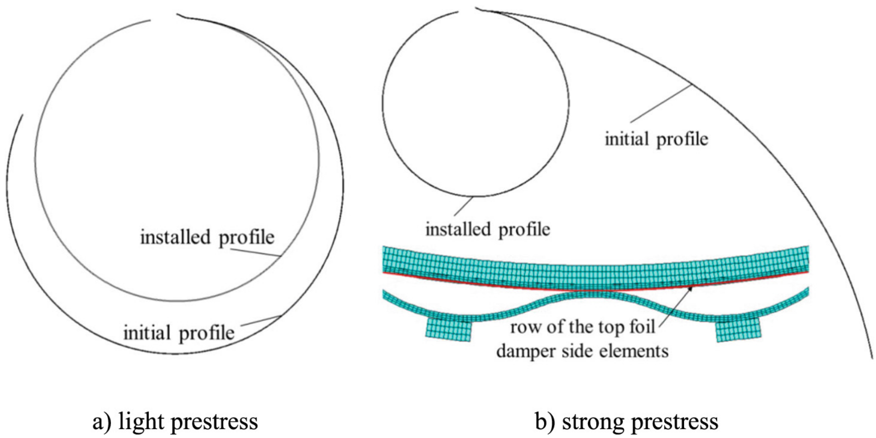


Fig. 4. Top foil prestress modelling

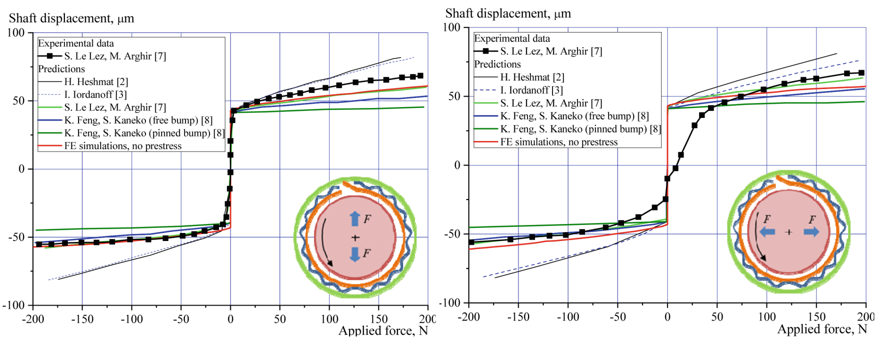
for modelling strong and light top foil prestress. Top foil initial profiles are shown in Fig. 4. Terms “light prestress” and “strong prestress” are terms introduced to describe two marginal top foil shapes:

– light prestress: top foil initial curvature is almost the same as bearing radius;
– strong prestress: top foil initial curvature is close to straight line.

Foil deformations are calculated in two loadsteps. On the first loadstep special loading is applied to the row of the top foil damper side elements with the shaft remaining fixed in its central position with respect to the bearing race. Thus top foil special loading simulates its prestress due to installation into the bearing race. On the second loadstep the prestressed bearing is loaded by the contact interaction with the shaft journal. Load is applied to the shaft in the certain direction. That simulates bearing elastic element deformations from the action of the supported shaft halfweight.

3 Calculation Results and Verification with Experimental Data

Bearing elastic characteristics are determined experimentally and represented in [6, 7] for 38.1 mm diameter bearing. Finite element model simulations presented hereafter are carried out for the same bearing structure basing on that experimental data. Foil bearing static elastic characteristics are represented in Fig. 5 in comparison with prediction and experimental data for the corresponding shaft displacement direction in the GFB. Developed finite element model shows a good agreement with prediction and experimental data for the full shaft displacement range. Nominal radial clearance is clearly identified both on experimental and calculation data. One can see that FE simulations [15–17] provide the most accurate result and the best agreement with experimental data (Fig. 5). However, FE simulation results strongly depend on contact interaction accuracy parameters and hence the required calculation time is much greater in comparison with analytical models [2, 3].



a) static stiffness characteristics for downward (α≈180°) and upward (α≈360°) force direction

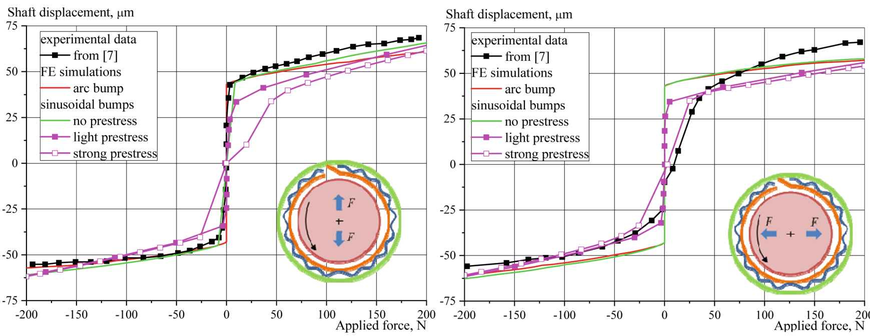
b) static stiffness characteristics for leftward (α≈90°) and rightward (α≈270°) force direction

Fig. 5. GFB elastic characteristics obtained with various prediction models

At the same time, non-zero bearing reaction exists for horizontal shaft journal displacements in the bearing according to experimental data [6, 7], that may be achieved due to the mismatch in shaft and bearing race curvature values. This effect proves foils prestress existence and necessity of its consideration in the process of calculations. Calculation results show slightly worse agreement with experimental data when foil bearing is loaded and unloaded in horizontal direction. That is caused by the smooth foil prestress during bearing assembly. At the same time good agreement between calculation and experimental data is achieved in zone of considerable loads.

