Design Criteria of Active Thrust Magnetic Bearing Using Improved Equivalent Magnetic Circuit Method and Finite Element Method

Seok-Myeong Jang[1], Kwan-Ho Kim[1], Kyoung-Jin Ko[1], Ji-Hwan Choi[1], So-Young Sung[2], Yong-Bok Lee[3]
Dept. of Electrical Engineering, Chungnam Nat'l Univ., 220, Gung-dong, Yuseong-gu, Daejeon, Korea[1]
Korea Ocean Research & Development Institute[2], Korea Institute of Science and Technology[3]
uranuskh@cnu.ac.kr

Abstract — This paper deals with the design criteria of active thrust magnetic bearing (ATMB) using improved equivalent magnetic circuit (EMC) method and finite element method (FEM). Because the EMC method which is commonly used in initial design of ATMB has low accuracy of result, this paper suggested improved EMC method considering fringing. Then, detail design is made up by 3D-FEM. Based on this method, ATMB is manufactured and proven whether satisfying the requirements or not by experiments.

I. INTRODUCTION

Magnetic bearings (MB) have advantages such as extending a limit of rotational speed, maintenance free, low acoustic noise and reliable operation in cryogenic or vacuum environment [1]-[3]. Largely, MB is divided into PMB and AMB. In case of PMBs, the attractive force is generated by permanent magnet and they are highly efficient due to their characteristic that doesn't need to control current. However, they have defects that they are enormously influenced by vibration or disturbance. Moreover, in case used permanent magnet, due to the facts such as high fluctuation of price or instability of material supply, today lots of studies are on the march briskly to replace permanent magnet machine with machinery using electromagnet. Though the ATM which is designed in this paper required flowing control current continuously, it has highlighted advantage to sustain regular stiffness because it controls the current actively up to outer circumstance [4], [5]. Besides, that is has more beneficial than PMB concerning maintenance and production fee due to its simple structure and mechanical firmness.

EMC method and FEM are used in designing MB. In case of EMC method containing high error rate, however, using FEM is more common when it is designed. Even though the accuracy of the results by FEM is highly reliable, it takes very long analysis time if it is only applied to consider each required design parameters. To overcome this problem, this paper suggests EMC method reducing error rate of result and through this method processed initial design. To satisfy the required thrust, the initial design using improved EMC is firstly performed, and the 3D FEM is applied for accurate characteristic analysis. This process can dramatically reduce the design period in that the EMC not only takes very short time but also can consider fringing effects, and the 3D FEM can offer specific results, such as saturation effects.

The ATMB model is designed to be thrust over 15N when air-gap is 3mm and input current is 3A. Based on this design, real model is manufactured and proven whether satisfying the requirements or not by experiments.

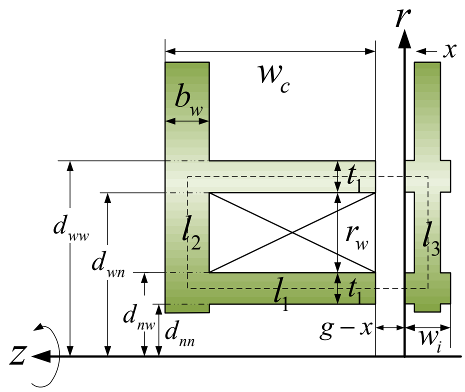

Fig. 1. Initial design model of ATMB

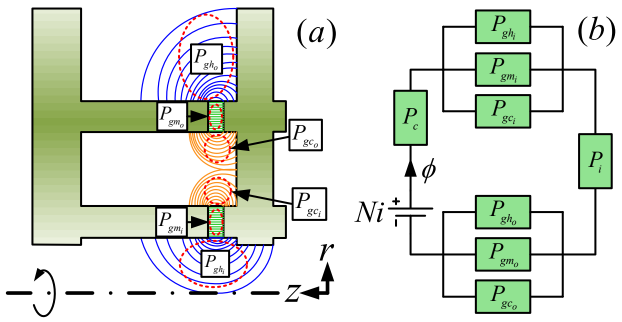

Fig. 2. (a) Fringing effect at air gap, (b)EMC considering fringing effect

II. DESIGN OF ATMB USING IMPROVED EMC

Fig. 1 shows the initial design model of ATMB for improved EMC method. The model is designed by predicting the magnetic force occurred by electromagnet. The magnetic bearing has fringing effect in air-gap, and its consideration is very essential for accurate design. When the permeance in air-gap is calculated in detail as suggested in this paper, the reliability of analysis results by EMC method can be dramatically increased. To calculate magnetic force accurately, the fringing effect should be considered, as shown in Fig. 2(a). For this reason, we deal with EMC considering fringing effect shown in Fig. 2(b). Because fringing effect only exists in air-gap, the other filed except air gap can be calculated by using conventional EMC method. The permeance of magnetic circuit is like (1).

$$P = \frac{\mu_0 \mu_r S}{l}\,. \tag{1}$$

TABLE I
SPECIFICATION OF DESIGE MODEL

Parameter		Values
Stator	Inner semi diameter of the inner magnetic ring [d_{nn}]	19.9[mm]
	Inner semi diameter of the outer magnetic ring [d_{nw}]	25.4[mm]
	Outer semi diameter of the inner magnetic ring [d_{wn}]	39.2[mm]
	Outer semi diameter of the outer magnetic ring [d_{ww}]	44.7[mm]
	Length of the outer housing [w_c]	42.3[mm]
	Area of the outer electromagnet ring [S_1]	782.73[mm2]
	Area of the inner electromagnet ring [S_2]	1449.7[mm2]
Mover	Length of the disk [w_i]	6.5[mm]
Coil	Number of turns in coil	200
	Diameter of the coil	1[mm]

In this formula, S presents cross-section area of flux path, l presents length of flux path, μ_0 present permeability of vacuum ($4\pi\times10^{-7}$), and μ_r presents permeability in the material.

