Design, Analysis and Control of a Radial Active Magnetic Bearing for High Speed Turbo-Machinery Motors

Do-Kwan Hong[1], Ki-Chang Lee[1], Yeon-Ho Jeong[1], Byung-Chul Woo[1], Dae-Hyun Koo[1], and Min-Cheol Lee[2]
[1]Electric Motor Research Center, Korea Electrotechnology Research Institute Changwon, 641-120, Korea
[2]School of Mechanical Engineering, Pusan National University, Geumjeong-gu, Busan, 609-735, Korea
dkhong@keri.re.kr

Abstract — This paper deals with the design of Active Magnetic Bearings (AMBs) for high speed motor-blower system, whose ratings are 220 kW, 30krpm. In this high-speed blower application, the rotating masses are high and this heavy rotor can limit the static and dynamic load capacities of the AMB actuators. So the performance of the AMBs can be degraded. First of all, the design specification of the high speed impeller is suggested. And electro-magnetic actuator design with magnetic field analysis and proper controller design with bias-current linearization techniques are carried out. Conventionally the 8-pole radial active magnetic bearings. The analytical and experimental results are suggested. Also 3-D dynamic analysis of rotor supported by active magnetic bearings is performed to find the critical speeds of rotor by Campbell diagram. The analysis shows that the critical speed of the rotor is higher than operating speed of the motor with sufficient separation margin. Finally the performances of the radial AMBs for the high speed motor prototype are verified successfully through feedback control test.

I. INTRODUCTION

The 30,000 rpm, 200 kW rated high-speed permanent magnet synchronous motor(PMSM) supported by Active Magnetic Bearings (AMBs) is designed for turbo-machinery applications. Fig. 1 shows a turbo machinery application of high speed motor with active magnetic bearings. This paper deals with design, simulation, of radial AMB. Then the verified radial AMBs are manufactured and tested by control system in static condition. To check bearing stiffness of the rotor supported by radial AMBs a magnetic field analysis is performed [1]. Then, the calculated radial stiffness is used rotordynamic analysis. It is essential that the developed rotor is verified for the critical speed [2].

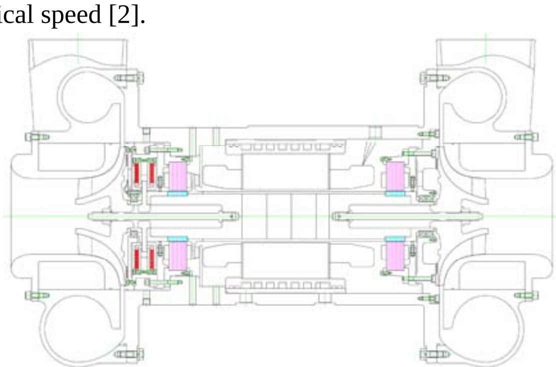

Fig. 1. A prototype of high speed motor-driven air blower supported by AMBs

The critical speed and separation margin can be extracted from Campbell diagram using 3D rotordynamic analysis. 3D rotordynamic analysis result will be shown in full paper. The active magnetic bearing actuators are supplied by constant bias current of 1.2A and tested by a proportional-integral-derivative (PID) controller [3].

II. DESIGN AND ANALYSIS OF AMBS

The developed force for each control axis and inductance of each actuator of the conventional 8-pole active magnetic bearings are as follows [4].

$$F_{net} = \frac{1}{4}\mu_o \frac{N^2}{{g_0}^2}\cos(22.5°) i_B i_c \ , \ L = \frac{1}{2}\frac{\mu_o N^2 A}{g_0 - x} \qquad (1)$$

Where F_{net} is resultant force of upper and lower electromagnetic actuator and L is inductance of each electromagnet. Also the μ_o is permeability of the air, N is number of coil turns per pole, A is the cross sectional area of each pole, g_o is nominal air gap, x is deviation of the rotor, i_B is bias current and i_c is control current.

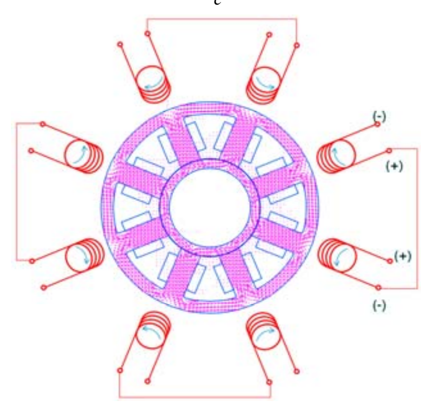

Fig. 2. Magnetic path of radial AMB

Design and analysis data of radial AMBs for rated 25.36 kg rotor is presented. Magnetic analysis is performed according presented dimension. The linearized position stiffness(kx) and current stiffness(ki) are obtained by that result within gap control range. Fig. 2 shows magnetic paths, winding and current directions of a radial AMB. Fig 3 shows variation of force of radial AMB according to gap and current for control. The model is considered on one side. The core material is used S12. Through the simulation result, the open-loop stiffness of the radial AMB has linear characteristics(2.3e6 [N/m]) within allowable deviation ranges($\pm$100[μm]). The calculated open-loop stiffness of radial AMB is applied for rotordynamics analysis. To regulate into origin the rotor which is supported by a radial magnetic bearing, inductance variation is shown varying gap and current in Fig. 3. The calculated inductance is shown with varying control current and air gap.