Foil bearing characteristics calculated with top foil prestress (both light and strong) taken into account are represented in Fig. 6a, b. Strong prestress model shows a good agreement with the experimental data taken from [7] for leftward and rightward force direction – see Fig. 6b. Light prestress model shows a good agreement with the experimental data for downward and upward force direction – see Fig. 6a. Obtained results confirm proposed top foil prestress model usability. However, more accurate prestress modelling is required, but cannot be provided within the presented investigation due to the absence of the top foil initial geometry (undeformed shape prior to its installation into the bearing race) in [6, 7].

Total shaft journal radial displacements calculated for different top foil prestress cases are represented in Table 2. Slight GFB static rigidity growth is noted for shaft journal displacement direction varying from leftward (α≈90°) to rightward (α≈270°).



a) static stiffness characteristics for downward (α≈180°) and upward (α≈360°) force direction

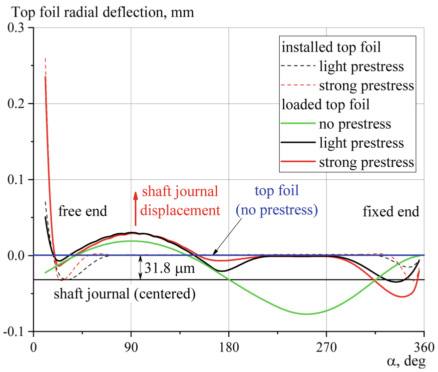
b) static stiffness characteristics for leftward (α≈90°) and rightward (α≈270°) force direction

Fig. 6. Static GFB elastic characteristics calculated for different top foil prestress cases

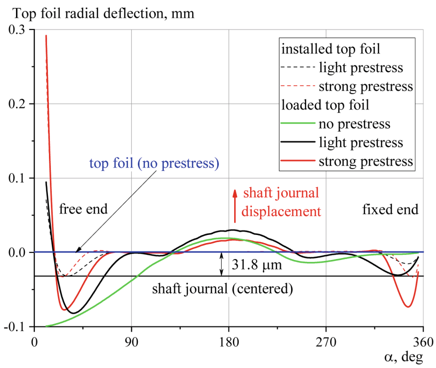
Figures 7a-d demonstrate the considerable influence of the top foil prestress on its deflections from round shape and, hence, bearing static stiffness characteristics. Top foil deflections in the area of the force application show a good agreement between the models being considered. At the same time, the considerable difference is noted in the areas, located farther from the force application one. Top foil deflections for the upward force direction considerably depend on the top foil configuration in the area of its attachment to the bearing race. Top foil stiffness in that area is much higher in

Table 2. Shaft journal total radial displacements (μm)

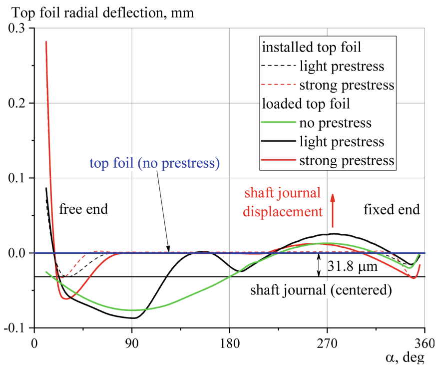
Shaft journal displacement direction	No prestress	Light prestress	Strong prestress
Leftward (α≈90°)	63	62	61
Downward (α≈180°)	62	62	62
Rightward (α≈270°)	58	56	54
Upward (α≈360°)	66	64	62



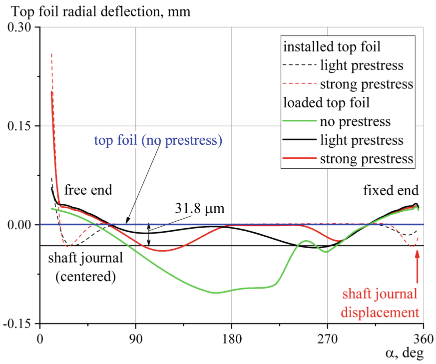
a) top foil radial deflections for the leftward (α≈90°) force direction



b) top foil radial deflections for the downward (α≈180°) force direction



c) top foil radial deflections for the rightward (α≈270°) force direction



d) top foil radial deflections for the upward force direction (α≈360°)

Fig. 7. Top foil radial deflections calculated for different top foil prestress cases

comparison with the rest of the top foil length, so relatively poor deflection distributions (see Fig. 7d) and deviations in static stiffness characteristics (see Fig. 6a) are detected.

It also may be noted that both prestress and non-prestressed models show acceptable agreement with experimental data in terms of static stiffness characteristics in general, especially within the maximum load value areas. But particular top foil deflections distribution (eventually the gap between top foil and shaft journal) will evidently affect gasdynamic pressure and, hence, bearing load when it comes to the shaft rotation. Such a problem is considered by the authors as a subject of further investigations.

4 Conclusion

Gas foil bearing prestress effect due to the top foil installation into the bearing race with pretention is investigated using FE model. Simulation results demonstrate considerable GFB prestress influence on its elastic characteristics and are of a good agreement with experimental data. Developed FE model provides multiple prestress level simulations ranging from light (top foil radius is close to the shaft journal radius) to strong (top foil radius is much greater than the shaft journal radius). Top foil deflections and, hence, gap distribution between top foil and shaft journal in the prestressed GFB considerably differs from the classic symmetrical one, that is usually may be observed between rigid rotating surfaces, and serves the base for elastohydrodynamic contact problem solution.

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