TECHNICAL ARTICLE 1

Permanent Magnetic Bearing (PMB) for an Overhung System

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Introduction

The application of the overhung rigid rotor system has commonly been used in the industries since the beginning of industrial era. Reliable engineering standards have been developed to support the manufacturing and operation of an overhung rigid rotor system for a machine. Elijah [3] has clearly defined an overhung rigid rotor system as one in which the balance correction plane is situated outside the supporting bearings and whose rotational speed is significantly below the first critical speed. This research aims to adopt existing industrial engineering standards for an overhung rigid rotor system while exploring the usage of permanent magnetic bearing for replacing the function of conventional radial as shown in Figure 1. In nature, the usage of permanent magnet as a bearing for an overhung rigid rotor system is a significantly unstable system that requires control elements for system stabilization. These claims are supported by British mathematician Samuel Earnshaw who demonstrated his theorem, which states that no stationary object made of magnets in a set arrangement can achieve stable equilibrium through any combination of static magnetic or gravity forces. A dynamic rigid rotor system must possess at least one control element at any axis to achieve stability. This study focuses on the construction of a radial magnetic bearing, employing a hybrid technique for the development of a radial bearing element. An analysis will be conducted focusing on parameters such as bearing stiffness, equipment lifespan, and electrical power consumption under varying loads, temperatures, and bearing clearances.

Related Work

According to Greek legend, magnetism was first discovered by a shepherd named Magnes who found his stick attracted to the magnetic rock. The stone was named magnetite. Later in ancient China, people used a spoon made of magnetite that pointed south as a compass from the 2nd century BC as per Figure 2.

The scientific term of Magnetic fields (H) begins with the discovery of electromagnetic, discovered by the Danish physicist Hans Christian Oersted in 1820. This sparked great research by André-Marie Ampère, who discovered Ampère's law on the relation between the two magnetic forces of two current-carrying wires. 40 years later, James Clerk Maxwell introduced the concept of Magnetic flux density (B) and Magnetic Moment (m) which establishes the concept of Magnetization (M) for a permanent magnet. A series of practical innovations in the 20th century, most notably, the discovery the development of magnet applications.

In 1954, Baermann [1] developed the permanent magnetic bearing, and Backers [4] provided an in-depth review of his work at Philips Laboratory.

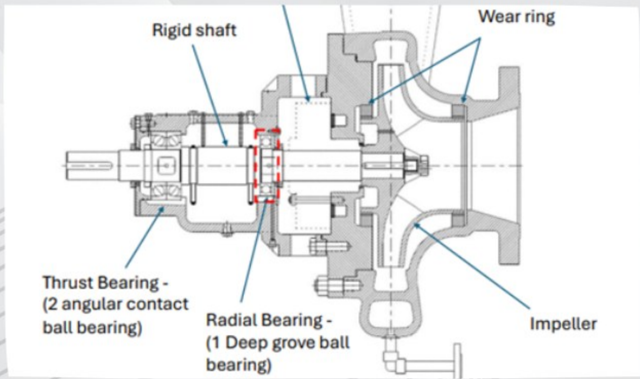

Figure 1: Schematic of an overhung system and the location of radial bearing for the B-Series API 610 OH1 Pump. (Amarinth [1])

Figure 2: South-pointing spoon of Si Nan spoon compass Model of a magnetic compass used in Chinese ancient. (Tsurkan, V. & Nidda, H. & Deisenhofer, J. & Lunkenheimer, Peter & Loidl, Alois [5])

Mathematical Model for a Horizontal Radial Magnetic Bearing

This research has developed a mathematical model and simplified the overall maximum force (F_{MAX}) for d=10mm is standardized with $(\frac{d}{\lambda})$ by a constant C_{10} of 1.2783 as given below,

$$F_{MAX} = 1.2783(\frac{2LRB_r^2}{4\mu_\circ}) \quad (1)$$

d = ring thickness
λ = ring width
L = total width
R = mean radius
Br = remanence magnet
$\mu 0$ = magnetic air permeability

A rigid structure for the base plate and rotor has been constructed according to industrial standard to achieve stability of the overhung system. A multi-ring of N35 grade magnet axially magnetized for an operating temperature of 80ºC has been considered for a total 17.8 kilogram (kg) of rotor mass. Rotor deflections, ambient temperature, base plate size and weight are considered as the external factors that has been validated to minimize system distributions that may occurs in overall result for vibrations to the system.

Designing the magnetic bearing housing requires a proper design for rotating and static element sections (Figure 3). A stiff housing structure is required to separate this section, especially for handling high axial force. Equation (1) created a pressure (Pa) between static and rotating element section for an air gap with found to be maximum at 0.344 mega-pascal (mPa) in generative pressure between the rings, above than design load of the rotor. High axial force acting on rotating sleeve secured to the shaft with calculated multiple grab screws and shaft inference with rotating sleeve at is designed to accommodate misalignment according to JIS B 0401 (1999). Overall axial thrust system is suited with two angular contact ball bearings, arranged in back-to-back arrangement with a split casing bearing housing according to ISO 113:2010. Maximum tolerance for axial movement to the rotor is at 300 µm according to American Petroleum Institute (API) 610 11th edition.

