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Technical Support Package

Method to Increase Performance of Foil Bearings Through Passive Thermal Management

NASA Tech Briefs
LEW-18789-1

National Aeronautics and
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Technical Support Package

for

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Method to Increase Performance of Foil Bearings Through Passive Thermal Management

Brief Abstract

This invention disclosure describes a new approach to designing foil bearings to increase their load capacity and improve their reliability through passive thermal management. In the present case, the bearing is designed in such a way as to prevent the carry-over of lubricant from the exit of one sector to the inlet of the ensuing sector of the foil bearing. When such passive thermal management techniques are used, bearing load capacity is improved by multiples and reliability is enhanced when compared to current foil bearings. This concept has recently been tested and validated and shows that load capacity performance of foil bearings can be improved by a factor of 2 at relatively low speeds with potentially greater relative improvements at higher speeds. Such improvements in performance with respect to speed are typical of foil bearings. Additionally, operation of these newly conceived bearings shows much more reliable and repeatable performance. This trait can be exploited in machine design to enhance safety, reliability, and overall performance. Finally, lower frictional torque has been demonstrated by this invention when operating at lower (non-load capacity) loads, thus providing another improvement above the current state of the art.

Section I Description of the Problem

Objective

The objective of the current invention is to incorporate features into a foil bearing that both enhance passive thermal management and temperature control while at the same time improve the hydrodynamic (load capacity) performance of the foil bearing. Foil bearings are unique anti friction devices that can utilize the working fluid of a machine as a lubricant (typically air for turbines and motors, liquids for pumps) and as a coolant to remove excess energy due to frictional heating. Current state of the art of foil bearings utilizes force cooling of the bearing and shaft, which represents poor efficiency and poor reliability. The current invention embodies features that utilize the bearing geometry in such a manner as to both support load and to provide an inherent and passive cooling mechanism. This cooling mechanism functions in such a way as to prevent used (higher temperature) lubricant from being carried over from the exit of one sector into the entry of the next sector of the foil bearing. This hot gas carryover can be prevented in several ways. Recent tests have validated that sector trailing edge treatments (such as chevrons and crescents) can accomplish this. Additionally it is postulated that surface treatments such as dimpling or etching can also implement this effect, as can such devices as inter sector seals, wipers, and “air curtains”.

Unique Problem Characteristics

The key characteristics of anti-friction devices (fluid films, rolling element bearings, magnet bearings, bushings, etc…) are load support between stationary and moving parts, thermal stability due to frictional heat generation, and rotordynamic stability for high rotational speed application. Foil bearings solve the third objective inherently through the coulomb friction of the compliant foundation. It is the first two objectives that are addressed herein. The disclosed invention combines the hydrodynamic (load supporting) behavior of foil bearings to establish gas dynamic mixing and convection patterns (thermal stability). This multifunctional design enables a type of foil bearing that possesses enhanced load support, efficiency, reliability, and safety.

Prior Art

High speed rotating machinery (such as motors, turbines, pumps, compressors, etc…) must contain anti-friction elements (fluid films, rolling element bearings, magnet bearings, bushings, etc…) to separate rotating and stationary components. In the current state of the art, antifriction devices must be actively cooled and lubricated, usually with oil, by an auxiliary sub-system. These sub-systems represent a burden to the primary machine and also add a level of un- reliability and in-efficiency. Additionally many of the traditional antifriction devices (rolling element bearings, magnetic bearings, and bushings) impose limitations on the size and speed of the rotating machinery. There is a class of antifriction devices that utilize the working fluid of the machine (air for turbines and motors, liquids for pumps) for lubrication and cooling. One such a device is know as the foil bearing. These bearings can support both radial loads (journal bearings) and axial loads (thrust bearings). A typical foil journal and foil thrust bearing is shown in figure 1. Foil bearings are comprised of four main components: the housing anchors the bearing to the non-rotating portions of the machine and serves as a rigid backbone of the bearing, the compliant foundation (often composed of corrugated sheet metal) provides an intermediate layer between the housing and top foil, the top foil (often composed of a smooth piece of sheet metal and coated with a solid lubricant) provides the stationary hydrodynamic surface, and the shaft or runner (the rotating part) provides the rotating hydrodynamic surface and in many instances also contains a surface treatment to enhance hydrodynamic action and reduce friction.

