DESIGN AND ANALYSIS OF NEW PERMANENT MAGNET BIASED HETEROPOLAR MAGNETIC BEARINGS

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ABSTRACT

A New permanent magnet biased heteropolar magnetic bearing is developed. The magnetic force to current relation for the new bearing is analyzed with both 1-D magnetic circuit and 3-D magnetic field modeling. The new magnetic bearing has a unique biasing scheme that directs the bias flux flow circumferentially to energize the working air gaps.

INTRODUCTION

All electromagnetic heteropolar magnetic bearings are widely used in industry since they have some advantages such as axially thin shape and easiness to manufacture. However, heteropolar magnetic bearings consume substantial amount of electric power because they typically use bias currents to energize the working air gaps. Unlike heteropolar magnetic bearings, homopolar magnetic bearings have a unique biasing scheme that directs the bias flux flow into the active pole plane where it energizes the working air gaps, and then returns through the other pole plane (typically dead) and the shaft sleeve. Homopolar magnetic bearings yield a very high efficiency when the permanent magnets are used as the source of bias flux to energize the air gaps and the electromagnetic coils are used to supply control fluxes [1]-[4]. Due to the axial bias flux flow through the dead pole plane, homopolar magnetic bearings have axially thick shape as well as undesirable additional negative stiffness. This paper describes the theory and following numerical analysis for the novel permanent magnet biased heteropolar type magnetic bearing.

MODELING

The schematic of permanent magnet biased heteropolar magnetic bearing is shown in Fig. 1.

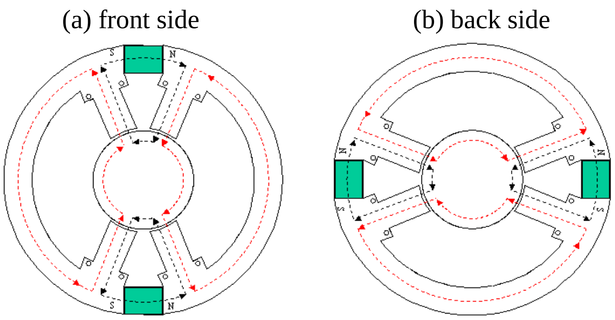


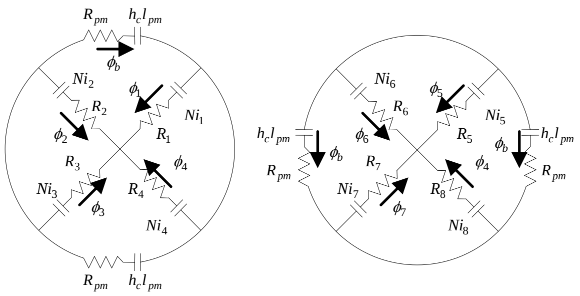
FIGURE 1: The schematic of permanent magnet biased heteropolar magnetic bearing

The bearing consists of two 4-pole magnetic bearing stators. The bearing stator shown in Fig. 1 (a) has two permanent magnets positioned between the C-cores to energize the working air gaps, and control coils are wound on the pole pairs to generate control fluxes. The net magnetic forces then should be produced along the y direction. The bearing stator shown in Fig. 1 (b) is also designed to produce magnetic forces along the x direction. Assuming that eddy current effects and material path reluctances are neglected, Maxwell's equations are reduced to the equivalent magnetic circuit for the magnetic bearing as shown in Fig. 2. The reluctance in air gap j of the active pole plane is;

$$R_j = \frac{g_j}{\mu_0 A} \tag{1}$$

Where

$$g_j = g_0 - x\cos\theta_j - y\sin\theta_j \tag{2}$$



(a) front side (b) back side

FIGURE 2: The Equivalent Magnetic Circuit for the permanent magnet biased heteropolar magnetic bearing.

Applying Ampere's law and Gauss's law to the two magnetic circuit leads to a matrix equations as follows. The front side of the magnetic circuit in Fig. 2 (a) represents y-direction flux-current relation which leads to;

$$\begin{bmatrix} R_1 + R_b/2 & -R_2 & 0 & R_b/2 \\ 0 & R_2 & -R_3 & 0 \\ R_b/2 & 0 & R_3 & -(R_4 + R_b/2) \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \end{bmatrix} = \begin{bmatrix} h_c l_{pm} \\ 0 \\ -h_c l_{pm} \\ 0 \end{bmatrix} + \begin{bmatrix} n & -n & 0 & 0 \\ 0 & n & -n & 0 \\ 0 & 0 & n & -n \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \\ i_4 \end{bmatrix} \tag{3}$$

or $$R_y \Phi_y = H_y + N_y I_y \tag{4}$$

The back side of the magnetic circuit in Fig. 2 (b) represents x-direction flux-current relation which leads to;

