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Maintenance Free Bearings

S. M. Muzakkir[1], Harish Hirani
Department of Mechanical Engineering, Indian Institute of Technology Delhi, India
[1]Corresponding Author Email: mez108659@mech.iitd.ac.in

Abstract—In the present research work the need of a Maintenance Free Bearings (MFB) is established. The paper presents preliminary friction calculations to highlight the ways to achieve maintenance free bearings. The existing technologies of well established maintenance free bearings are described. The hybridization of bearing technologies to achieve low cost maintenance free bearings has been exemplified. Finally a combination of passive magnetic repulsion and hydrodynamics has been proposed and recommended as source terms to develop maintenance free bearings.

Keywords—Journal Bearing, Passive Magnetic Bearing, Active Magnetic Bearing, Hybrid Bearing, Maintenance Free Bearing

I. Introduction

Bearing is a system that support, guides and reduces the friction between relatively moving machine parts. Bearings are “necessary evil” for almost every (i.e. agriculture, automotive, manufacturing, home appliance, marine, aerospace, electronic, medical, electric power, oil, construction, etc.) industry. The evils of bearing are often minimized by reducing friction losses that occurs during support/guidance and zeroing the wear of bearing surfaces. The un-ending objective of bearing design is to extend bearing life so that maintenance expenses and downtime of machinery can be minimized. Frequent replacement of bearings happens to be a maintenance practice in India. Many industries spend huge amount on bearing replacements, such huge expenditure on “unproductive” machine element necessitates development of “maintenance free bearings”. Through extensive research into extending bearing life, SKF [1] has discovered that about 60% of premature bearing failures can be contributed to poor fitting, inadequate lubrication and contamination. Therefore they introduced self-aligning (spherical) bearings that incorporate special sliding layers of modern materials which have very low friction. The SKF named these spherical bearings as Maintenance Free Bearings (MFB). The aim of the present article is to introduce the concept of MFB and recent development occurred in the area of MFB.

II. Contact Bearings

Bearings are often classified as contact (i.e. rolling element bearings, dry bearings) and non-contact type (i.e. hydrodynamic, hydrostatic, magnetic) bearings. To understand the effect of physical contact between bearing surfaces, let us consider topography of two surfaces shown in Fig.1. This figure highlights the surface roughness of each surface (having peaks and valley relative to perfect flat surface) on microscopic level. In fig. 1 the maximum value of surface peak is 5 microns (μm) and the maximum amplitude of valley is -5 microns (μm).

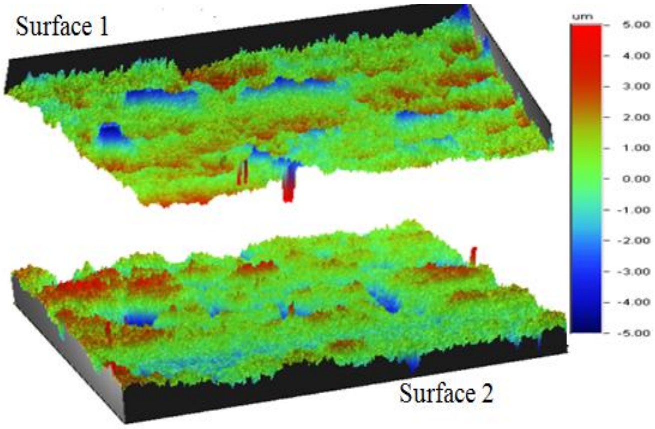


Figure 1 Topography of common bearing surfaces

When these two rough surfaces contact each other under a normal load, *W*, then interlocking and cold-junction formation occurs at the asperity interfaces. A tangential force, *F*, is required to slide one surface relative to other surface. To slide one surface relative to the other, cold junctions at the interfaces of asperities need to be sheared. Such shearing occurs if tangential force, F is greater than required shearing force. To evaluate this force, Mohr’s circle equations (Eq. 1-4), can be used.

