Manufacturing of Journal bearing for reverse turbine

Bangladesh Industrial Technical Assistance Center (BITAC)

116(Kha), Tejgaon Industrial Area

Dhaka- 1208

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Abstract

In Bangladesh, a large quantity of highly expensive journal bearing is imported by power stations, fertilizer factories, sugar mills, paper mills and other industries. Several attempts were taken to manufacture locally by private industries but fruitful result was not found.

The main aim of this work was to study the feasibility of manufacturing journal bearing using indigenous technology cost effectively. The specific properties under consideration include (i) mechanical properties, (ii) chemical properties and (iii) casting defects of the cast journal bearing. Shell manufacturing of journal bearing is not complicated. But the main challenge is casting babbitt metal with bearing shell. Two types chemical composition babbitt metal used in journal bearing manufacturing. These are Tin base babbitt metal and lead base babbitt metal. Chemical elements tin base babbitt metal such as Tin (Sn), Copper(CU), Antimony (Sb).

Fig:1 Journal Bearing Testing (NDT)

Lot of journal bearing manufactured did not satisfy the requirements of NDT (Ultrasonic test). Only qualified journal bearing were supplied for trial run. Eventually BITAC manufactured a lot of journal bearing and satisfied the requirements of power stations, fertilizer factories, sugar mills, paper mills and other industries.

Journal bearing misalignment arise generally from the shaft deformation under load, deflection of the shaft, manufacturing and assembly errors, improper installation, and asymmetric loading.

During operations, misalignment has a considerable effect on the static and dynamic performances. It could cause wear, vibration and even system failure. In this article, a literature review of misalignment of the journal bearings is presented. The basic theory for the misalignment and some results for the circular journal bearing are also presented to show the general trends of the misalignment.

Keywords: misalignment; journal bearing; NDT, analysis; mass conservation; cavitation

1. Introduction

Journal bearings consist of a shaft or journal which rotates freely in a supporting metal sleeve or shell. There are no rolling elements in these bearings. Their design and construction may be relatively simple, but the theory and operation of these bearings can be complex. Low-speed pins and bushings are a form of journal bearing in which the shaft or shell generally does not make a full rotation. The partial rotation at low speed, before typically reversing direction, does not allow for the formation of a full fluid film and thus metal-to-metal contact does occur within the bearing. Pins and bushings continually operate in the boundary lubrication regime.These types of bearings are typically lubricated with an extreme pressure (EP) grease to aid in supporting the load. Solid molybdenum disulfide (moly) is included in the grease to enhance the load-carrying capability of the lubrican. Many outdoor construction and mining equipment applications incorporate pins and bushings. Consequently, shock loading and water and dirt contamination are often major factors in their lubrication. These bearings are limited to low-load and low-surface speed applications. Semilubricated journal bearings consist of a shaft rotating in a porous metal sleeve of sintered bronze or aluminum in which lubricating oil is contained within the pores of the porous metal. These bearings are restricted to low loads, low-to-medium velocity and temperatures up to 100°C (210°F). The advantage of this design is the more accurate alignment of the supporting shell to the rotating shaft and the increase in shaft stability which is obtained.[1]Journal bearings are meant to include sleeve, plain, shell and babbitt bearings.

The term babbitt actually refers to the layers of softer metals (lead, tin and copper) which form the metal contact surface of the bearing shell. These softer metals overlay a stronger steel support shell and are needed to cushion the shell from the harder rotating shaft. Simple shell-type journal bearings accept only radial loading, perpendicular to the shaft, generally due to the downward weight or load of the shaft. Thrust or axial loads, along the axis of the shaft, can also be accommodated by journal bearings designed for this purpose. Figure 1 shows a tilt-pad bearing capable of accepting both radial and thrust loads. Journal bearings operate in the boundary regime (metal-to-metal contact) only during the startup and shutdown of the equipment when the rotational speed of the shaft (journal) is insufficient to create an oil film. It is during startup and shutdown when almost all of the damage to the bearing occurs.

2. Objectives of the Research Work

The main aim of this work was to produce sound casting of journal bearing using indigenous technology and raw materials with low cost to reduce import, enhance the skills of the manpower engaged in this field and increase employment opportunities.

3. Methodology

The methodology comprises of Design and creation of drawing, Chemical components selection and formulation, metal melting temperature maintain, casting process follow and pouring into mold, Cleaning, machining followed drawing, inspection & testing.

