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An Experimental Study On Load Carrying Capacity Of A Magnetic Bearing

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***Abstract*— The use of bearing is essential to all types of machines they provide the function of supporting heavier component in a desired position. These bearings have contact with the rotating part and causes surface wear which can be controlled by lubrication. The standards of performance for rotating equipment can be raised by providing robust, cost effective and easy to implement 'Magnetic bearings'. A radial magnetic bearing, consisting of two permanent magnets, is an attractive choice because of its zero wear, negligible friction, and low cost, but it suffers from low load capacity, low radial stiffness, lack of damping and high axial instability. To enhance the radial load and radial stiffness and reduce the axial thrust, a theoretical and experimental study of various radial configurations, including hydrodynamic lubrication to improve dynamic performance of the magnetic bearing is made.**

***Index Terms*— Magnetic, Bearing, Levitation, surface, wear.**

I. Introduction

A magnetic bearing supports the load using magnetic levitation. Magnetic bearings support moving machinery without physical contact. These bearing can levitate a rotating shaft and permit relative motion with very low friction and no mechanical wear.

It is difficult to build a magnetic bearing using permanent magnets due to the limitations and techniques in diamagnetic materials as they are relatively undeveloped. As a result, most magnetic bearings require continuous power input and an active control system to hold the load stable. Many bearings can use permanent magnets to carry the static load, and then only use power when the levitated object deviates from its optimum position. Magnetic bearings also typically require some kind of back-up bearing incase of power or control system failure and during initial start-up conditions.

Two sorts of instabilities are very typically present in magnetic bearings. Firstly, attractive magnets give an unstable static force that decreases with greater distance and increases at close distances. Secondly, since magnetism is a conservative force, it gives little in and off. because If any damping and oscillations may cause loss of successful suspension.

The evolution of magnetic bearings may be traced during World War II and are concerned with ultracentrifuges for purification of the isotopes of various elements for the manufacture of the first nuclear bombs. But the technology did not mature until the advances of solid-state electronics and modern computer-based control technology. Further improved designs were not manufactured due to expensive costs of production. However, some of those designs are used where extremely high RPM is required.

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II. CONSTRUCTION

Radial passive magnetic bearing with Halbach array consists of the ring-shaped permanent magnets with radial and axial orientation of the magnetization vector. The radial permanent magnets have orientation of vector magnetization direct outside of ring diameter and inside the ring diameter.

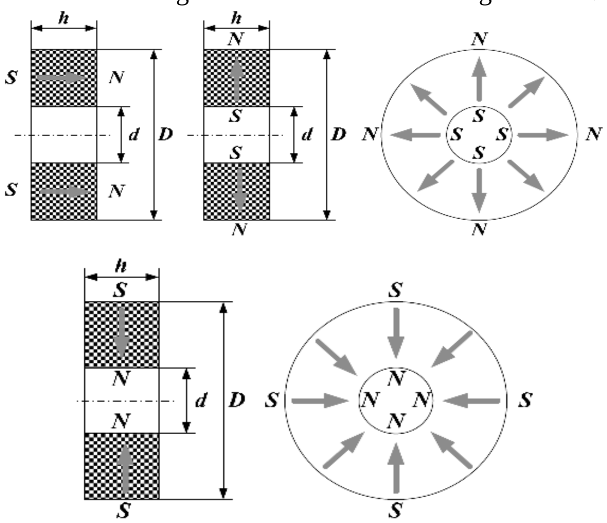
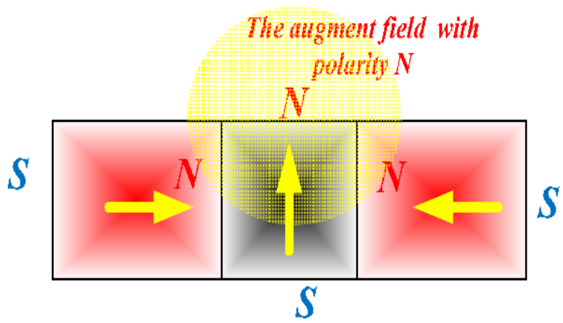


Fig 1: Ring-shaped magnets with radial and axial orientation of magnetization.

The Halbach array has a special arrangement that augments the magnetic field on one side and cancels it on the other side. We can select concentrated magnetic flux regions by proper design. Three ring-shaped magnets are connected here. The first and the third magnets are axially magnetized and direction of magnetization vectors is indicated in Fig. The second magnet is radially magnetized and the magnetization vector is directed outside of the magnet.



