Composite Structures 201 (2018) 747–759

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Dynamic characteristics of composite tilting pad journal bearing for turbine/generator applications

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ARTICLE INFO

Keywords:
Composite tilting pad journal bearing
Carbon fiber/epoxy
Hydrodynamic lubrication analysis
Dynamic coefficients
Vibrational amplitude

ABSTRACT

Tilting pad journal bearings have been employed for turbine, compressor, pump, and generator applications owing to their high loading capacity, excellent stability, and service durability at high operation speed compared to conventional journal bearings. For high-speed and high-performance applications, tilting pad journal bearings should reduce the rotor vibration. Therefore, the bearings are designed to have excellent damping characteristics. In this study, composite tilting pad journal bearings consisting of carbon fiber/epoxy composites and a backup metal are fabricated to increase the dynamic performance and durability. A modal analysis is performed to investigate dynamic stability of the composite tilting pad. Moreover, the damping coefficient of fluid film, oil film pressure, and orbit of rotor are calculated with respect to the liner materials under a hydrodynamic lubrication state. To verify the analysis results, hydrodynamic lubrication tests of composite and white metal tilting pad journal bearings are conducted using an industrial test bench. As a result, the composite tilting pad journal bearing has effectively reduced the rotor vibration and increased the stability and durability of the bearing system compared to the white metal tilting pad journal bearing.

1. Introduction

Owing to their inherent dynamic stability characteristics and excellent load upholding ability, fluid film tilting pad journal bearings have been widely used to support and constrain the rotors of high-speed rotating machineries. Compressors, turbine generators, turbo chargers, and other rotating machineries could suffer from severe vibrations in a structural resonant mode excited by harmonic loading due to rotor imbalance or fluctuation of fluid dynamic force, which may cause mechanical damages. In particular, fatigue damage of the babbitt metal on the statically unloaded upper pads at the leading edge of the tilting pad journal bearing could occur by pad fluttering, which is defined as the unstable vibration of a pad that is continuously floating back and forth between the pivot point and the journal during shaft rotation [1]. Therefore, a reduction in system vibration is required for reliability of tilting pad journal bearing systems. Yang et al. showed the effect of supply oil flow rate to reduce the pad fluttering [2]. Feng et al. investigated the effect of preload coefficient on the rotor orbits and vibration amplitudes [3]. Cha et al. showed the influence of pad backing elasticity, pad support geometry, and pad liner properties on the bearing dynamic characteristics [4]. Despite many scientific reports showing the effect of the design parameters of tilting pad bearings such as pivot position, type of pivot, and shape of tilting pad on the dynamic properties, there is little information available regarding the effect of materials employed as pad facings on the bearing performance characteristics. White metal has been extensively used as pad facing material because of its low cost, good conformability, and embeddability. However, in the case of unexpected oil cut situation or insufficient oil film formation between the bearing and rotor, the conventional white metal-faced bearings immediately fail, which induces serious damage to the rotor [5]. Furthermore, white metals can fail by fatigue loading induced from the rotating shaft because the metallic materials have low damping properties. Fatigue stress plays an important role in the failure of conventional white metal tilting pads owing to the consistent vibration in the bearing system. Simmons et al. introduced polymer-faced (PEEK and PTFE) tilting pads for enhancing the damping properties [6]. Polymers can provide higher damping properties than metals owing to their excellent damping coefficients. However, the ability to increase the load carrying capacity is limited because of the poor mechanical properties and thermal conductivity problems of polymer-faced tilting pads.

The high specific stiffness and strength, and good dynamic

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https://doi.org/10.1016/j.compstruct.2018.06.095
Received 10 April 2018; Received in revised form 17 June 2018; Accepted 25 June 2018
Available online 26 June 2018

