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Air Bearings for High-Speed Applications: A Viable, Clean Solution

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Abstract - This paper will first give an overview of the various applications domains of high-speed gas bearings, with a special focus on newly emerging and sustainable applications. The stability problem is outlined after which various stabilising strategies are discussed in detail. Before considering solutions to this stability problem, it might be interesting to determine its underlying mechanism and to investigate how and to what extent the different rotor-bearing parameters affect the situation

1. Introduction

High-speed air bearings offer very specific advantages over other, more conventional bearing technologies. Gas-lubricated bearings present an oil-free solution characterised by virtually wear free operation and low frictional losses. These advantages turn them into a clean and environment friendly bearing solution for various high-speed applications such as optical scanning equipment and machine tool spindles for PCB-drilling and micro-milling. Newly emerging application domains concern micro gas turbines for combined heat and power generation (CHP) at a household scale and efficient oil-free heat pumps.

However, the principal drawback involved in the application of high-speed air bearings concerns the dynamic stability problem. A sound understanding of this problem in combination with the application of effective stabilising strategies are therefore required in order to enable the successful application of air bearings as a viable, clean bearing solution for newly emerging application domains.

Application Domains

High-speed bearings compose a key component of an increasing number of applications such as optical scanning equipment, machine tool spindles and compact turbo machines. In the application field of tool spindles for PCB-drilling and micro-milling, the trend towards smaller tool diameters pushes the limits of the spindle technology towards higher rotational speeds.

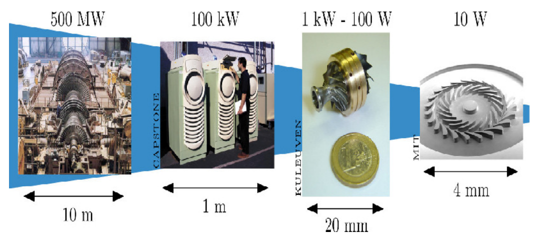

Figure 1. Downscaling trend observed in gas turbines for power generation.

In the turbo machinery domain, there exists a trend towards oil-free bearing solutions and downscaling (Figure 1). Newly emerging application domains concern micro gas turbines for combined heat and power generation (CHP) at a household scale, efficient oil-free heat pumps and PEM fuel cells.

2. Stability Analysis

The occurrence of dynamic instabilities in the form of sub synchronous self-excited whirling very often limits the maximal attainable rotational speed of the rotor-bearing system, thereby leading to suboptimal operating conditions. To this end, a relatively simple Jeffcott configuration is adopted consisting of a rotor dynamic system with only two degrees of freedom (x and y) as shown in Figure The linearization of the dynamic gas film behaviour around the steady-state operating point leads to the formulation of a set of stiffness and damping coefficients.

Two coefficients respectively represent the direct stiffness and damping behaviour (k_{xx}, k_{yy} and c_{xx}, c_{yy}) of the supporting film, while the two other coefficients describe the cross-coupled behaviour (k_{xy}, k_{yx} and c_{xy}, c_{yx}). This cross-coupling is best understood as a reaction of the gas film in a direction perpendicular to the applied perturbation.

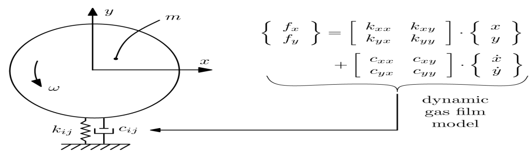

Figure 2. Dynamic model of a Jeffcott rotor-bearing system.

2.1 Strategies for Enhancing the Bearing Stability

Based on this stability analysis, three strategies have been developed to enhance the stability of high-speed journal bearings. Each of these strategies has been worked out into detail and is experimentally validated at a miniature scale (rotor diameter up to 10 mm). Figure 3 illustrates the outcome of the developed strategies in terms of achieved rotational speed (with the DN-number being defined as the product of bearing diameter in mm and rotational speed in rpm).

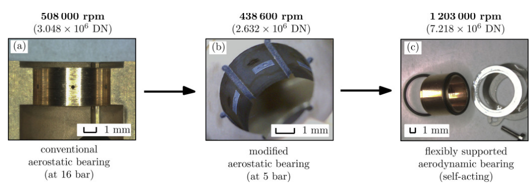

Figure 3. Illustration of the outcome of the developed stabilising strategies:

Optimal design of conventional aerostatic bearings with inherent restrictors. The conclusions from this study may be summarised as follows: (i) the stability is unconditionally enhanced by a reduction of the radial clearance and an increase in bearing length; (ii) for each combination of bearing clearance and length, there exists an optimal value of the feedhole diameter; and (iii) the bearing can be stabilised to some extent by increasing the supply pressure.

These conclusions have some important implications for practical bearing design. Acceptable performance in terms of high-speed stability can only be attained by reverting to small values of the radial clearance. This, in turn, demands closer control of the manufacturing tolerances, leads to increased frictional losses and creates problems due to thermal and centrifugal distortions. Stabilisation by means of a supply pressure increase, on the other hand, is also not interesting from a practical point of view.

The limitations of conventional aerostatic bearings are illustrated by a first series of experiments performed by the author. Plain aerostatic journal bearings with various design parameters have been evaluated at high speed. Rotational speeds up to 506 880 rpm and 3.1 million DN could

3. Conclusion

This paper has presented air bearings as a clean, viable solution for high-speed applications. The dynamic stability problem has been treated by means of a stability analysis followed by the formulation of three strategies for enhancing the bearing stability. The last strategy poses a fundamental solution to the stability problem by the introduction of damping external to the gas film. The effectiveness of this approach is demonstrated by the successful operation of a 6 mm aerodynamic bearing at 1.2 million rpm, which translates to a record DN-number of 7.2 million.

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