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Tribological failure analysis of a heavily-loaded slow speed hybrid journal bearing

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ABSTRACT

In the present work, the feasibility of hybridizing a magnetic arrangement in the conventional journal bearing system has been experimented for the operating conditions of heavy load and slow speed. A test setup has been developed to perform testing on four types of bearing arrangements: conventional journal bearing arrangement, cylindrical magnetic bearing arrangement, circular arc (180°) magnetic bearing arrangement and a hybrid bearing arrangement. The magnetic levitation force was determined theoretically for these arrangements to identify reasons for the mechanical contact between rotor and stator magnets. The results of the experimental investigations in terms of the weight loss (wear), reduction in the magnetic flux density, acceleration signals, and photographs of worn & fractured rotor are reported.

1. Introduction

The operating conditions of heavy load and slow speed are encountered in many applications, like sugar mills, cement-manufacturing plants and steam turbines, where the support bearings operate in mixed-lubrication regime. Under these conditions the asperity contact occurs and excessive wear of bearing causes failure [1–3]. One way adopted by various researchers is to reduce friction and wear in the mixed-lubrication regimes using different material combinations, better lubricants & additives [4] and improving geometry (bearing clearance [5], grooving [6], texturing [7]). Other approach adopted is to hybridize the different bearing technologies, like hydrodynamic bearing and hydrostatic bearing [8], electromagnetic bearing and permanent magnetic bearings [9], hydrodynamic and permanent magnetic bearing [10,11], etc. It has been investigated earlier that the hybridization of magnetic bearing and hydrodynamic bearing is feasible for several applications.

In the present work, experiments have been conducted to determine the feasibility of hybridized bearing (magnetic and journal bearings). The experiments were conducted in four phases. In the first phase experiments were conducted on conventional journal bearings under the operating conditions of heavy load and slow speed. The wear of the bearing was measured as its weight loss after the test. In the second phase the experiments were conducted on cylindrical magnetic bearing arrangement under the similar operating conditions of heavy load and slow speed and it was observed that the arrangement is not capable of supporting the dynamic load. In the third phase the experiments were conducted on circular arc (180°) magnetic bearing arrangement under the similar operating conditions and it was observed that even though the magnetic arrangement was able to separate the journal in static condition, but rotor experienced vibrations under dynamic conditions and finally resulted into the breakage of the rotor magnets. Significant wear was also observed on the surface of stator

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Nomenclature

r_1	inner radius of rotor magnet, mm
r_2	outer radius of rotor magnet, mm
r_3	inner radius of stator magnet, mm
r_4	outer radius of stator magnet, mm
B_{r1}	magnetic remanence, Tesla
B_{r2}	magnetic remanence, Tesla
μ_0	permeability of free space, H/m
F_r	radial force, N
e	eccentricity ratio
α	angular variable of rotor, Radian
β	angular variable of stator, Radian
z	axial offset, m
L	length of cylindrical magnet, m
η	dynamic viscosity, Pa s
N	journal speed, rpm
S	Sommerfeld number
Λ	specific film thickness

magnet. In the fourth phase experiments were conducted on the hybrid bearing arrangement. Significant wear of both the rotor and stator was observed in this arrangement with a consequent reduction in the magnetic strength.

The reasons of the bearing arrangement failures were analyzed and the conclusions drawn are reported.

2. Experimental details

The schematic diagram of the experimental setup is shown in Fig. 1a. The provisions have been made in the setup to conduct experimental studies on four types of bearing arrangements:

1. Conventional journal bearing.
2. Cylindrical magnetic bearing arrangement.
3. Circular sector (180°) magnetic bearing arrangement.
4. Hybrid bearing arrangement.

These arrangements are shown in Figs. 1b–1e. The main experimental setup, shown in Fig. 1a, consists of a stainless steel (grade 303) shaft whose one end is free and other is connected, using a spiral coupling, to an induction motor (AC, 3 phase, 1.5 kW). The motor is rigidly mounted on a base plate and is controlled by an ABB frequency drive (IP20/µl open type). The loading arrangement consists of a horizontal loading platform supported on linear bearing mounted on vertical slide ways of circular cross section. A maximum of 500 N load may be applied on the bearing. A (shielded) deep groove ball bearing transfers the load from the loading platform to the shaft. Two accelerometers (type: KS 76C-10, voltage sensitivity:

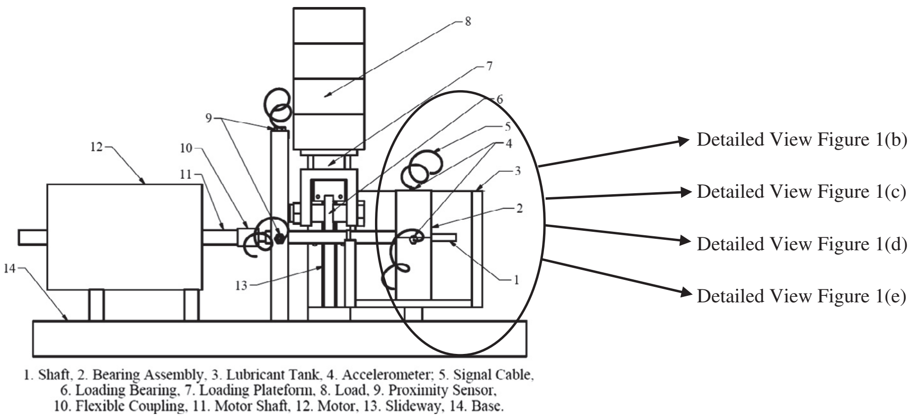

Fig. 1a. Schematic diagram of the main experimental setup.