Disadvantages of Prior Art

The prior state of the art of foil bearings utilizes forced cooling through the bump foil in order to carry away energy generated in the bearing due to frictional heating. This force cooling is required because the heat capacity of the gas is low especially in comparison to the frictional heating. There are several deleterious side effects caused by this forced cooling. Primarily, the performance of the rotating machine is compromised because the forced cooling gas is taken from the primary product of the machine. Secondly, the high flowrates required to cool a foil bearing often lead to substandard hydrodynamic conditions of the foil bearing. Finally, forced cooling often masks the true stress of an operating foil bearing, which causes bearing failure to be chaotic and unpredictable.

Section II Technical Description

Description of the Innovation

The disclosed innovation is an improved foil bearing design that reduces or eliminates the need for force cooling of the bearing while at the same time improving the load capacity of the bearing by at least a factor of two. These improvements are due to the elimination of lubricant carry-over from the trailing edge one sector into the leading edge of the next, and the mixing of used lubricant with the surrounding ambient fluid.

Identification of components

Traditional foil bearings are composed of 4 main components: the housing, the compliant foundation, the top foil, and the rotating shaft. In the disclosed innovation, the top foil is redesigned to include features that cause natural fluidic mixing, thus preventing lubricant carry-over. These features are designed in such a way as to also enhance the desired hydrodynamic fluid flow of the bearing.

Functional Operation

During the operation of a foil bearing, lubricant is driven by shear force through the gap between rotating and stationary components. The primary outcome of this fluidic action is the generation of hydrodynamic pressure, which separates the two parts in relative motion. A secondary effect of this shear force is the frictional heating of the lubricant. Traditional anti-friction devices use active cooling to remove this heat. Current state of the art of foil bearings use forced cooling through the compliant foundation of bearing housing to remove this heat. However, this is an inefficient process and much of the heat is carried from one sector of the bearing to the next sector. If left unchecked this mechanism leads to the catastrophic failure of the foil bearing. The functional operation of the disclosed invention exploits fluidic lubricant mixing through the use of special top foil designs that break apart the lubricant film.

Alternate Embodiments

In addition to incorporating features into the trailing edge of a top foil with chevrons and crescents, alternate embodiments exist to enhance the foil bearing performance. Alternate embodiments of this invention can include inter-sector seals and wipers or direct lubricant injection. They may also include surface texturing with dimples or etchings or any such features that mitigate the effects of hot gas carry-over.

Supportive Theory

Figure 2 demonstrates the theory of operation of hydrodynamic bearings. The moving surface is the bottom of the figure and represents the rotating shaft. Fluid is forced through the convergent channel, which raises the pressure of the lubricant and allows for load support. The red area on the right side of the figure represents the temperature and velocity of the lubricant at the exit of a bearing sector. This high temperature and high velocity lubricant is often carried into the ensuing bearing sector which leads to ever increasing temperatures as the lubricant continues to be reused. The current invention minimizes this lubricant carry-over to improve the performance of foil bearing.

Section III   Unique or Novel Features of the Innovation

Novel Features

The disclosed invention contains novel features that prevent the carry-over of lubricant from one sector into the inlet of the ensuing sector of a foil bearing. Recent testing has shown that trailing edge features such as chevrons can double the load capacity of a foil thrust bearing at low speeds (≈20,000 rpm). These tests have also demonstrated, in a qualitative sense, a more robust, reliable and safer characteristic of operation. Additional embodiments of features that minimize lubricant carry-over include dimples, etchings, seals, wipers, and gas injection.

