COMPUTATIONAL MECHANICS 2022
37th conference with international participation
Srní
November 7 - 9, 2022

Treatise on dynamic behaviour modelling of tilting pad journal bearing under operating conditions: From the real world to numerical simulations

J. Rendl[a], L. Smolík[a], Š. Dyk[a], R. Bulín[a], Z. Kubín[b]

[a]*NTIS, Faculty of Applied Sciences, University of West Bohemia, Technická 8, 301 00 Plzeň, Czech Republic*
[b]*Výzkumný a zkušební ústav Plzeň, Tylova 1581/46, 301 00 Plzeň, Czech Republic*

Tilting pad journal bearings, see Fig. 1a, are used to support machinery with journals of high circumferential speed. A unique design of these bearings prevents the formation of oil-induced instability and causes low sensitivity to load direction, reducing the shaft axial misalignment and is known for relatively low oil consumption [2]. The pads can tilt around the pivots with respect to the journal and the housing, see Fig. 1b.

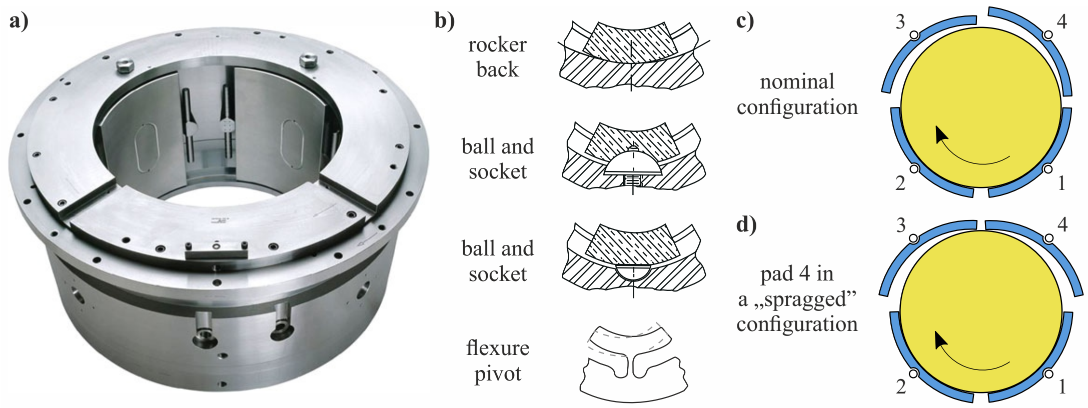

Fig. 1. (a) Tilting pad journal bearing with four pads, (b) various pivot designs, (c, d) comparison of common and abnormal operating configurations of the bearing

The pads are supplied with lubricant oil which fills the bearing gap during the operation. In the ideal case, the bearing gap has a wedge form, see Fig. 1c. Lower pads are loaded mainly by rotor mass and tend to tilt to achieve a convergent bearing gap from the leading edge. However, upper pads are loaded only by their mass and can move freely in the bearing gap [1, 2]. In this case of the unloaded pad, the leading edge can come close to the journal and form the divergent bearing gap, see Fig. 1d, due to operating conditions dependent on the preload, pad moment of inertia, volume of supplied oil, circumferential journal speed and pivot position. Furthermore, the pressure gradient disappears, and solid contact between the journal and the pad can occur. This state can be distinguished into two phenomena [1, 4]:

- Spragging – the journal and/or pad positions jump into the new positions due to rapid changes in the pressure field.

- Fluttering – repeated formation and reformation of the pressure field cause fluctuation and/or solid contact between the bearing parts, and vibrations at subsynchronous frequency occur.

Computational modelling of tilting pad journal bearing is a complex problem involving the modelling of hydrodynamic lubrication and sufficient description of the pads' motion [4]. The planar lateral motion of the pad without axial misalignment is supposed. Hence, the pad motion is described by one degree of freedom (tilting around the pivot necessary for proper tilting pad journal bearing operation). The additional degree of freedom (radial) can be added to consider the radial pivot flexibility under the loading transferred through the oil film.

A load of the individual pad is mainly given by pad preload and can be considered different for separate pads. The spragging or fluttering phenomena can occur in case of improperly chosen preload, mainly for upper pads. Then, the bearing clearance can disappear and the modelling of solid contact between the part based on Hertz contact theory must be taken into account.

The pressure distribution in the bearing gap is given by the Reynolds equation. The laminar or turbulent flow is distinguished based on the Reynolds number, which involves the bearing dimensions and operating conditions. Developed hydrodynamic pressure acts on the bearing parts by the hydrodynamic force determined by pressure integration over the pad surface. It is a nonlinear force coupling. A slight change of resultant force sets the pad into motion. Pressure distribution is influenced by the relative position of the pads and the journal. Another aspect of the bearing modelling is the thermodynamics in the lubricant flow, which affects the dynamic viscosity of the lubricant and cavitation.

The friction in the pivots, mainly in the ball-and-socket coupling, can be considered, and the stick and slip phases of the pad can further occur. The friction has a negative role on the pad tilting behaviour, and the global bearing behaviour can be close to the bearing with fixed geometry. The most used friction models are the Bengisu-Akay model and the Lugre model [3]. Both models are susceptible to the control parameters, and it is necessary to focus more on their establishment during the modelling.

