International Journal of Advance Industrial Engineering
E-ISSN 2320 –5539

Available at http://inpressco.com/category/ijaie/

Research Article

Manufacturing of Hybrid (Hydrodynamic-Passive) Magnetic Bearing

Lijesh K.P.†* and Samanta P.‡

†Mechanical Engineering Department, Indian Institute of Technology, Delhi, New Delhi, India
‡Surface Engineering and Tribology, CMERI Durgapur, India

Accepted 29 March 2015, Available online 31 March 2015, **Vol.3, No.1 (March 2015)**

Abstract

Performance of bearings in the machinery governs its life. Among all type of bearings, hydrodynamic bearings are the economic to implement. However these bearings show undesired performance during low rotational operating speed and during starting and stopping of the machinery (due to insufficient development of hydrodynamic film). To overcome this problem, the hydrodynamic bearing is hybridized with magnetic bearing. To develop the hybrid bearing three methods have been attempted. The advantage and short coming of each method has been reported

Keywords: *bearing, Passive Magnetic Bearing, Hydrodynamic Bearing, Hybrid Bearing.*

1. Introduction

Hydrodynamic bearing (Hirani, 2009, Hirani *et al*, 1999, Hirani *et al*, 2000, Hirani *et al*, 2000, Hirani *et al*, 2001, Hirani *et al*, 2001, Muzakkir *et al*, 2011, Hirani *et al*, 2002, Hirani,2004, Hirani,2005, Hirani, Suh, 2005, Hirani, Verma, 2009, Muzakkir *et al*, 2013, Muzakkir *et al*, 2015, Muzakkir *and* Hirani 2015, Rao *et al*, 2000, Muzakkir *et al*, 2015, Muzakkir *et al*, 2015, Muzakkir *et al*, 2015, Hirani *et al*, 1997, Hirani *et al*, 1999), ball bearing (Hirani, 2009, Lijesh *et al*, 2015, Lijesh and Hirani, 2015) and magnetic bearings (Lijesh, Hirani, 2014, Lijesh, Hirani, 2015, Lijesh, Hirani, 2015, Lijesh, Hirani, 2015, Muzakkir *et al*, 2014, , Samanta, Hirani, 2007, Samanta, Hirani, 2008, Shankar *et al* 2006, Hirani, Samanta, 2007, Lijesh, Hirani, 2015, Lijesh, Hirani, 2014, Lijesh *et al,* 2015, Lijesh, Hirani, 2015) are well known today. Even MR brakes (Sarkar, Hirani, 2015, Sarkar, Hirani, 2013, Sarkar, Hirani, 2013, Sarkar, Hirani, 2014, Sarkar, Hirani, 2015, Sukhwani, Hirani, 2008, Sukhwani *et al,* 2008, Sukhwani, Hirani, 2008, Sukhwani *et al,* 2009, Sukhwani *et al,* 2007, Muzakkir *and* Hirani 2015) can act as fluid bearing. Each bearing has merits as well demerits. Hydrodynamic bearing is well known for its high load carrying capacity at moderate speed when full fluid film is formed. However high friction and high wear at low speed, i.e. during starting and stopping condition (i.e hydrodynamic film is not formed) reduces the life of the bearing. On the other hand, passive magnetic bearing (PMB) is renowned for its non-contact support, minimum wear and friction at both low and high speed, but its low load carrying capacity restricts its use from different application.

In view of augmentation of hydrodynamic bearing performance at low speed and to enhance the operating life of the bearing, the permanent magnetic bearing has been hybridized with the hydrodynamic bearing. By hybridizing both magnetic and hydrodynamic bearing, followings advantages are obtained:

1. Load carrying capacity can be enhanced (static load is supported by passive magnetic bearing and the dynamic load is handled by hydrodynamic bearing)
2. Low friction and no-wear
3. Increased service-life of bearing

Due to the low load carrying capacity of the PMB, the bearings are rarely used. However the load carrying capacity of the PMB can be enhance by having configuration suggested by (Hirani, Samanta, 2007) as shown in figure 1. In the present work different attempts has been made to manufacture the suggested configuration. The advantages and disadvantages of each attempt are described in detail.