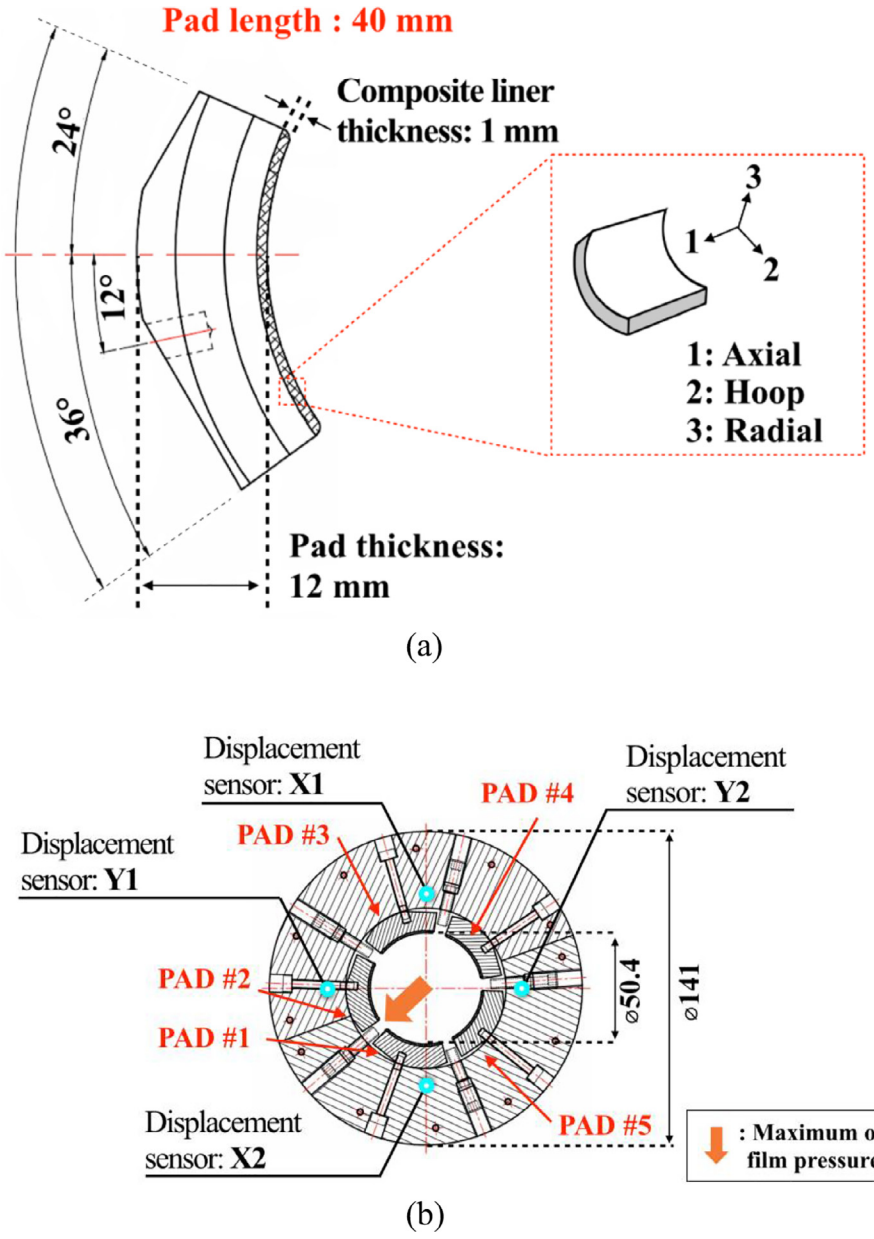

Fig. 1. Bearing configuration; (a) tilting pad, (b) bearing assembly.

Table 1
Material properties of carbon fiber/epoxy composite, white metal, and backup metal.

	E (GPa)	E_{11} (GPa)	E_{22} (GPa)	E_{33} (GPa)	ν	ν_{12}	ν_{13}	ν_{23}	G (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)
Carbon fiber/epoxy composite		66.6	66.6	7.6		0.039	0.5	0.5		6.2	4.7	4.7
White metal	50				0.3				19			
Steel backup metal	207				0.3				79.6			

characteristics of fibrous composites have enabled them to be applied in the design of composite bearings [7–11]. However, one of the main problems of polymer composite bearings is their low thermal conductivity in the through-thickness direction, which leads to lengthy curing cycles, thermal lag, and thermal spiking. The resulting non-uniformity in temperature and degree of cure across the thickness direction of the composites leads to non-uniformity in residual stresses, fiber volume fraction, and mechanical properties [12]. Furthermore, the low thermal conductivity of the composites causes poor heat dissipation, which can lead to critical problems during bearing operation. The temperature of lubricant could significantly increase when the frictional heat generated between the rotor and the pads is not effectively dissipated in the through-thickness direction of pads owing to low thermal conductivity of the pad materials. Subsequently, the load