$$\begin{bmatrix} R_5 & -R_6 & 0 & 0 \\ 0 & R_6 & -(R_7 + R_b/2) & -R_b/2 \\ -R_5 & 0 & R_b/2 & R_8 + R_b/2 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} \phi_5 \\ \phi_6 \\ \phi_7 \\ \phi_8 \end{bmatrix} = \begin{bmatrix} 0 \\ -h_c l_{pm} \\ h_c l_{pm} \\ 0 \end{bmatrix} + \begin{bmatrix} n & -n & 0 & 0 \\ 0 & n & -n & 0 \\ -n & 0 & 0 & -n \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_5 \\ i_6 \\ i_7 \\ i_8 \end{bmatrix} \tag{5}$$

or $$R_x \Phi_x = H_x + N_x I_x \tag{6}$$

The flux density vector in the air gaps is described as;

$$B_x = \varsigma A^{-1} R_x^{-1} (H_x + N_x I_x) \tag{7}$$

$$B_y = \varsigma A^{-1} R_y^{-1} (H_y + N_y I_y) \tag{8}$$

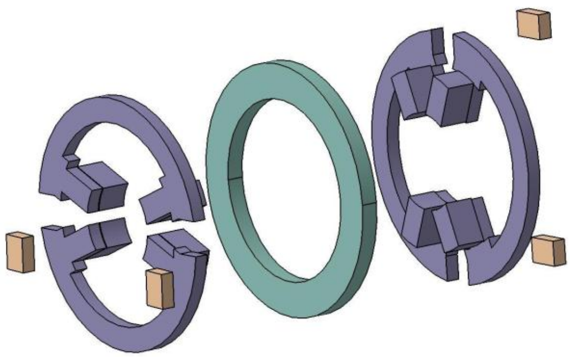
The magnetic forces developed in the bearing are described as;

$$f_x = B_x^T \frac{\partial D}{\partial x} B_x, \quad f_y = B_x^T \frac{\partial D}{\partial y} B_x \tag{9}$$

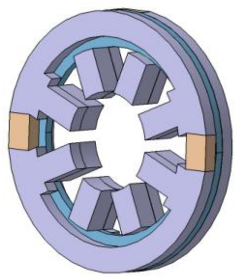
and where the air gap energy matrix is;

$$D = diag([g_j a_0 / (2\mu_0)]) \tag{10}$$

A new 8 pole permanent magnet biased magnetic bearing is designed based on the theory of two separate bearing actuators. The two magnetic bearing stators in Fig 1 are assembled together with a non-magnetic spacer ring between the two stators such that the spacer may separate the magnetic fluxes between the two actuators. The combined magnetic bearing has 8 poles which are lined up at the bearing center as shown in Fig. 3.



(a) Stretched Magnetic Bearing Assembly



(b) Combined Magnetic Bearing Assembly

FIGURE 3: New permanent magnet biased Heteropolar Type magnetic bearing

MAGNETIC FLELD SIMULATION

The 3-D magnetic field model is constructed for the designed magnetic bearing shown in Fig. 3. A commercial magnetic field software (MAXWELL3D) is used for the 3-D field calculation.

Some examples of 3-D magnetic field simulation are calculated for the new magnetic bearing with the nominal air gap g_0 (0.5 mm), pole face area a_0 (180 mm^2), number of coil turns n (50 turns). Permanent magnets are selected as SmCo24 with coercivity of 756000 Amp/m and size of 12mm*16mm*6mm. The bias flux density vector driven by the permanent magnets in the bearing is shwon in Fig. 4.

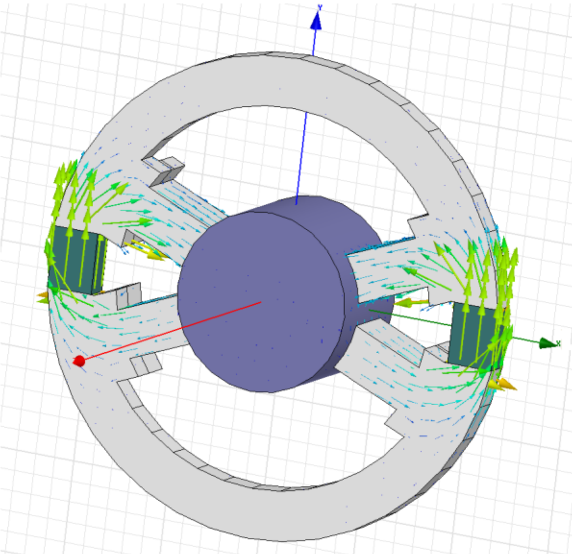


FIGURE 4: Bias Flux Density Vector calculated in the magnetic bearing

The bias fluxes in the bearing are formed in C-cores and the bias flux density in the working air gaps is calculated to be 0.6 tesla. Two coil pairs are wound in one pole and then wound in a opposite pole in a reverse direction to generate C-core control fluxes. Control currents of 4 Amperes are then applied on each coil pairs of the bearing to generate net magnetic forces. Bias fluxes and control fluxes add up in the right poles and are subtracted in the left poles such that net magnetic forces are generated. The combined bias fluxes and control fluxes in the bearing are shown in Fig. 5. It is notable that the magnetic fluxes are uniformly distributed through the poles.