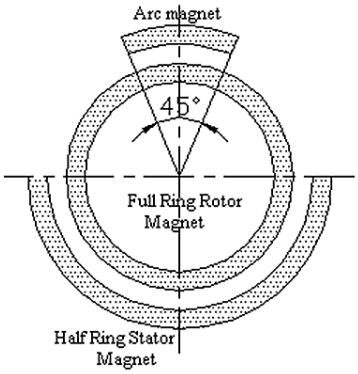

Fig.1 Hybrid Bearing

*Corresponding author: **Lijesh K.P.**

2. Development of Hybrid Bearing

Following three different methods were tried to develop the hybrid bearing:

Method 1: Segmented sector magnets in slots of aluminum ring

To develop hybrid bearing, an aluminum ring with two slots, shown in figure 2, was fabricated. Half ring magnet and 45° arc magnet were inserted into the aluminum ring to get a full ring suitable for film formation of hydrodynamic bearing as shown in Figure 2

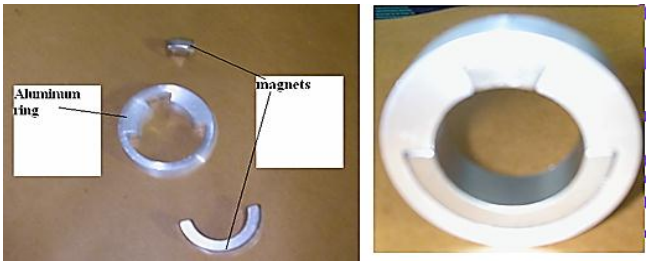

Fig. 2 Hybrid bearing

However during the developing process following problems were encountered

1. It is difficult to fix the magnets properly into the slots of aluminum ring
2. It is hard to get proper circular and smooth inner surface of the ring which is one of the prime objectives for hydrodynamic bearing

Method 2: Structure with Teflon coating

To get the smoother inner surface from aluminum ring fitted with permanent magnets, as discussed in method 1, the ring along with magnets was coated with Teflon as shown in figure 3 and magnetized with the help of magnetizer. This effort solved the problem of fixing of magnet into slots of aluminum ring, but following problems persists in the bearing.

Fig.3 Teflon Coated Hybrid bearing

1. Getting close tolerance
2. Getting proper circular inner surface
3. Need of demagnetization and re-magnetization of permanent magnets to get the final hybrid bearing

Method 3: Powder Metallurgy

In third method, a powder metallurgy process was adopted to make the hybrid bearing. The materials used in the powder metallurgy process were NdFeB magnetic powder, aluminum alloy-7010 powder, Loctite Binder, zinc stearate (as solid lubricant) and acetone. Following steps were adopted to manufacture the hybrid bearing by powder metallurgy process:

1. Weighing the required powder of each NdFeB powder and aluminum powder.
2. Diluting the binder in acetone and forming a liquid form of binder
3. Mixing the liquid binder with measured NdFeB power.
4. Mixing the liquid binder with the measured Aluminum powder separately
5. Placing the powers (mixed with binder) in the die at desired locations and punching surface with zinc stearate with the help of acetone
6. Compress the powder in hydraulic press
7. Cure the green compact at 120°C for 30 minutes in argon gas atmosphere
8. Magnetized the cured sample by magnetizer

The developed hybrid bearing is shown in figure 4. The induced magnetic flux in the bearing was low (500 Gauss), so to improve the magnetic flux following different procedure was followed:

- The powder was place in the die and compressed by the hydraulic press.
- The green powder was magnetized in the die and cured.
- The mixture was magnetized.

