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Modeling of a Gas Foil Bearing for Microturbine Applications: Predictions versus Experimental Stiffness and Damping Force Coefficients

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ABSTRACT

A successful commercial power generation microturbine relies on gas foil bearings (GFBs) for increased efficiency and enhanced rotordynamic stability. The patented gas bearing has three top aerofoils and undersprings elements with an engineered stiffness distribution, circumferential and axial. A computational model couples the foil structure, modeled with finite elements, to the gas film flow governed by Reynolds equation. An empirical structural damping loss factor, representative of mechanical energy dissipation in the undersprings, is integrated into the predictive model. Predicted GFB dynamic stiffness and damping force coefficients versus excitation frequency agree well with test data obtained by an independent user. The predictions and test data demonstrate the unsurpassed stability characteristics of the unique GFB technology.

INTRODUCTION

Gas foil bearings (GFBs) have enabled the successful deployment of commercial microturbomachinery (<250 kW) providing low drag friction and tolerating high level vibrations, transient rubs, and severe misalignment [1]. Commercial power generation microturbines implementing GFBs in oil-free compact units improve mechanical efficiency and reduce life cycle costs, for example. Recent advancements in GFB load capacity, high temperature coatings, and modeling technique extend GFB applications to *green* energy systems, such as microturbine-energized hybrid electric vehicles (HEVs). Clean engine driven vehicles are promising for heavy duty city transits due to their low emission and high fuel efficiency [2].

Figure 1(a) shows the configuration of the patented foil bearing [3] comprising of three independent aerofoils, each supported on its own elastic underspring layer. The underspring layer is a 3rd generation type [1], with (specific) variations, circumferential and axial, in the distribution of individual elastic supports to provide engineered bearing stiffness, as shown in Fig. 1(b). With rotor spinning, a self-generating hydrodynamic gas film pressure pushes the aerofoils away from the shaft to enable near drag-free operation.

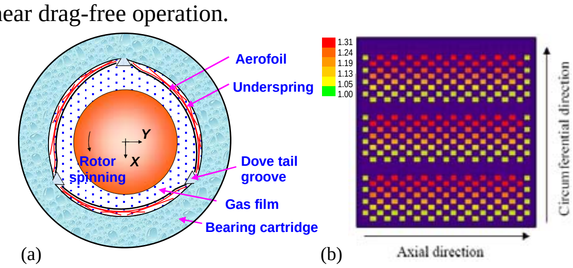

Fig. 1 (a) Schematic view of patented GFB for micro turbine and (b) representation of underspring support with engineered stiffness distribution

COMPUTATIONAL MODEL

The GFB combines (in series) the stiffness and damping coefficients of the gas film with those from the underspring support structure. Presently, a FE analysis models the aerofoil as a 2D shell structure, and elastic strain energy principles deliver stiffnesses for the underspring layers modeled as a set of distributed support elements. A structural loss factor ~0.6, representing the mechanical energy dissipation due to micro-slip between the assembled underspring and the bearing cartridge, is determined experimentally and integrated into the structural stiffness matrix. The analysis couples the structural model representing the aerofoils and undersprings to the gas film analysis governed by Reynolds equation.

RESULTS AND DISCUSSION

For a centered GFB operation and a rotor speed of 20 krpm (333 Hz), Fig. 2 shows predicted dimensionless dynamic force coefficients, (a) stiffness and (b) damping, versus excitation frequency. An independent user obtained the test data with dynamic load excitations at frequencies below the synchronous rotor speed. In Fig. 2(a), the direct stiffnesses (K_{XX}, K_{YY}) range from ~20 to ~35. The magnitudes of the cross-coupled coefficients (K_{XY}, K_{YX}) are but a fraction of the direct stiffness coefficients, thus favoring dynamically stable rotor performance. In Fig. 2(b), the direct damping coefficients (C_{XX}, C_{YY}) drop rapidly as the excitation frequency increases. The cross-coupled coefficients (C_{XY}, C_{YX}) vary little with excitation frequency, their magnitudes being almost nil. Overall, model predictions agree well with the test data.

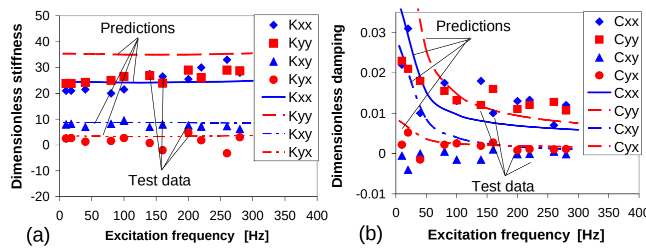

Fig. 2 Dimensionless GFB (a) stiffness and (b) damping coefficients versus excitation frequency. Predictions and test data for centered operation at 20 krpm

CONCLUSIONS

The paper presents a computational model of a 3rd generation GFB with an engineered underspring stiffness distribution. The analysis couples the 2D aerofoil shell-undersprings model to an isothermal gas film flow model. Predicted stiffness and damping coefficients agree with the experimentally identified parameters, thus validating the computational model.

ACKNOWLEDGMENTS

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