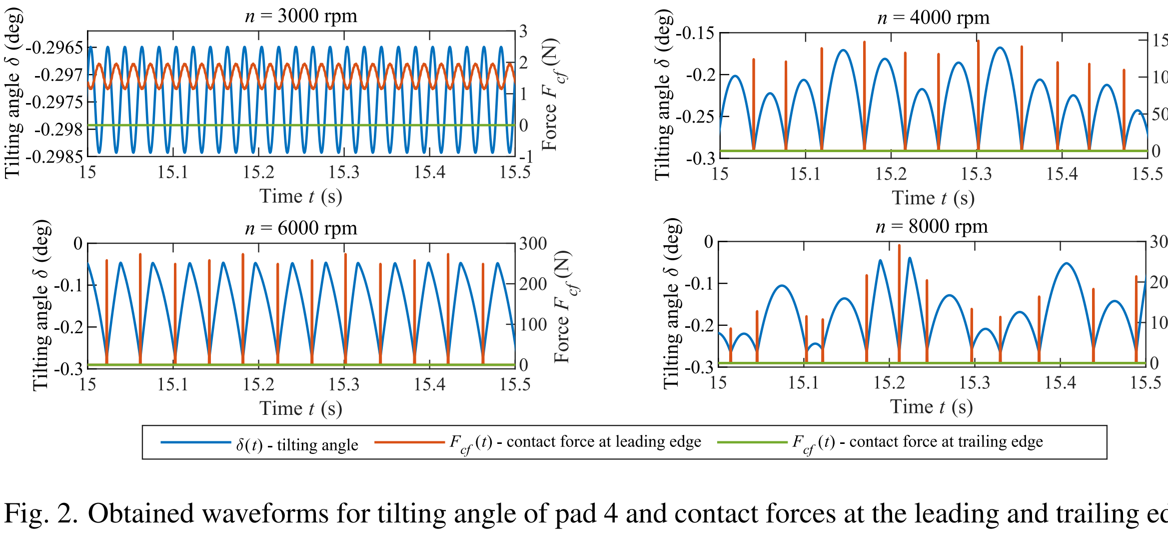

Fig. 2. Obtained waveforms for tilting angle of pad 4 and contact forces at the leading and trailing edges

Obtained waveforms from the steady-state simulations [4] of the unbalanced rotor supported by the four-pad tilting pad journal bearing in the configuration load-between-pads are depicted in Fig. 2. The figure contains the tilting angle of a lightly loaded upper pad 4 (Fig. 1) and contact force at the leading and trailing edges for various rotor speeds. The pad lies on the rotor for a speed of 3000 rpm, and the contact force fluctuates due to journal vibrations. For higher rotor speeds, the pad tilts out of the journal and repeatedly hits the journal, see the force impulses at the leading edge. The tilting angle becomes irregular or chaotic due to pad hits and changing operating conditions. The contact at the trailing edge is secured by hydrodynamic force from the newly reformated pressure gradient during the pad tilting. The solid contact at this edge does not occur.

Long-lasting operation with undesirable phenomena has a negative impact on the durability of the affected pad. The main problem is the damage at the place of contact between the pad and the journal [1]. It is the leading edge of pad 4 along the whole axial length. This damage is apparent in illustrative Fig. 3. This failure progress to 1/3 of the pad surface in the journal rotation direction. Repeated impacts negatively affect durability due to the development of cracks and the cover layer can disappear [1], see Fig. 3. Operating diagnostics of undesirable phenomena is quite tricky. Distinguishing of the phenomena during the operation is dependent only on sensors capturing the relative and absolute bearing pedestal vibrations. The sensors measuring the tilting angle are not usually installed, and the pad's spragging and fluttering are not directly detectable.

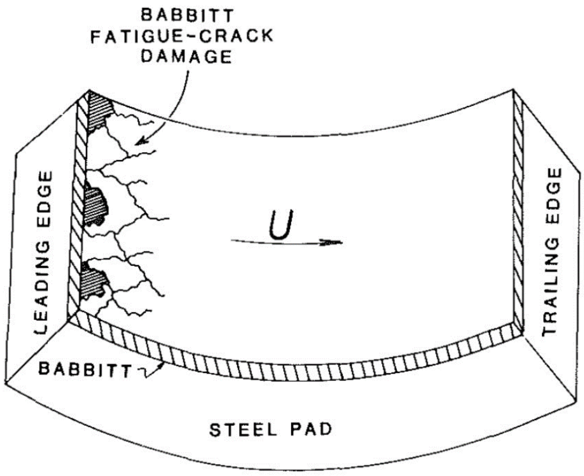

Fig. 3. Illustrative scheme of Crack failure development at the leading edge of the pad [1]

Acknowledgement

This paper was supported by the Technology Agency of the Czech Republic under the THETA Programme within the TK04020057 project.

References

[1] Adams, M. L., Payandeh, S., Self-excited vibration of statically unloaded pads in tilting-pad journal bearings, Journal of Lubrication Technology 105 (3) (1983) 377-383.

[2] Dmochowski, W. M., Dadouche, A., Fillon, M., DeCamillo, S. M., Hydrodynamic tilting-pad journal bearings, In: Encyclopedia of tribology, Q. J. Wang, Y.-W. Chung (eds), Springer, New York, 2013, pp. 1749-1757.

[3] Marques, F., Flores, P., Claro, J. C. P., Lankarani, H. M., A survey and comparison of several friction force models for dynamic analysis of multibody mechanical systems, Nonlinear Dynamics 86 (3) (2016) 1407-1433.

[4] Rendl, J., Dyk, Š., Smolík, L., Nonlinear dynamic analysis of a tilting pad journal bearing subjected to pad fluttering, Nonlinear Dynamics 105 (2021) 2133-2156.