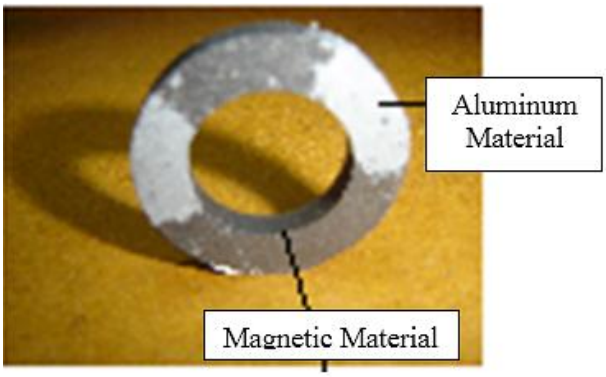

Fig. 4 Hybrid bearing using powder metallurgy method

Again the magnetic field was measured and an increase in magnetic field to 1700 Gauss was observed. This value is still low. The magnetic field can be enhance further by using higher magnetic field magnetizer and sophisticated tools like (1) Power pack for hydraulic

system, (ii) Piston and cylinder and (iii) Fixture for electromagnet. This type of press is difficult to get in the market and market price is very high.

Conclusions

To develop an hybrid bearing (Hydrodynamic + PMB), three different methods were adopted in the present work: (i) Method 1-Inserting sector magnets in the aluminum slots, (ii) Method 2- Structure with Teflon coating, (iii) Method 3. Powder Metallurgy. On comparing the fabricated bearings, it is concluded that method-3 is best method make hybrid bearing. However, to observe real benefits of methods, industry scale machines are required.

References

Hirani, H., Athre, K., Biswas, S. (1998), Rapid and Globally Convergent Method for Dynamically Loaded Journal Bearing Design, *Proc. IMechE (UK), Journal of Engineering Tribology*, vol. 212, pp. 207-214.

Hirani, H., Athre, K., Biswas, S. (1999), Dynamic Analysis of Engine Bearings, *International Journal of Rotating Machinery*, vol. 5, no.4, pp. 283-293.

Hirani, H., Athre, K., Biswas, S. (2000), A Hybrid Solution Scheme for Performance Evaluation of Crankshaft Bearings, *Trans. ASME, Journal of Tribology*, vol. 122, no. 4, pp. 733-740.

Hirani, H., Athre, K., Biswas, S. (2000), Transient Trajectory of Journal in Hydrodynamic Bearing, *Applied Mechanics and Engineering*. vol. 5, no 2.

Hirani, H., Athre, K., Biswas, S. (2001), A Simplified Mass Conserving Algorithm for Journal Bearing under Dynamic Loads, *International Journal of Rotating Machinery*, vol. 1, pp. 41-51.

Hirani, H., Athre, K., Biswas, S. (2001), Lubricant Shear Thinning Analysis of Engine Journal Bearings, *STLE, Journal of Tribology Transaction*, vol 44, no. 1, pp 125-131.

Muzakkir, S.M., Hirani, H., Thakre, G.D., Tyagi, M.R. (2011), Tribological Failure Analysis of Journal Bearings used in Sugar Mill, *Engineering Failure Analysis*, vol. 18, no. 8, pp. 2093-2103.

Hirani, H., Athre, K., Biswas, S. (2002), Comprehensive Design Methodology for Engine Journal Bearing, *IMechE (UK), Part J, Journal of Engineering Tribology*, vol 214, pp. 401-412.

Hirani, H. (2004), Multi-objective Optimization of a journal bearing using the Pareto optimal concept, *Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology*, vol. 218, no. 4, pp. 323-336.

Hirani, H. (2005), Multiobjective optimization of journal bearing using mass conserving and genetic algorithms, *Proc. Institute Mech. Engineers., Part J, Journal of Engineering Tribology*, vol. 219, no. 3, pp. 235-248.

Hirani, H., and Suh, N. P. (2005), Journal Bearing Design using Multi-objective Genetic Algorithm and Axiomatic Design Approaches", *Tribology International*, vol. 38, no. 5, pp. 481-491.

Hirani, H., and Verma, M. (2009), Tribological study of elastomeric bearings of marine shaft system, *Tribology International*, vol. 42, no. 2, pp. 378-390.