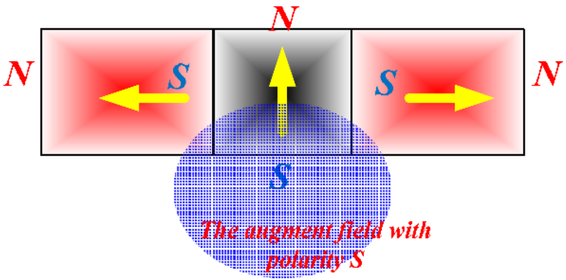


Fig 2: *The augmented field with polarity N (A) and with polarity S (B)*

By connecting these magnets we can obtain strong augmented fields. At concentration poles N of magnets, we get the strong field with polarity N. At change of direction of magnetization vector of axial magnetized magnets, the strong field with polarity S (ref Fig) is obtained. Whereas, at connection of five magnets we can build the array of magnets with polarity *N* and *S*. The magnetic fields of the array are shown in Fig. 3. There are one side with polarity N and two sides with polarity S. This configuration of Halbach array is used in the design of passive magnetic bearing.

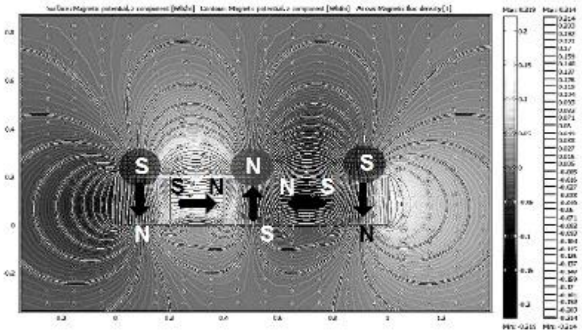


Fig. 3. Configuration of magnets in Halbach array.

III. EXPERIMENTAL SETUP

For Dynamic test:

The work setup has to be assembled on lab stand that consists of three supports. They are

a. The self-aligning bearing (the first support)

b. The active magnetic bearing (the second support)

c. The passive magnetic bearing (the third support)

The active magnetic bearing suspends rotor and it is the source of external forces and an oscillator of rotor motion. The flexible rotor connects a self aligning support and an active magnetic support. This rotor isolates the passive bearing model from the ground vibration. The rigid rotor connects an active magnetic support and the passive magnetic support. The rotor carries extortion displacement generated by the active magnetic bearing to a surface of the passive magnetic bearing.

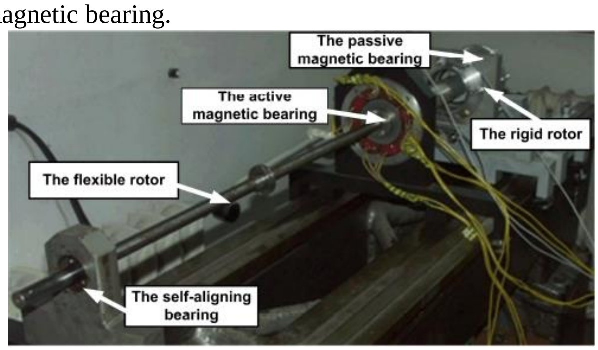


Fig 4: The lab stand for experimental tests of PMB

For Radial Stiffness:

Another experiment is conducted to find stiffness.

a. Drive motor is removed from the setup.

b. Now the radial load is given to the rotor with help of turn buckle arrangements. The applied load is measured by dynamometer. With the help of position sensor, the rotor displacement for the corresponding loading is noted.

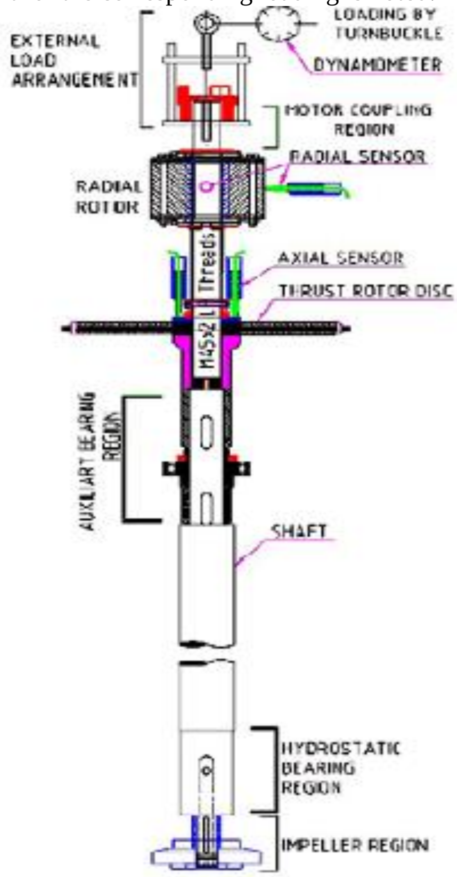


Fig 5: Stiffness Calculation of Radial Magnetic Bearing Based on Experimental Displacement Value of Rotor