Designing the shaft manufactured from rolled round steel forgings for Ø50 mm step diameters withstand the role of bending moment and torque with Marine grade according to DIN 1.4401, X5CrNiMo17-12-2, 316S16, Z6CND17.11, SUS316, 2347 in a consideration of load and wear, corrosion resistance, temperature and thermal expansion and machinability and maintainability. The shaft flexibility factor (SFF) is according to the overhung system calculation and Industrial Standard American Petroleum Institute (API) 610 11th edition for Shaft flexibility index (I_{sf}) for length 1 (L_1), length 2 (L_2), diameter 1(D_1) and diameter 2 (D_2) as shown in Equation (2) and Figure 4.

$$SFF = \frac{{L_1}^3}{{D_1}^4} + L_1.\frac{{L_2}^3}{{D_2}^4} \quad (2)$$

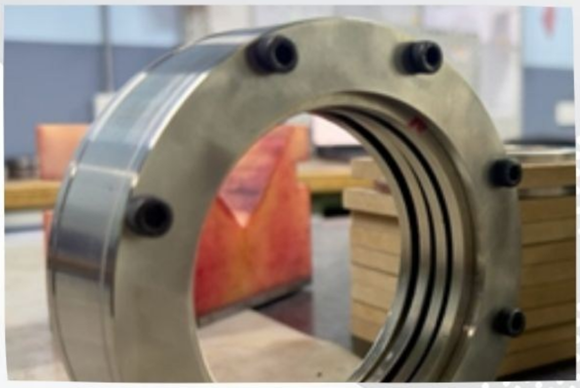

Figure 3: The arrangement of magnetic bearing assembly

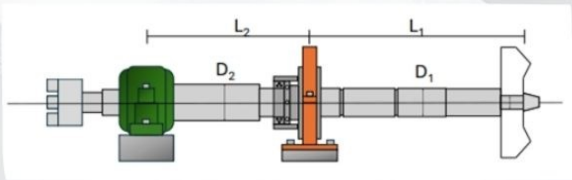

Figure 4: Schematic arrangement for magnetic bearing assembly.

Experimental Set Up and Result

Multiple points have been considered during the test, including rotational speeds of 30 %, 50 % and 83 % at 300 rpm with a rigid base plate of 141.7 kg and a constant ambient room temperature of 26.5 ºC. At two different loads, 15.7 and 17.7 kilograms (kg), at three with bearing spans at 300, 400 and 500 mm, multiple deflection values have been formed for the PMB sleeve at 0.444, 1.294, 0.444, 1.294, 0.310, 0.334, 0.973, 0.197 and PMB 0.132, 0.179, 0.114, 0.172, 0.246 and 0.145 mm. The reaction profiles have also been formed in the system at 71.8, 74.8, 87.9, 91.8, 115.1, and 120.4 Newtons. The PMB has a maximum force capability of 570 Newtons. The test has been successfully conducted with a small power of motor at 1.9 times lower than the conventional power requirement for a conventional bearing as shown in Figure 5. The figure shows a complete structure on an overhung system which consist of an impeller; a set of loads in the system,

Permanent Magnetic Bearing (PMB) assembly with a set of PMB cartridge with housing, a conventional thrust ball bearing; two sets of ball bearing with split housing, electric motor and a controller. It is revealed that the PMB is able to absorb misalignment at the sleeve and PMB, even when the condition was 2 times higher than a conventional number of deflection values for normal sleeve bearing clearance. The test also revealed that the loss of magnetic volume efficiency was more than 12 % due to shaft sagging is the biggest contributor to limiting the operation of the system.

It is essential to make the right material choices and understand their behaviour in order to develop a magnetic bearing that is appropriate, with a particular emphasis on axial forces.

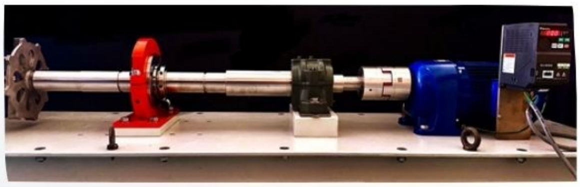

Figure 5: The arrangement for an overhung PMB assembly.

Conclusion

This research provides a thorough review and advancement of magnetic bearing technology which proves that PMB can reduce vibration and subsequently reduce noise to the environment. Multiple references have been made, including with mathematical models with the enhancement of Maximum Force (F_Max) for standardization with other design patterns and size, defined stretch limit for magnetic volume efficiency loss more than 12 %, alongside with constructions of magnetic bearing concept design featuring with a compact housing, as well as insights gained in misalignment, reduction of power and bearing support.

Acknowledgement

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- Vibration is a Hidden Peril in Human Life
- Permanent Magnetic Bearing for an Overhung System
- Materials Lecture Competition 2025, Semi-Final
- IMM Miri Regional Chapter – One-Day Corrosion and Corrosion Control Awareness Course for Oil & Gas Industry
- Oil & Gas Asia 2025

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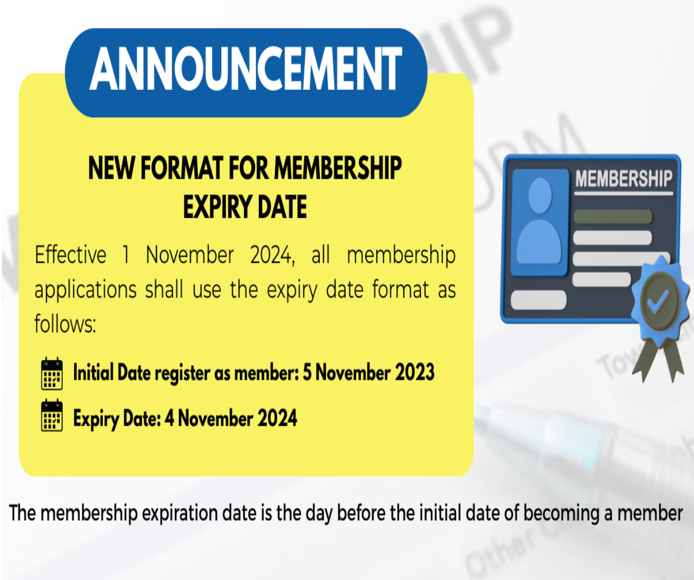

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