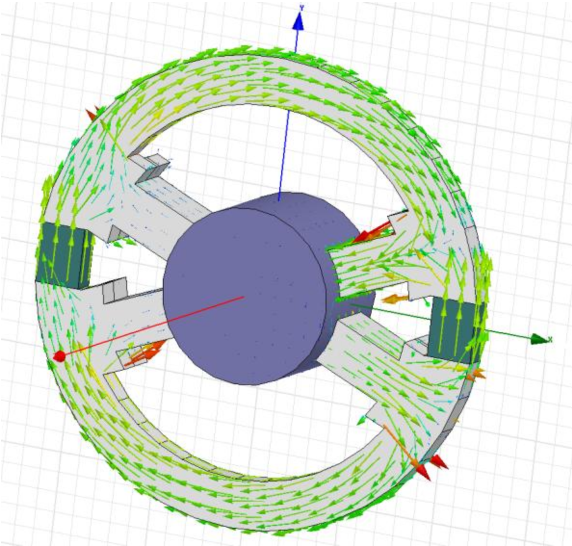


FIGURE 5: Combined Bias Flux and Control Flux Density Vector calculated in the magnetic bearing

The two bearing actuators are combined with a spacer ring as shown in Fig. 3. Magnetic field simulations are conducted on the new magnetic bearing. Currents of 3 amperes are applied on all 4 coil pairs such that the magnetic bearing should generate magnetic forces in the 45^o direction from the x axis. The combined bias fluxes and control fluxes in the bearing are shown in Fig. 6. The magnetic field calculated in the magnetic bearing shows that the bearing can generate the magnetic forces in a desired directions. However, there exists some flux leakage between the two stators.

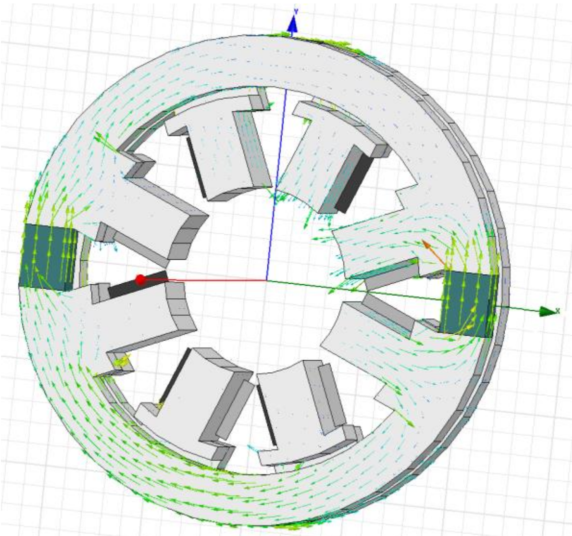


FIGURE 6: Magnetic Field calculated in the magnetic bearing

CONCLUSION

A novel permanent magnet biased heteropolar type magnetic bearing is developed. The equivalent magnetic circuits for each of the magnetic bearing stators are developed so that flux density to current relations on the magnetic bearings is calculated. Based on the magnetic circuit analysis magnetic forces also can be developed. The new permanent magnet biased magnetic bearing has a unique biasing and control path such that the fluxes flow in the circumferential direction. This design makes the bearing axially thin and does not require a dead pole plane. Some magnetic field simulations show that the bearing can generate arbitrary magnetic forces. However, the bearing has relatively complex flux paths and hard to manufacture. Energy efficient heteropolar magnetic bearings may find great use in some applications such as flywheel energy storage systems.

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[1] C.R. Meeks, E. DiRusso, and G.V. Brown, "Development of a Compact, Light Weight Magnetic Bearing," AIAA Paper No. AIAA-90-2483, 1990.[2] C.K. Sortore, P.E. Allaire, E.H. Maslen, R.R. Humphris, and P.A. Studer, "Permanent Magnet Biased Magnetic Bearings – Design, Construction and Testing," *Proceedings of the Second International Symposium on Magnetic Bearings*, pp. 175-182, Tokyo, Japan, June 1990.[3] P.E. Allaire, E.H. Maslen, R.R. Humphris, C.K. Sortore, and P.A. Studer, "Low Power Magnetic Bearing Design for High Speed Rotating Machinery," *Proceedings of the NASA International Symposium on Magnetic Suspension Technology*, pp. 317-329, 1992.[4] E.H. Maslen, P.E. Allaire, M.D. Noh, and C.K. Sortore, "Magnetic Bearing Design for Reduced Power Consumption," *ASME Journal of Tribology*, Vol. 118, pp. 839-846, 1996.