With the calculated force from analysis and experimental displacement of rotor from sensor output, the stiffness of the bearing X and Y direction is calculated as:

Along X-direction, Force=24.11 N

Actual displacement (from sensor) = 172.5 μm

New stiffness = 139.77 kN/m

Along Y-direction Force 17.79 N

Actual displacement (from sensor) = 133 μm

New stiffness = 136.76 kN/m

IV. RESULTS AND DISCUSSION

Dynamic and static characteristics were obtained for a passive magnetic bearing with Halbach array. The rotor was loaded by the static force and the displacement of rotor was measured by the sensor. The stiffness coefficient was estimated from this characteristic and it is equal to 129297,075 N/m. A position of rotor for a load 90 N is shown in the fig. The passive magnetic bearing has steady state error of rotor position in the air gap. The rotor position is a result of superposition of the external forces and of the repelling magnetic force. The radial passive magnetic bearing makes full use of differential magnetic force, So the static characteristic is linear.

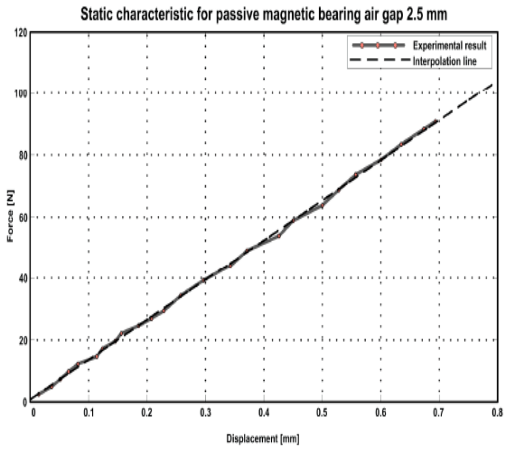


Fig 6: The static characteristic of passive magnetic bearing

The Bode diagram between external forces and rotor displacement according to the passive support surface is illustrated in Fig. The bandwidth at resonance frequency 45 Hz is presented there. The frequency of 45 Hz is observed from the signal of displacement sensors for the step response and for the environment background.

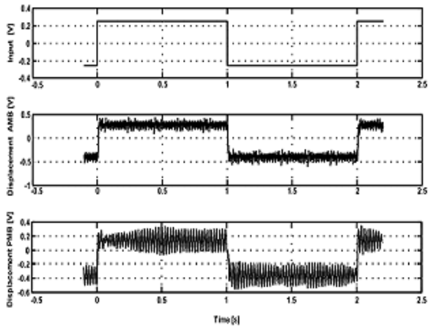


Fig 7: Step response of active (AMB) and passive (PMB) magnetic bearing to excitation by external signal at the axis Ox

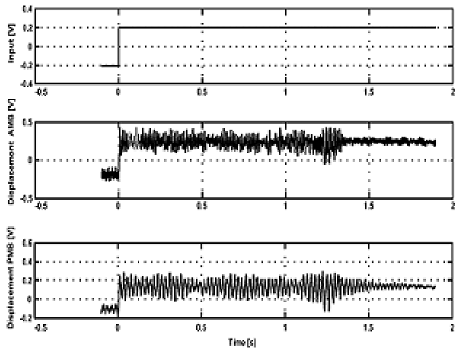


Fig 8: Step response of active (AMB) and passive (PMB) magnetic bearing to excitation by external signal at the axis Oy.

In the next step, the dynamic characteristics were obtained where the only excitation source was the active magnetic bearing. The step response is shown in fig. indicates damped response frequency of about 45 Hz, settling time of 0.42 s, time delay 0.00937 s and rise time of 0.0131 s.

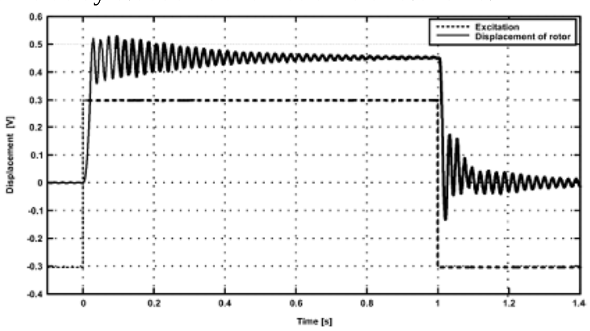


Fig 9: The step response of the PMB

Dynamic condition:

Calculation of Stiffness of Radial Magnetic Bearing using Centrifugal Force and Displacement of Rotor

The AMB shaft is dynamically balanced to IS 1940 G2.5 grade standard. The final unbalanced mass of the system in each plane is within the limits of grade G2.5. The centrifugal force created by unbalance mass on radial magnetic bearing plane is as follows

$Fc = mr(w^2)$

Where, m = Unbalanced mass (kg)

r = radius of the unbalanced mass (taken as the radial bearing rotor radius)

w = 2 /60 = 303.68 rad/s for n=2900 rpm

Permissible residual unbalance for each balancing plane (Upper) = 413.557 g mm per plane [8]

Centrifugal force created by the unbalance =413.557E-6* (w^2) = 38.139 N

From the centrifugal force due to unbalance mass acting on rotor & displacement of the rotor from sensor output the stiffness of the magnetic bearing in dynamic condition is found out.