Advantages

The advantages of the newly designed foil bearing are increased load capacity, increased reliability, and zero forced cooling flow.

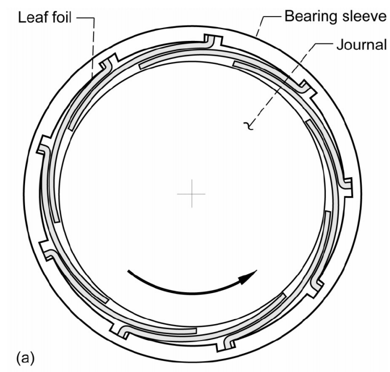
Test Data

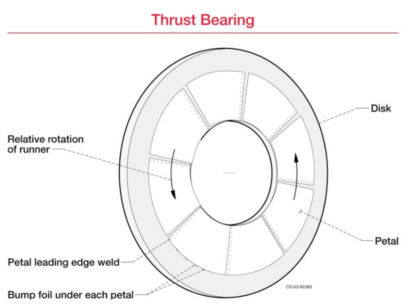
Recent test data is shown in figure 3 and 4. This data demonstrates that the trailing edge modification has a direct positive effect on the load capacity of the foil thrust bearing. The load capacity of the newly invented bearing is twice that of the two baseline bearings that were tested in this experiment. Data also shows that the disclosed bearing has lower frictional torque than the current state of the art of foil bearings.

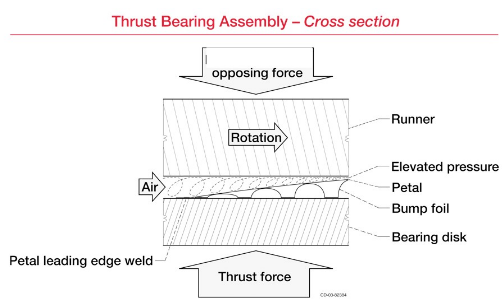
Section IV Potential Commercial Applications

Many commercial and industrial products are comprised of high speed rotating machines. The table below summarizes several commercial sectors and applications of the disclosed invention.

Field	Application
Aerospace	• Aircraft turbine engines • Auxiliary Power Units • Air cycle Machines • Turbopumps
Ground Transportation	• Automotive / truck Turbochargers
Power Generation	• Microturbines • Power conversion units
Industry	• Air Conditioning • High speed blowers /compressors • High speed bearings • Universal motors







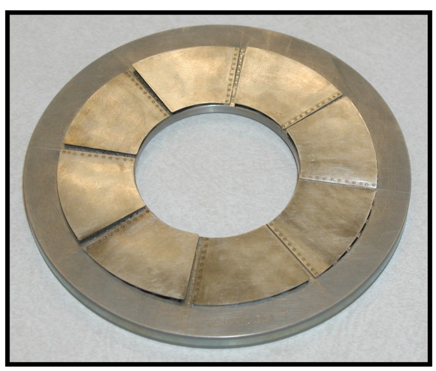


Figure 1. A. Drawing of a foil journal bearing having a sectored construction. B. Drawing and photograph of foil

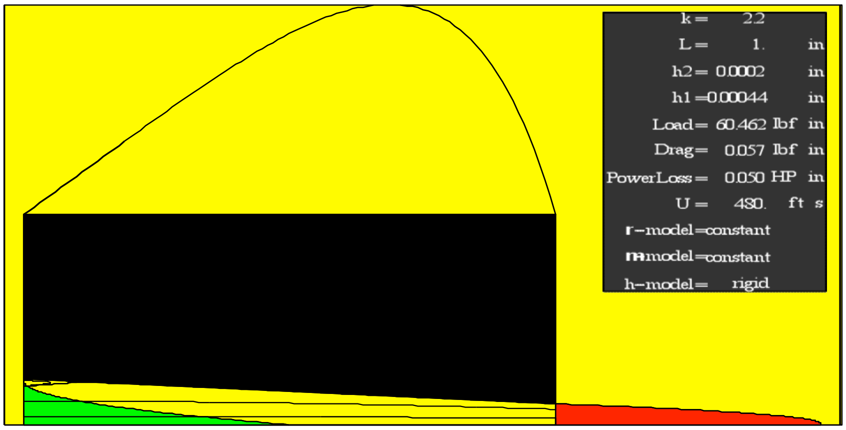


Figure 2. Typical characteristics of a hydrodynamic bearing.