4. Film Thickness

The most important effect of bearing misalignment is the drastic alteration of the protective film thickness in both the circumferential and axial directions. Therefore, the Reynolds equation should be modified to allow the variation of film thickness in both directions. This needs to be carefully taken into consideration in the analysis.

Figure 2 shows the schematic geometry of a misaligned journal bearing system. Referring to Figure 2, the film thickness in journal bearing with provision for misalignment can be expressed as:

$$h=C+eo\cos(\theta-\varphi o)+e'(zL-12)\cos(\theta-\alpha-\varphi o)$$

(1)

where C is the clearance, R is the journal radius and L is the bearing width, φ_o is the attitude angle between the vertical line (Y-axis) and the line of centers (Y'-axis), and e_o is the eccentricity at the bearing mid-plane. The parameter e' is the magnitude of the projection of the axis of the misaligned journal on the mid-plane of the bearing. The misalignment angle α is the angle between the line of centers and the rear center of the misaligned journal (see Figure 2). The misalignment eccentricity ratio is $\varepsilon'=e'/C=DM\varepsilon'max$, where DM is the degree of misalignment in value from 0 to 1. $\varepsilon'max$ is the maximum possible ε' [1]. The position of the journal specified by means of its eccentricity ratio and attitude angle at its mid-plane and by two important parameters, the degree of misalignment D_M and misalignment angle α, defining the extent and direction of the misalignment.