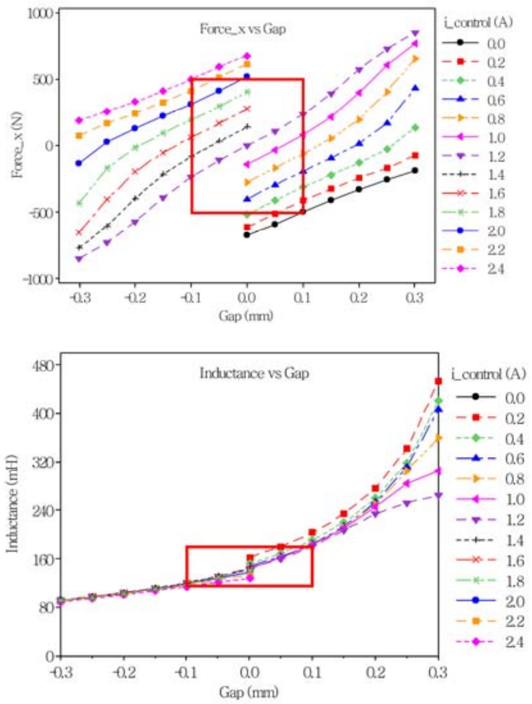

Fig. 3. Magnetic force and inductance of radial AMB

III. LOCAL PID CONTROLLER DESIGN FOR RADIAL AMBS

A test setup is made for the assessment of the developed AMBs, which is shown in Fig. 4. In the test setup, all the component of turbo-blower such as impellers, rotors and radial and thrust bearings are used, except the stator of the high speed PM motor. In rotor dynamics aspects, this missing component is not significant. In spite of successful control of the rotor in center in axial axis(z-axis) with the thrust AMBs, the result of axial rotor control is not shown in next figures. It is because the axial behavior of the rotor is not seriously important in rotor dynamics aspects. Table I shows control parameter for a local AMB just as shown in Fig. 4. Active magnetic bearings are installed in a blower simulator. The coordinates for each bearings (2 radial bearings and 1 thrust bearing) are displayed in the following

TABLE I
CONTROL PARAMETER FOR LOCAL AMB

Item	Symbol	Value	Unit	Item	Symbol	Value	Unit
Mass of rotor	m	25.32	N	Proportional	k_P	0.45	A/V
Position stiffness	k_s	2.3e6	N/m	Derivative frequency	w_D	325	rad/s
Current stiffness	k_i	675	N/A	Integral Gain	k_I	2.25e-3	A/V
Sensor gain	k_s	0.01	V/µm				

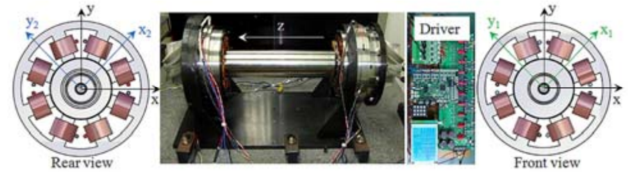

Fig. 4. Test setup for AMBs for high speed rotor system

Fig. 4. independent AMBs are used for supporting the rotating rotors. For each control axis, the control commands are made by proportional and derivative control of displacement deviations, and integral control is used for the compensation of rotor static mass. Fig. 5 shows the experimental results for actuator x_1 axis. For Fig. 5, the active magnetic bearing actuators are supplied by constant bias current of 1.2A. The moment of 0.2 seconds, the levitation control is started.

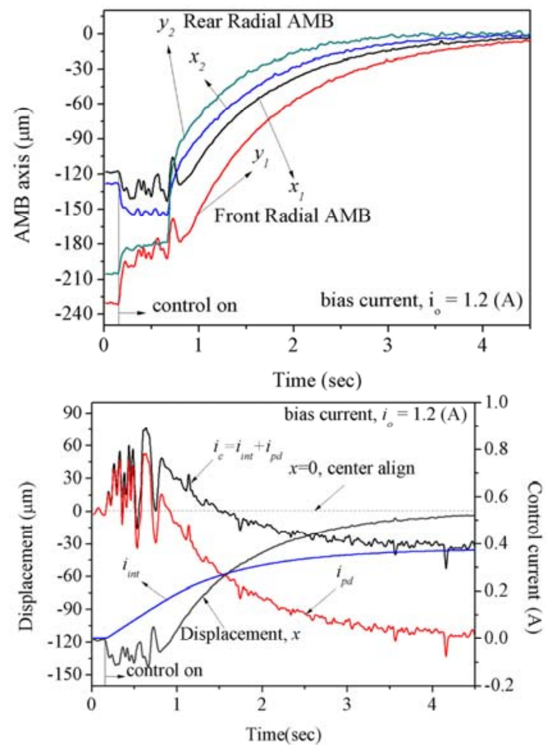

Fig. 5. Test result for AMBs for high speed rotor system

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