Muzakkir, S.M., Hirani, H., Thakre, G.D., (2013), Lubricant for Heavily-Loaded Slow Speed Journal Bearing, Tribology Transactions, vol.56, no. 6, pp. 1060-1068.

Muzakkir, S.M., Lijesh, K. P., Hirani, H., Thakre, G.D. (2015) Effect of Cylindricity on the Tribological Performance of Heavily-Loaded Slow Speed Journal Bearing, Proc. Institute Mech. Engineers., *Part J, Journal of Engineering Tribology*, 2015, vol 229, no.2, pp.178-195.

Muzakkir, S.M. and Hirani, H. (2015), A Magnetorheological Fluid Based Design Of Variable Valve Timing System For Internal Combustion Engine Using Axiomatic Design, International Journal of Current Engineering Research, Vol.5, No.2 (April 2015), pp 603-612.

Rao, T. V. V. L. N., Hirani, H., Athre, K., Biswas, S. (2000), An Analytical Approach to Evaluate Dynamic Coefficients and Non-linear Transient Analysis of a Hydrodynamic Journal Bearing, *STLE Tribology Transactions*, vol. 23, no.1, pp. 109-115.

Muzakkir, S. M., and Harish Hirani. (2015)"Maintenance Free Bearings." *International Journal of Engineering Research,* vol 4, no.3, pp.133-136.

Muzakkir, S. M., Harish Hirani, and G. D. Thakre. (2015), "Experimental Investigations on Effectiveness of Axial and Circumferential Grooves in Minimizing Wear of Journal Bearing Operating in Mixed Lubrication Regime." *International Journal of Current Engineering and Technology*, vol.5, no.1, pp.486-489.

Muzakkir, S. M., K. P. Lijesh, and Harish Hirani. (2015)."Effect of Base Oil on the Anti-Wear Performance of Multi-Walled Carbon Nano-tubes (MWCNT), *International Journal of Current Engineering and Technology*, vol.5, no.2, pp.681-684.

H Hirani, T Rao, K Athre and S Biswas, (1997), Rapid performance evaluation of journal bearings, *Tribology international*, vol. 30, no.11, pp. 825-834.

H Hirani, K Athre, S Biswas, (1999), "Dynamically loaded finite length journal bearings: analytical method of solution". *Journal of tribology*, vol. 121, no. 4, pp. 844-852.

Hirani, H. (2009),"Root cause failure analysis of outer ring fracture of four row cylindrical roller bearing", *Tribology Transactions*, vol.52, no.2, pp.180-190.

Lijesh, K. P., S. M. Muzakkir, and Harish Hirani. (2015), "Failure Analysis of Rolling Contact Bearing for Flywheel Energy Storage Systems.", vol.5, no.1, pp. 439-443.

Lijesh K.P. and Harish Hirani, (2015), "Shaft Alignment Systems: A Comparative Study", vol.5, no.2, pp. 1009-1014.

Lijesh, K. P., Hirani, H., (2014), Stiffness and Damping Coefficients for Rubber mounted Hybrid Bearing, *Lubrication Science*, vol. 26, no.5, pp. 301-314.

Lijesh, K. P., Hirani, H., (2015), Development of Analytical Equations for Design and Optimization of Axially Polarized Radial Passive Magnetic Bearing, *ASME, Journal of Tribology*, vol. 137, no. 1, (9 pages).

Lijesh, K. P., Hirani, H., (2015), Optimization of Eight Pole Radial Active Magnetic Bearing, *ASME, Journal of Tribology*, vol.137, no.2.

Lijesh, K. P. and Hirani, H. (2015), Design and Development of Halbach Electromagnet for Active Magnetic Bearing, *Progress In Electromagnetics Research C*, vol. 56, 173–181.

Muzakkir, S.M., Lijesh, K. P. and Hirani, H. (2014), Tribological Failure Analysis of a Heavily-Loaded Slow Speed Hybrid Journal Bearing, *Engineering Failure Analysis*, vol. 40, pp.97–113.