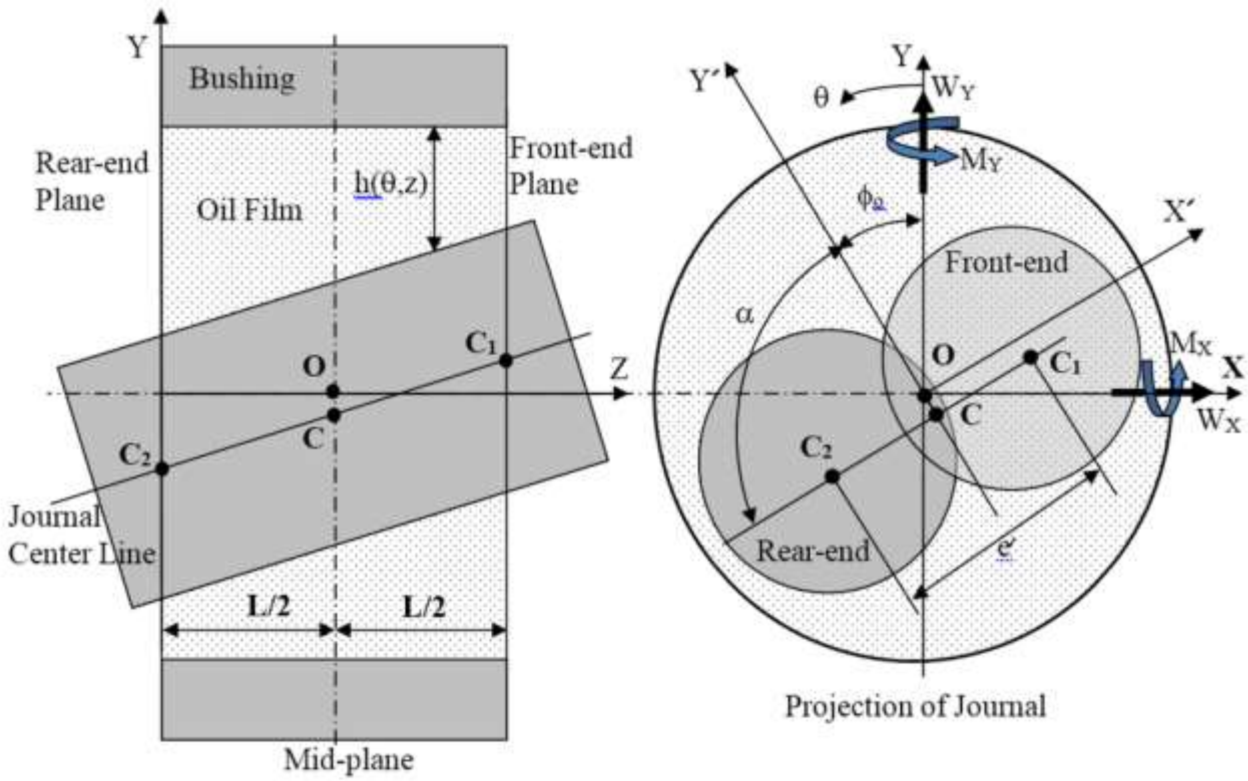

Figure 1. Nomenclature of misaligned journal bearing

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5. Literature Review

5.1. General Effects

The performance characteristics of misaligned journal bearings are generally functions of load. The bearing characteristics are normally classified as static and dynamic characteristics. The static characteristics include eccentricity ratio, attitude angle, Sommerfeld number, friction force, maximum hydrodynamic pressure, minimum film thickness, leakage flow-rate, mean and maximum temperatures. The dynamic characteristics normally include stiffness coefficients, damping coefficients, and stability threshold, *etc*. Misalignment causes an appreciable reduction in the load-carrying capacity. Misalignment also reduces the minimum film thickness drastically, and makes the pressure distribution asymmetric. Misalignment reduces the leakage flow-rate at higher loads. Somewhat surprisingly, however, it has been shown that misalignment significantly improves the stability margin of all journal bearing systems. Experimental results verify that journal bearings are relatively more stable under misalignment and the stability is even better when the load is higher. Noting that power loss induced by bearing misalignment is greater than an aligned bearing,

5.2. Application to Different Types of Bearings

Stockley and Donaldson in 1969 presented the widely-used Raymondi and Boyd diagrams for the centrally loaded 180° partial hydrodynamic journal bearings with provision for shaft misalignment. They showed simulation results for aspect ratios of 1, 0.5, and 0.25 and a range of tilt angles are presented in design charts and tables.

Pinkus and Bupara in 1979 presented a comprehensive isothermal solution for a two-groove finite bearing in the form of charts and tables. The equations are valid for finite bearings with grooves at any angular position where the misalignment can vary in both magnitude and direction with respect to the bearing boundaries. However, the application of their data is inconvenient since the load direction varies depending on the eccentricity and the misalignment. Mokhtar *et al.* in 1983 showed that the misalignment of journal bearings with both *axial and spiral feeding* has a pronounced effect on bearing performance, particularly when the minimum film thickness approaches zero. They showed that bearings with axial feeding produce higher loads and smaller friction coefficient than bearings with spiral feeding. Safar *et al.* in 1985 obtain an adiabatic solution of the misaligned finite journal bearings considering the both axial and spiral oil inlet conditions. They showed that thermal effects are more pronounced for bearings with axial rather than spiral oil inlet grooves.

5.3. Experimental Tests

Asanabe *et al.* in 1972 studied the misalignment of a grooved bearing, limiting their consideration to the misalignment in the vertical plane only. They noted that the pressure distribution was seriously affected by the misalignment. Nicolas and Frene in 1973 compared theory and experimentation for a bearing subjected to a central load and a misalignment torque, with an axial groove. They showed that plain bearings have a weak resistance against misalignment. Tieu and Qiu in 1996 built an experimental device to measure the film thickness, the hydrodynamic pressure and the temperature in the misaligned bearing for static and dynamic approaches. The relationships of eccentricity, attitude angle, and side flow to the Sommerfeld number are experimentally determined. Arumugam *et al.* in 1997 conducted experiments to investigate the effects of journal misalignment on the performance of three-lobe journal bearings. They analyzed the dynamic characteristics of a bearing under the horizontal misalignment, and showed that the system damping increases as the misalignment increases.

Huber *et al.* in 1998 investigated the misaligned plain circular bearing under a static load experimentally and theoretically. In the theoretical investigation, the adiabatic oil film and static equilibrium position of the journal were assumed. The pressure, oil flow and power loss were compared with the results observed from experimental investigations.

Bouyer and Fillon in 2002 experimentally studied the hydrodynamic plain journal bearing submitted to a misalignment torque. Hydrodynamic pressure and temperature in the mid-plane of the bearing, temperatures in two axial directions, oil flow rate, and minimum film thickness were measured for various operating conditions and misalignment torques. They showed that the maximum pressure in the mid-plane decreased by 20% at their maximum torque of 70 Nm while the minimum film thickness was reduced by 80%. The misalignment caused more significant changes in bearing performance when the rotational speed or load was low.