$$\delta A\sigma_1 = \frac{\delta W}{2} + \sqrt{\left(\frac{\delta W}{2}\right)^2 + \delta F^2}$$

where σ_1 is first principal stress, and δA is elemental area (1)

$$\delta A\sigma_2 = \frac{\delta W}{2} - \sqrt{\left(\frac{\delta W}{2}\right)^2 + \delta F^2}$$

where σ_2 is second principal stress (2)

$$\text{or}\quad \delta A(\sigma_1 - \sigma_2) = 2\sqrt{\left(\frac{\delta W}{2}\right)^2 + \delta F^2} \quad (3)$$

If yield strength of material is $\sigma_y = \sigma_1 - \sigma_2$, then

$$\delta A^2\,\sigma_y^2 = \delta W^2 + 4\,\delta F^2 \quad (4)$$

Equation (4) indicates that increasing tangential force (δF) increases the area of contact. In limiting case, $F_{\max} = \tau_i A_{\max}$, where τ_i is shear strength of interface between two surfaces. Using Eq. (4) and limiting friction force, static coefficient of friction is given as $\mu_{static} = \frac{F_{\max}}{W} = \frac{\tau_i}{\sqrt{\sigma_y^2 - 4\tau_i^2}}$ or $\mu_{static} = \frac{F_{\max}}{W} = \frac{\tau_i}{2\sqrt{\tau_y^2 - \tau_i^2}}$ where τi is shear strength of weaker material. By and large, interface shear strength, τ_i is lesser than τ_y (i.e. steel-tin tribo-pair). However, if τ_i is greater than τ_y (i.e. steel-lead, copper-steel), then Eq. (4) will be invalid and catastrophic (severe) wear of bearing surfaces will occur. Therefore, in order to increase bearing life the interface shear strength of contacting surfaces need to be as low as possible.

III. Non-contact Bearings

Easiest way to minimize interface shear strength is to lubricate the bearing surfaces and maintain a complete separation between two solid surfaces. This can be achieved by using hydrostatic/aerostatic and hydrodynamic/aerodynamic lubrication mechanisms. Table 1 lists the merits and demerits of these bearing technologies.

Table 1: Characteristics of bearing technologies

Bearing Technology	Merits	Demerits
Aerostatic Bearing (μ_s=0.001, μ_k =0.001)	1. Minimum start-up friction. 2. Stiffness and load carrying capacity can be designed.	1. Requires: high pressure subsystem, filtering subsystem, feedback control system 2. Complex geometry. 3. High initial and running costs.
Hydrostatic Bearing (μ_s=0.001, μ_k =0.002)		
Aerodynamic Bearing (μ_s=0.15, μ_k =0.001, k= 10^{-6}-10^{-15}))	1. Develops positive pressure by virtue of relative motion. 2. High damping coefficients, particularly under fully developed hydrodynamic lubrication mechanism. 3. Ideally these bearings permit unlimited service life.	1. Metal-to-metal contact at start/stop and low speed, causing bearing wear and excessive power loss.

Approximate values of static friction coefficient (μ_s), kinetic friction coefficient (μ_k) and wear constant (k) are reported in Table 1. The minimum difference between static friction coefficient and kinetic friction coefficient is always preferred. To understand it let us consider the example of hydrodynamic bearing, which has μ_s=0.15 and μ_k =0.001. If a rotor bearing system requires T N.m operating torque for normal operation, then it needs 150T N.m torque during start-up operation. This requirement of huge torque just for starting purpose is intolerable in the present competitive world, where minimization of power loss, weight and cost are main objective functions. To overcome these problems it is often recommended to replace sliding motion with rolling motion.

IV. Rolling Element Bearing

Ball bearings, roller bearings, linear (roller) bearings are some examples that involve much lesser static friction in comparison to the sliding bearings. These bearings also require lubrication, but intermittent supply of lubricant is sufficient. In other words, requirement of re-lubrication only once a day eliminates the accessories (i.e. pump, compressor, piping, tank to store lubricant, etc) required for lubricating sliding bearings. Therefore, maintaining these rolling element bearings is much simpler compared to fluid-film bearings. Recently the maintenance-free bearings (no greasing) were launched by a number of bearing companies to satisfy the users' need to reduce the time required for daily maintenance. Operators want to start their work without greasing the bearing daily and often they hate to crawl under the machine to grease bearings. The rolling element bearings lubricated with solid lubricants such as ultra low-friction Teflon (PTFE) fabric, PTFE based fluoro-polymer, molybdenum disulphide etc are among the class of maintenance free bearings. These self lubricating bearing materials permit easy sliding movement between bearing surfaces and resist corrosion. Generally these bearings are spherical sleeves which minimize the chances of misalignment. Due to usage of solid lubricants, these bearings are free from the need of oil passages or grease nipples. The complete absence of liquid lubricants widens the operating temperature capability of these bearings. In other words the usage of solid lubricant make these bearings free from maintenance related to oil piping, foreign particles and that is why they often named as maintenance free bearings. Unfortunately these rolling element based maintenance free bearings face problem of noise (due to metal to metal contact) and vibration (due to negligible damping). Therefore, there is a need to rethink maintenance free bearing which save energy, survive longer and remain silent during operation.

