Guidelines for Determining Foil Bearing Applicability

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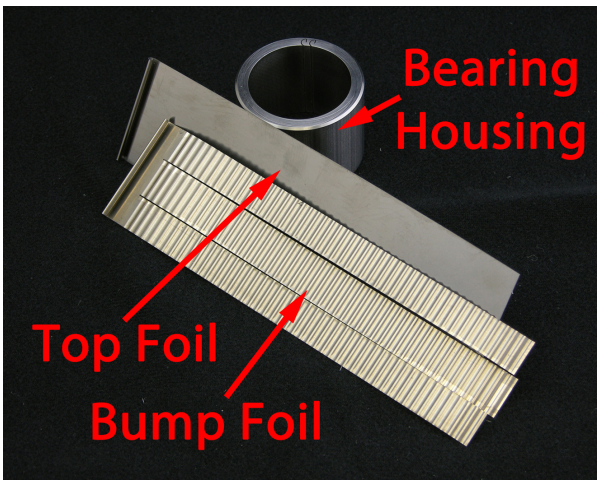
Abstract

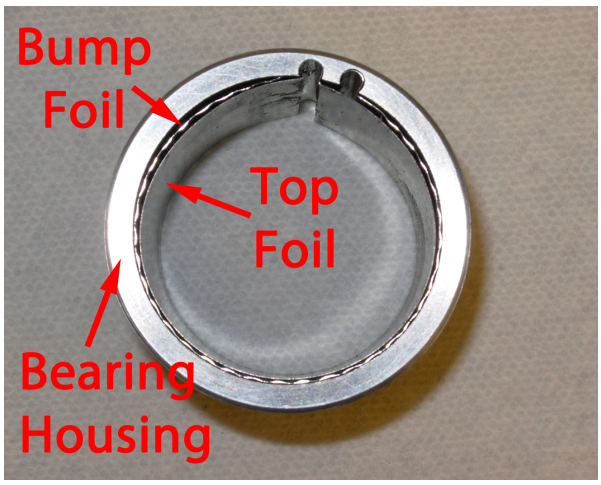
Foil bearings, also known as gas or foil-gas bearings, are bearings that carry a load on a thin film of gas and work well in high speed rotating equipment. But as with any tool, they are not all things to all machines and this paper seeks to help the reader determine when foil bearings will be of greatest benefit.

Foil Bearing Technology Overview

Foil bearings operate on the principle of hydrodynamic pressure and can be applied to both radial and thrust bearing applications. At low speed during start-up and shut-down the journal, in radial bearing applications, or the disc, in thrust bearing applications, is supported by flexible foils. The most common foil arrangement consists of a smooth top foil which is in contact with the journal/disc at low speed and an elastic bump foil that provides support. But as the machine accelerates to operating speed hydrodynamic pressure increases, the elastic bump foil is compressed and the top foil is pushed away from the journal/disc at which point physical contact and wear are eliminated.



Radial Foil Bearing Before Assembly



Radial Foil Bearing After Assembly

Under What Conditions Are Foil Bearings Preferable To Roller Element Bearings?

Rotating machines typically derive the greatest benefit from foil bearings when they are operating at high speed in systems where process fluid contamination must be avoided. A bearing's relative surface speed, often specified in ft/s or m/s, is the primary driver. Roller element

bearings are reliable, commercially available, and inexpensive; but as relative surface speed increases their Mean Time Between Maintenance (MTBM) decreases and this is where foil bearings start to become more attractive. Because foil bearings ride on a thin gas film, MTBM is unaffected by relative surface speed. And as an added benefit, foil bearing hydrodynamic pressure increases with relative surface speed which consequently improves load capacity, bearing stability, and vibration/shock load capacity. And finally, because the thin gas film on which a foil bearing rides is the system process fluid no petroleum lubricants, which may contaminate the process fluid, are required.

A bearing system's Sommerfeld number is the the quickest way to determine if foil bearings might make sense. If the Sommerfeld number is greater than 6, the bearing system is a good candidate for foil bearings.

Sommerfeld Number = $\left(\frac{r}{c}\right)^2 \frac{\mu N}{P}$

r = Shaft Radius
c = Radial Clearance
μ = Absolute Viscosity of the Lubricant (Often the Process Fluid)
N = Shaft Speed in rev/sec
P = Load Per Unit of Projected Bearing Area

Foil Bearing Advantages

Low Maintenance & High Reliability. Foil bearings have an extremely long life because there is no physical contact between the foils and the journal/disc at operating speed. Additionally, foil bearings are highly reliable due to their simple design and minimal number of moving parts.

Zero Contamination. Because foil bearings are lubricated with the process gas in which they operate, no petroleum based lubricants are required which could contaminate the process gas.

Wide Temperature Range. Many petroleum based lubricants breakdown at extremely high temperatures and become too viscous at extremely low temperature. Because foil bearings are lubricated with the process gas in which they operate, they can be effectively used at temperature extremes.

High Speed Operation. Because there is no physical contact between the foils and the journal/disc at operating speed, foil bearings do not limit the operating speed of the machine in which they operate. Greater operating speeds improve aerodynamic efficiency and do not adversely affect bearing life. Additionally, greater operating speeds increase the bearing's load capacity, stability, and vibration/shock load capacity.

Foil Bearing Disadvantages

Development Effort. Foil bearings are not a commercially available product that can simply be ordered from a catalog. Each bearing is designed for a specific application which required

development time and expense. However due to their simple design and limited number of moving parts, foil bearings can be very economical at production quantities.

Low Speed Operation. Because foil bearings depend on sufficient hydrodynamic pressure for proper operation, machines that spend time operating at low speed are poor candidates for foil bearings. Low speeds, as related to foil bearings, are typically less than 40,000 rpm or a Sommerfeld number that is less than 6.

Start/Stop Wear. Because foil bearings experience wear during start-up and shut-down, machines with frequent start/stop cycles are potentially poor candidates for foil bearings.

Foil Bearing Development

Christopher DellaCorte's paper entitled "Preliminary Foil Gas Bearing Performance Map" presented at the 2006 Society of Tribologists and Lubrication Engineers Annual Meeting and Exhibition prescribes a four-step process for foil bearing development risk mitigation.

Step 1 - Rotor Layout & Conceptual Design Feasibility Study. Bearing load, performance requirement, and shaft geometrical layout trade studies are conducted to establish a preliminary rotor design for which bearing requirements, including but not limited to, load capacity, stiffness and damping, and orbit control.

Step 2 - Bearing Design & Testing. Bearings that meet Step 1 criteria are designed, manufactured, and tested to verify lift-off speed, load capacity, and power loss. Additionally, rudimentary dynamic characterization are conducted.

Step 3 - Rotordynamic Simulation Testing. Multiple bearings are tested in a rotordynamic test rig with a physical mock-up of the system rotor (shaft) to verify orbital control and estimate nominal stiffness and damping.

Step 4 - Full Scale System Demonstration.

Summary & Conclusions

Rotating machines that operate for long periods of time at high speed, have a Sommerfeld number greater than 6, have an infrequent start/stop cycle, and process fluids where contamination must be avoided are prime candidates for foil bearings. And to justify the development effort, future production quantities should be a realistic possibility.

References

Hydrodynamic Fluid Film Bearings and Their Effect on the Stability of Rotating Machinery
by Luis San Andrés

Preliminary Foil Gas Bearing Performance Map
by Christopher DellaCorte, Kevin C. Rakill, Robert J. Bruckner, and S. Adam Howard

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