5.4. Surface Roughness

The effect of surface roughness on the performance characteristics of bearings has long been of interest in tribology and has intensified in recent years. The effects of surface roughness on the hydrodynamic pressure are included using either stochastic model or the average flow model proposed by Patir and Cheng .The stochastic model is limited to one dimensional ridges oriented either longitudinally or transversely. The average flow model modifies the Reynolds equation by using the pressure and shear flow factors to adjust the amount of the flow-rate. The pressure and shear flow factors vary with the standard deviation of the surface roughness (rms) and the surface pattern. It is shown that the load capacity decreases and the attitude angle increases with an increase in the roughness parameter. The leakage flow-rate increases with an increase in the roughness parameter at higher values of the eccentricity ratio for a certain value of the degree of misalignment. Note that these results are under the operating conditions where the metal-to-metal contact does not occur. If the metal-to-metal contact is included, then contact pressure is generated at the asperity level, which could contribute to supporting a portion of the applied load. The contact pressure can be determined from the elastic contact models or the elastic-plastic/plastic contact models .

Sun *et al.* in 2014 analyzed the lubrication characteristics of misaligned journal bearings considering the viscosity-pressure effect of the oil, the surface roughness and the elastic deformation at the same time. They found that the oil viscosity-pressure relationship and the deformation of the bearing have a significant effect on the lubrication of misaligned journal bearings. They also showed that surface roughness affects the lubrication of misaligned journal bearings when both the eccentricity ratio and misalignment angle are large.

5.5. Structural Effects

Sun and Gui in 2004 studied the effect of journal misalignment caused by shaft deformation. The pressure, load-carrying capacity, attitude angle, end leakage flow-rate, frictional coefficient, and misalignment moment were calculated for different values of misalignment degree and eccentricity ratio. The results showed that there are obvious changes in pressure distribution, the maximum pressure, film thickness, the minimum film thickness, and the misalignment moment when misalignment takes place. Later Sun *et al.* . in 2005 investigated the effects of journal misalignment caused by shaft deformation under static and rotary loads. The results showed that the higher the load on the shaft, the larger is the journal misalignment resulted from shaft deformation, and the more obvious becomes the effect on lubrication performance of journal bearing. The main effects are: The maximum pressure increases markedly, the minimum film thickness reduces, the leakage flow-rate increases, and the friction coefficient changes slightly. Ebrat *et al.* in 2004 developed a new model based on a local perturbation of the oil film that captures the effects of misalignment and bearing structural deformation in rotor dynamics and engine NVH (Noise, Vibration and Harshness) applications.

5.6. Thermally-Induced Bearing Failure

Khonsari and Kim in 1989 examined the influence of misalignment on the bearing seizure during start up. They showed that the rapid thermal expansion of the shaft during the start-up period can lead to a complete loss of bearing clearance and seizure in the absence of lubrication, and the presence of shaft misalignment can significantly influence the time of seizure. Wang gives a review of relevant literature to this type of a failure which is more likely to occur in bearings that have been out of service for an extended period of time so that the system runs dry at the first usage. Similar type of a problem can occur if the oil supply is interrupted during the operation and the bearing runs dry. Of course, the thermally-induced seizure is not confined to start up condition in misaligned bearings. It can occur in perfectly aligned bearings with dry contact as well as lubricated bearings with or without radial load. Unloaded journal bearings widely used in vertical pumps, agitators and mixers and special care must be taken in their design to avoid failure.

5.7. Wear Effects

Wear is progressive loss of material from the surfaces in contact as the result of relative motion between them. Wear is the most influential factor which shortens the effective life of machine components. The main purpose of a lubricant (liquid or solid) is to minimize the friction and reduce the wear. The types of wear are the abrasive wear, erosive wear, adhesive wear, surface fatigue, and corrosive wear. Landheer *et al.* in 1990 provided transition diagrams for plain journal bearings operating under conditions of moving contact on the basis of experimental data in terms of Stribeck curves and a few simple principles from lubrication and heat transfer theories. These diagrams may serve as wear mechanism maps. Ligterink *et al.* in 1996 derived the wear equation for the calculation of the specific wear rate of the bearing material as a function of the wear depth based on the Holm/Archard wear law.

The shaft misalignment in bearings is one of the most common causes of wear. Wear can be observed in both the dry and lubricated bearings which are affected by speed, load, and temperature and working time. Bearings are particularly susceptible to wear during the startup operation, before the shaft lifts off and prior to the generation of hydrodynamic pressure to protect the surfaces from coming into contact. A similar situation also exists during the coast- down operation when the engine is shut down and the speed drop to zero. Thus, stop/start is responsible for significant wear during the life of a bearing for both aligned and misaligned bearings. During the starting and stopping periods, the lubricant film thickness is not adequate enough to separate the surfaces and lift off does not occur Below the lift-off speed, mixed lubrication prevails and the surface interaction at the asperity level should be taken into consideration. For this purpose, the load-sharing concept can be employed. Progress toward this for EHL line contact has been reported in references Progress in engine bearing has been reported by Priestner *et al.* These papers have dealt with aligned configuration. Extension to misaligned configurations requires further research. The operation of the bearing with misalignment is more severe because, additionally, it can cause load concentration on the bearing edges, leading to the mixed lubrication, unstable operation and intensive wear of mating parts.