V. Maintenance free magnetic bearings

Magnetic levitation has come out as one of a major research to make "maintenance free bearings". In the recent past, technological improvements in electronic and control hardware/software made electromagnetic magnetic bearings as feasible option in various mechanical systems such as pumps, turbines, compressors, machine tools, etc. Table 2 lists the merits and demerits of magnetic bearings.

Table 2: Magnetic bearings

Bearing Technology	Merits	Demerits
Permanent magnetic bearing	-No wear and negligible energy loss. -Self centring.	-Low damping and low load carrying capacity. -Axial instability.
Electro-magnetic bearings	-Lubricant free operation, -Adjustable damping and stiffness characteristics. -Allows high-speed relative motion.	-High cost. -Relatively low capacity.

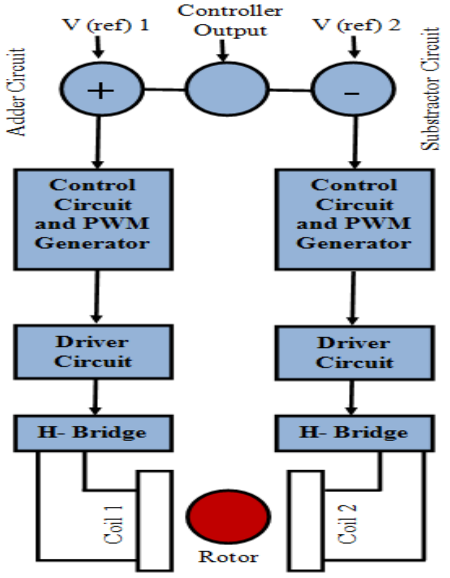


Figure 2 H-Bridge Circuit

The electromagnetic bearings are also known as “Active Magnetic Bearings (AMB)”. Shankar et al [2] compared the economics of three, electromagnetic, rolling and hydrodynamic, bearing technologies. They concluded that it was hard to justify active magnetic bearing which cost Rs. 65,000/- compared to similar sized greased lubricated rolling element and hydrodynamic bearings which cost lesser than Rs. 650/-. Further they compared power consumed by these bearings and illustrated, using a typical example, that active magnetic bearing consumes 48 Watts compared to 7 Watts required for rolling element bearing. Based on these observations they concluded that magnetic bearings cannot replace conventional bearings if direct cost is a primary constraint. In other words magnetic bearings cannot be selected for low cost machines. But AMB works as a “maintenance free bearing”. Its online condition monitoring system determines misalignment, which can be rectified immediately by applying “magnetic levitation force” against misalignment. Therefore active magnetic bearings can be named as “maintenance free bearings”.

An attempt to develop low cost AMB was made by Meena and Hirani [3]. They made a switching amplifier, which reduces the running cost of AMB. Complete schematic of the switching amplifier is shown in the Fig 3. It is composed of preprocess electronic circuit (control circuit), PWM generator, driver for power circuit i.e. H-bridge, power supply etc. Switching amplifier uses Pulse-width Modulation (PWM) technique to generate a high frequency signal, continuously switching in between a low voltage (-V) and a higher voltage (+V) with a variable duty cycle. By varying the duty cycle of the PWM, one gets a desired resultant voltage between –V and +V. This kind of amplifier provides energy efficient solution for AMBs.