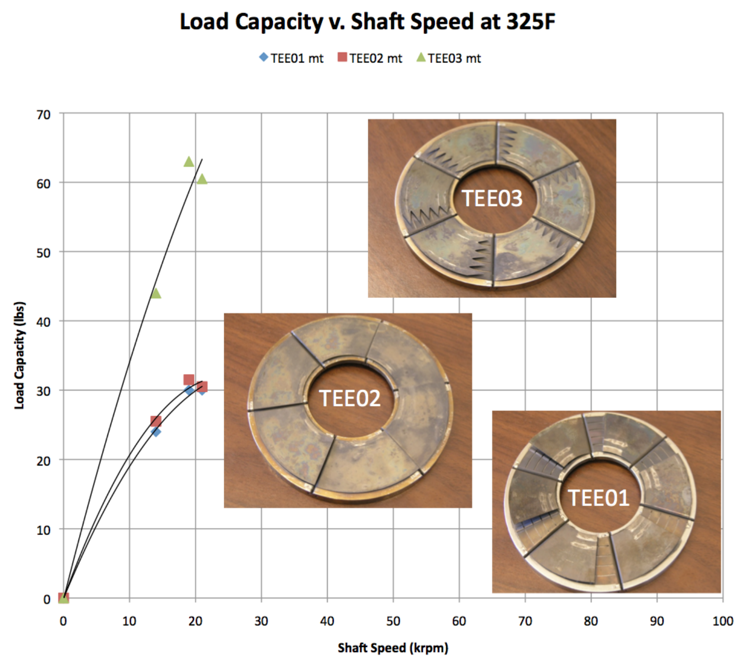


Figure 3. Low speed data showing the increased load capacity of this disclosed invention.

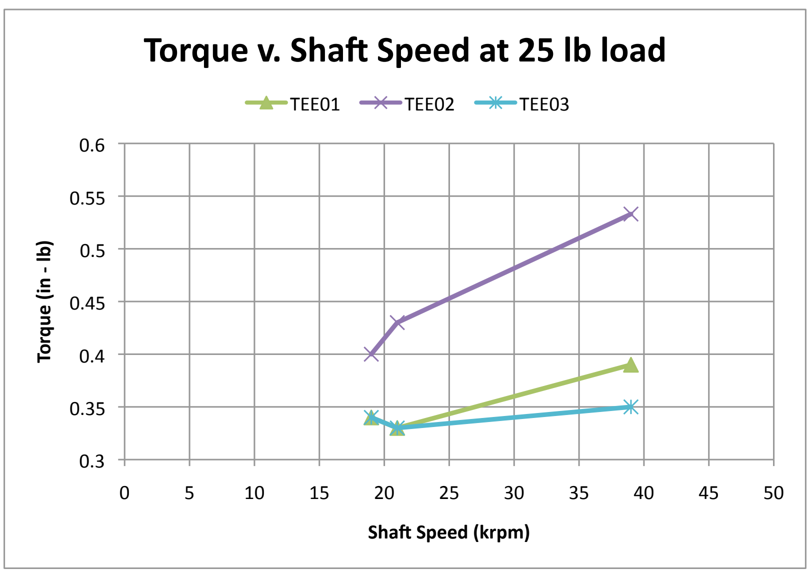


Figure 4. Test data showing the reduced friction of the disclosed invention compared to the current state of the art of foil bearings.