5.8. Porosity Effects

Elsharkawy in 2003 investigated the effect of journal misalignment on the performance of flexible porous journal bearings. They showed that the effect of misalignment in porous journal bearings can be neglected when the permeability is high. Gulwadi and Shrimpling in 2003 studied the effect of shaft tilting due to moment acting on it during an engine cycle. They described the features and capabilities of a computational tool ORBIT developed for analyzing journal bearings, *i.e.*, connecting rod bearings and crankshaft bearings. ORBIT is capable to consider: (i) non-circular journal bearing geometry; (ii) oil-feed holes/grooves; (iii) surface roughness; (iv) journal misalignment, (v) rise in oil temperature; and (vi) bearing elasticity effects (EHL) on bearing performance.

5.9. Variable Axial Profile

Heat elongation of bearing supports during the operation changes the static deflection line of the rotor determined during assembly and it causes an increase in the stresses on the bearing edges. To avoid the edge stresses, the variable axial profile (*e.g.*, hyperboloidal profile) can be applied to the bearings. The variable axial profile extends the bearing operation range without the stress concentration on the edges of bush. These bearings successfully carry the extreme load under the misalignment eliminating the necessity of using self-aligning bearings.

6. Conclusions

Journal bearings are commonly used in various rotating machines such as pumps, compressors, fans, engines, turbines and generators. Journal bearings quite often operate under some degree of misalignment. Investigations of misalignment of the journal bearings date back to the 1930s. It is shown that the static and dynamic characteristics are significantly influenced by misalignment, particularly when the load is heavy and misalignment is large. Generally, the misalignment is disadvantageous on the performance of the journal bearings, leading to the bearing failure. Of late, many influencing factors, such as bearing configuration, groove type and its location, thermal effect, surface roughness effect, elastic and thermal deformation, and non-Newtonian lubricants, *etc.*, are considered to more accurately predict the behavior of misaligned journal bearings. Significant progress has been made in the development of thermohydrodynamic analyses of misaligned journal bearings. The development of the appropriate boundary conditions for the heat transfer and cavitation remain to be active areas of research. Thus far, the majority of research activities have focused on stationary-loaded bearings and much less analyses are available on the TEHD analysis of dynamically loaded bearings with proper cavitation analysis. Another area where research is needed is the development of an analytical tool for prediction of wear in engine bearings, particularly for bearings with a protective over-layer and its wear as a function of time.

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Author contributions

Both authors contributed to the writing of this article.

References

1. Vijayaraghavan, D.; Keith, T.G. Effect of Cavitation on the Performance of a Grooved Misaligned Journal Bearing. *Wear* **1989**, *134*, 377–397. [**Google Scholar**] [**CrossRef**]
2. Elod, H.G. A Cavitation Algorithm. *ASME J. Lubr. Tech.* **1981**, *103*, 350–354. [**Google Scholar**] [**CrossRef**]
3. Elrod, H.G.; Adams, M. A Computer Program for Cavitation and Starvation Problems. In Proceedings of the 1st Leeds-Lyon Symposium on Cavitation and Related Phenomena in Lubrication, Leeds, UK, September 1974; pp. 37–41.
4. Booser, E.R.; Ryna, F.D. Linkinhoker, Maximum Temperature for Hydrodynamic Bearings under Steady Load. *Lubr. Eng.* **1970**, *26*, 226–235. [**Google Scholar**]
5. Khonsari, M.M.; Booser, E.R. *Applied Tribology: Bearing Design and Lubrication*, 2nd ed.; John Wiley & Sons: West Sussex, UK, 2008. [**Google Scholar**]

6. Khonsari, M.M.; Wang, S.H. On the Maximum Temperature in Double-Layered Journal Bearings. *ASME J. Tribol.* **1991**, *113*, 464–469. [Google Scholar] [CrossRef]
7. Khonsari, M.M.; Wang, S. On the Role of Particulate Contamination in Scuffing Failure. *Wear* **1990**, *137*, 51–62. [Google Scholar] [CrossRef]