As Fig. 2(a), fringing effect is the phenomenon which makes flux line to expend toward outside in air gap. Due to this effect the effective area where magnetic force is generated are enlarged and it bring about growth of magnetic force. Therefore, the EMC method considering fringing effect could design the part of teeth about less 17% than when it carried on by using conventional EMC method. As a result of that process, the error of existing design could be reduced.

III. DETAIL DESIGN AND THE EXPERIMENT RESULTS

A. Verification and Detail Design of Initial Design Model Using FEM

In this chapter, the detailed design and its verification are performed based on the initial design using the improved EMC method dealt with above. The design model form is showed Table 1 and the mesh of 3D-FEM which is needed to analysis is showed Fig.3 (a). It could be convinced that the EMC method suggested in this paper has higher accuracy results than those of conventional EMC method because the fringing effect is generated in air-gap as illustrated in Fig. 3(b).

B. Verification Required Thrust through Manufacture of Detail Design Model

To examine the fitness of commission, the detail model is designed by 3D-FEM and then the inductance and thrust were measured by organized equipment of Fig. 4. The inductance according the change of Air-gap is deducted by time constant which is gained from Turn-on test of input current, and the thrust that air-gap is 3mm, and it is measured using load sell. The results which are analysis results for each design method and experiment results shown in Fig. 5, and analysis and experiment results were satisfied with the thrust requirements.

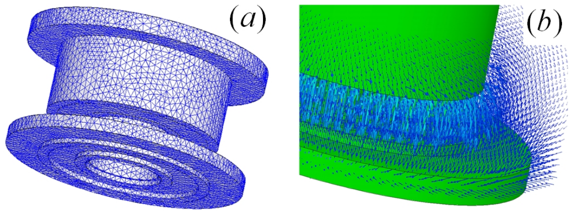

Fig. 3. (a)3D-FEM Mesh to analyze of ATMB, (b)Flux density vector of ATMB by 3D-FEM

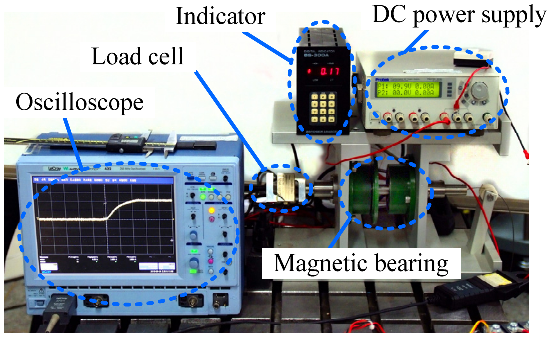

Fig. 4. Experiment equipment for inductance and magnetic force measurement of ATMB

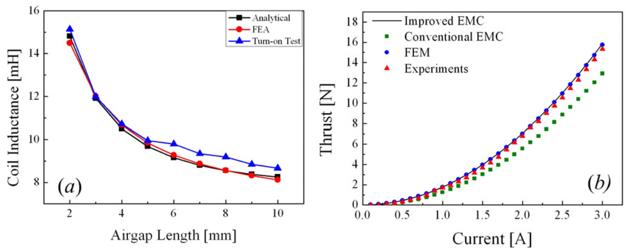

Fig. 5. (a) Inductance for current variation, (b) Thrust for current variation

IV. DISCUSSION

In this paper, to satisfy the required thrust, the initial design using improved EMC is firstly performed, and the 3D FEM is applied for accurate characteristic analysis. ATMB which is manufactured through detail design model is verified the required thrust through experiment. In existing EMC method case, design errors are up by 20%. But improved EMC method's errors are round about 2%. This is considered very useful development in reduce the design period of ATMB.

V. REFERENCES

[1] G. G. Sotelo, R. de Andrade, and A. C. Ferreira "Magnetic bearing sets for a flywheel system" *IEEE Trans. Appl. Supercond.*, v. 17 no.2, pp. 2150-2153, 2007.

[2] A. Chiba, T. Fukao, O. Ichikawa, M. Takemoto, and D. G. Dorrell, Magnetic Bearings and Bearingless Drives. U.K.: Newnos, 2005, pp. 1–15.

[3] W. K. S. Khoo, S. D. Garvey, and K. Kalita, "The specific load capacity of radial-flux radial magnetic bearings," *IEEE Trans. Magn.*, vol. 43, no. 7, pp. 3293–3300, Jul. 2007.

[4] T. Azukizawa, S. Yamamoto, and N. Matsuo, "Feasibility study of a passive magnetic bearing using the ring shaped permanent magnets," *IEEE Trans. Magn.*, vol. 44, no. 11, pp. 4277–4280, Nov. 2008.

[5] R. Ravaud, G. Lemarquand, and V. Lemarquand, "Force and stiffness of passive magnetic bearings using permanent magnets. Part 2: Radial magnetization," *IEEE Trans.Magn.*, vol. 45, no. 9, pp. 3334–3342, Sep. 2009.