Maximum displacement of rotor in radial direction at 2900 rpm is 281.7 µm (or) 2.817e-4 [9]

Bearing Stiffness = Force/displacement

= 38.139 / 2.817e-4 = 135.39kN/m

V. CONCLUSION

a. Limitations in Magnetic Bearings arise from two reasons: the state of the actual technology in design and material, and from basic physical relations. The paper has given a survey on such limitations, giving a brief theoretical background, showing examples and pointing to actual data.
b. The design of passive magnetic bearing with Halbach array is presented in the paper The classical design of a bearing does not assure flexibility of suspension as the designed passive magnetic bearing does. The active magnetic bearing can assure flexibility at this level. However, it requires a lot of energy for generation of magnetic forces in the bearing with such air gap.

The passive magnetic bearing ensures levitation of rotor, high stiffness, dynamic parameters and flexibility suspension and it does not absorb energy during the operation. If increase of stiffness and dynamic parameters is needed, decrease of the air gap of bearing provides it.

VI. ADVANTAGES OF MAGNETIC BEARING

a. These bearings work on the principle of magnetic repulsion thus making it contact free. Hence there is no friction.
b. There is no usage of lubrication. Hence there is no maintenance required.
c. Permanent magnetic property can tolerate against heat, cold, vacuum and chemicals.
d. Since there is no friction, losses due to friction are less and very high rotational speeds can be achieved.
e. The range of operating temperature is very wide.

VII. APPLICATIONS

Magnetic bearing advantages include very low and predictable friction, ability to lubrication and in a vacuum.

Magnetic bearings are increasingly used in industrial machines such as compressors, turbines, pumps, motors and generators. Magnetic bearings are commonly used in watt-hour meters by electric utilities to measure home power consumption. Magnetic bearings are also used in high-precision instruments and to support equipment in a vacuum, for example in flywheel energy storage systems. Magnetic bearings are also used to support maglev trains in order to get low noise and smooth ride by eliminating physical contact surfaces.

A new application of magnetic bearings is their use in artificial hearts. The use of magnetic suspension in ventricular assist devices was pioneered by Prof. Paul Allaire and Prof.Houston Wood at the University of Virginia culminating in the first magnetically suspended ventricular assist centrifugal pump (VAD) in 1999.

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References

[1] 1. Falkowski K., Gosiewski Z. "The differential passive magnetic bearing for high- speed flexible rotor", SOLID STATE PHENOMENA (2009), volume 144, pp. 273-278.

[2] 2. Jiangbo Wang, Chunsheng Li, Yaohun Li, Luguang Yan, "Optimization Design of Linear".

[3] 3. "Halbach Array", IEEE Xplore

[4] 4. Q. Han, C. Ham, R. Phillips, "Four- and eight-piece Halbach array analysis and geometry".

[5] 5. "Optimization for Maglev", IEE Proc.-Electr. Power Appl., Vol.152, No. 3, May (2005)

[6] 6. Jeffrey Hillyard, “Magnetic Bearings” Joint Advanced Student School, April 2006 –St Petersburg, Russia.

[7] 7. Q. Tan, W. Li, and B. Liu, “Investigations on a permanent magnetic hydrodynamic-hydrodynamic journal bearing,” 2002, Tribol. Int., vol. 35, pp. 443–448.

[8] 8. J. Delamare, E. Rulliere, and J. P. Yonnet, “Classification and synthesis of permanent magnet bearing configurations,” Nov. 1995, IEEE Trans. Magn., vol. 31, no. 6, pp. 4190–4192.

[9] 9. S. C. Mukhopadhyay, T. Ohji, M. Iwahara, S. Yamada, and F. Matsumura, “Disturbance attenuation and H control on repulsive type magnetic bearing,” IEEE Trans. Magn., vol. 33, no. 5, Sep. 1997, pp. 4233–4235.

[10] 10. J. P. Yonnet, “Permanent magnet bearings and couplings,” IEEE Trans. Magn., vol. MAG-17, no. 1, Jan. 1981, pp. 1169–1173.

[11] 11. K.Y. Zhu a, Y. Xiao , Acharya U. Rajendra a “Optimal control of the magnetic bearings for a flywheel energy storage system”.

[12] 12. Marinescu, M., and Marinescu, N., 1994, ‘‘A New Improved Method for Computation of Radial Stiffness in Permanent

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