Samanta, P., Hirani, H., (2007), A Simplified Optimization Approach for Permanent Magnetic Journal Bearing, *Indian Journal of Tribology*.

Samanta, Pranab, and Harish Hirani. (2008), "Magnetic bearing configurations: Theoretical and experimental studies." Magnetics, IEEE Transactions on vol. 44, no. 2, pp. 292-300.

Shankar, S., Sandeep, Hirani, H. (2006), Active Magnetic Bearing, *Indian Journal of Tribology*, pp 15-25.

Hirani, H., Samanta, P. (2007), Hybrid (Hydrodynamic + Permanent Magnetic) Journal Bearings, Proc. Institute Mech. Engineers., *Part J, Journal of Engineering Tribology*, vol. 221, no. J8, pp. 881-891.

Lijesh, K. P., and Harish Hirani. (2015), "The Performance of Hybrid Journal Bearing under Extreme Operating Conditions." International Journal of Current Engineering and Technology, vol. 5, no.1, pp. 277-282.

Lijesh, K. P., and Hirani, H. (2014). "Design of eight pole radial active magnetic bearing using monotonicity. In Industrial and Information Systems (ICIIS), 2014 9th International Conference on IEEE, pp. 1-6.

Lijesh K.P., Harish Hirani, Samanta P., (2015), "Theoretical and Experimental Study for Hybrid Journal Bearing", International Journal of Scientific and Engineering Research, Volume 6, Issue 2, pp. 133-139.

Lijesh K. P, Harish Hirani, (2015), Magnetic Bearing Using RMD Configuration, Journal of Tribology.

Sarkar, C. and Hirani, H., (2015), "Development of magnetorheological brake with slotted disc", *Proc. IMechE, Part D: Journal of Automobile Engineering*, DOI: 10.1177/0954407015574204.

Sarkar, C. and Hirani, H., (2013),"Theoretical and experimental studies on a magnetorheological brake operating under compression plus shear mode", *Smart Materials and Structures*, vol.22. no.11, art. no. 115032

Sarkar, C. and Hirani, H., (2013), "Synthesis and Characterization of Antifriction Magnetorheological Fluids for Brake", *Defense Science Journal*, vol. 63, no.4, pp.408-412.

Sarkar, C. and Hirani, H., (2013), "Design of a Squeeze Film Magnetorheological Brake Considering Compression Enhanced Shear Yield Stress of Magnetorheological Fluid", *Journal of Physics: Conference Series*, vol.412, no.1, 012045.

Sarkar, C. and Hirani, H., (2014), "Effect of particle size on shear stress of magnetorheological fluids", Smart Science, http://dx.doi.org/10.6493/SmartSci.2015.317.

Sukhwani, V. K., Hirani, H., (2008),"A Comparative Study of Magnetorheological-Fluid-Brake and Magnetorheological-Grease-Brake", *Tribology Online*, vol 3, no.1, pp. 31-35.

Sukhwani, V. K., Hirani, H., and Singh, T. (2008), "Synthesis and Performance Evaluation of MR Grease", *NLGI Spokesman,* vol. 71, no.10.

Sukhwani, V. K. and Hirani, H., (2008)," Design, Development and Performance Evaluation of High Speed MR Brake", *Proc. Institute Mech. Engineers., Part L, Journal of Materials: Design and Applications*, vol. 222, no.1, pp. 73-82.

Sukhwani, V. K., Hirani, H., and Singh, T. (2009), "Performance Evaluation of a Magnetorheological Grease Brake", *Greasetech India*, vol. 9, no.4, pp. 5-11.

Sukhwani, V. K., Hirani, H., and Singh, T. (2007),"Synthesis of Magnetorheological (MR) Grease", *Greasetech* India.

Muzakkir, S.M. and Hirani, H. (2015), A Magnetorheological Fluid Based Design Of Variable Valve Timing System For Internal Combustion Engine Using Axiomatic Design, International Journal of Current Engineering Research, vol.5, no.2, pp. 603-612.