Second choice of maintenance free bearing is “Permanent magnet bearing”. Magnetic repulsion between stator and rotor magnet provides “non-contact load support”. These bearings are good option for large static and low dynamic load. Further, these bearings are designed for “well defined load” and generally perform unsatisfactorily under fluctuating load. Now a question comes whether it is possible to perform research on magnetic bearings to reduce the running cost of AMB and provide dynamic controllability to “permanent magnet bearings”. To reduce expenses of bias current (from 1.0 A to 0.0 A), electromagnetic bearings can be hybridized with the technology of permanent magnetic bearing. Such hybrid bearing will be known as frictionless and zero-wear bearing, and running cost of these bearing will be lesser than AMB bearings. Therefore such hybrid combination of “permanent and electromagnet” bearings provides benefits and can be used in low cost machines.

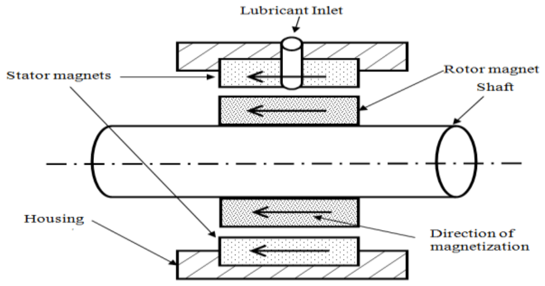
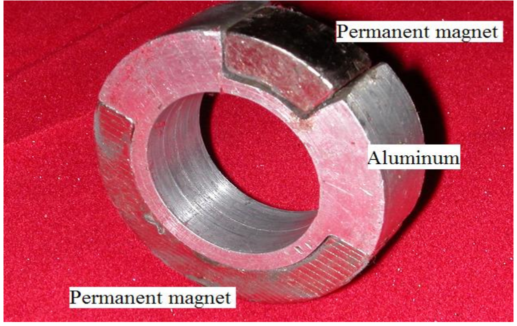


Figure 4 Conceptual Hybrid Bearing [4]

Another possible concept for low cost noise free maintenance free bearings is a hybrid bearing which is made of axially magnetized magnets and works as hydrodynamic as well as magnetic bearing. The sketch of such bearings is shown in Fig. 4 [4]. The repulsive force between rotor and stator levitates the rotor-shaft system and does not allow the rotor magnet to touch the surface of stator magnet. In addition such conceptual bearings can be operated in relatively high temperature environment as cooling liquid can be circulated between permanent magnets. Fig 4 shows a static position of hybrid bearing, but under the rotation of shaft and supply of lubricant generate a hydrodynamic film. Such hydrodynamic film can bear the dynamic loads that cause due to unbalance, misalignment, etc. In short the bearing arrangement shown in Fig. 4 provides all the merits of hydrodynamic (damping, medium to high load capacity, etc.) and magnetic (zero wear, negligible friction, etc.); and removes demerits of hydrodynamic bearing (high friction and wear at low speeds) and magnetic bearing (low load capacity and low damping) bearing. Such bearing configuration does not allow contact between solids (if applied load is lesser than designed load) and makes contact-less bearing throughout its operation period, leads to zero value of coefficient of wear and make an infinite life of the bearing. Only drawback of these bearings is the requirement of lubricant. However, to avoid such restriction, bearings can be fabricated as shown in Fig. 5. In Fig. 5(a) an arrangement of aluminium and magnetic piece is shown. Fig. 5(b) illustrates the Teflon coating on assembly shown in Fig. 5(a). The magnetic repulsion of these bearings avoids metal to metal contact, which in turn reduce the noise. These bearings are far better than maintenance free rolling element bearing in terms of cost, noise, and survivability. However, their restricted load range is only a limitation, which can be overcome if these bearings are customized for a particular application.



(a) Assembly of magnetic and aluminium pieces

(b) Teflon coating on assembly

Fig. 5: Low cost, low noise maintenance free bearing

V. Conclusions

Various combinations of "maintenance free bearings" can be designed. A combination of "active magnetic bearings with switching amplifier" and permanent magnets will provide low cost maintenance free bearing. Hybrid bearings made of permanent magnet and works on repulsion and hydrodynamics is a better choice compared to hybridization of "active and passive magnetic bearing". To avoid maintenance related to lubricant and its accessories, one can employ Teflon coated magnetic bearing arrangement. However, more research and design efforts are needed to convert this hybrid bearing into a successful commercial product.

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