Characteristics of superconducting magnetic bearings for 50kWh-class flywheel system

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ABSTRACT: We are developing a 50 kWh-class flywheel energy storage system as a national project, using a new axial superconducting magnetic bearing (Ax_SMB) technology. The project has started in FY2005 and will continue to FY2007. The Ax_SMB is composed of Fe core and superconducting coil, which are simply torus-shape. It generates strong restoring force in axial direction. It can realize non-contact levitation of 25t mass of flywheel, combined with active controlled magnetic bearings for radial direction (Ra_AMB).

1 INTRODUCTION

1.1 Overview of the project

We are developing a 50 kWh-class flywheel energy storage system as a national project, using a new type of axial superconducting magnetic bearing (Ax_SMB) technology which is based on powerful magnetic force generated by a superconducting coil. The project is entrusted to Central Japan Railway Company from NEDO (New Energy and Industrial Technology Development Organization). The aim of the project is to establish 50kWh-class superconducting flywheel energy storage system for various purposes in industrial fields, such as electric-load leveling, stabilization for distributed natural generation of electricity, and stable operation of regenerative brake for railway systems (Yamauchi et al. 2006).

It has started in FY2005 and will continue to FY2007. We analyzed the characteristics of the Ax_SMB. We also developed a testing device for evaluation of basic characteristics of the bearing. After the test with this device, a pilot system will be fabricated for establishment of 50kWh-class superconducting flywheel energy storage system technology (Yamauchi et al. 2006).

1.2 Feature of the new type of Ax_SMB

Various superconducting magnetic bearings using pinning effect of bulk superconductor such as YBCO have been developed. (Ichihara et al. 2005, Werfel et al. 2005). The flywheel using pinning effect is made of carbon fiber reinforced plastics (CFRP) (Ichihara et al. 2005). In contrast, the new type of Ax_SMB, we have proposed, utilizes powerful magnetic force generated by a super-conducting coil, instead of the pinning effect. Therefore, even in low rotational speeds, the flywheel system can provide larger energy storage capacity by enlarging the mass of flywheel. Thus, this system does not need to apply high-strength materials, such as CFRP, that are mechanically strong enough against large centrifugal force caused by its high circumferential velocity. It means that we will be able to produce low-cost systems. In addition, this bearing needs only a superconducting coil of simple form, so it will be able to flexibly utilize the future development of high temperature superconducting materials (Yamauchi et al. 2006).

2 FEATURES OF THE FLYWHEEL SYSTEM

2.1 Fundamental configuration of the system

Figure 1 shows one example of composition of the flywheel system.

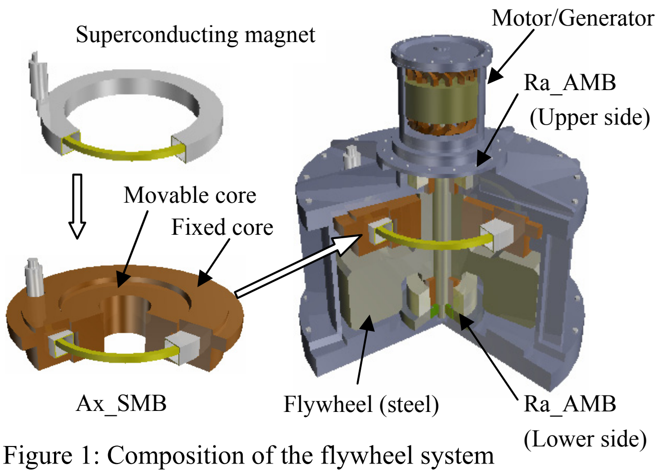

Figure 1: Composition of the flywheel system

It is composed of an Ax_SMB, two active controlled magnetic bearings for radial direction (Ra_AMB), a motor/generator, and a flywheel.

2.2 Configuration of the Ax_SMB

The Ax_SMB is one of the main components of the flywheel system. It is composed of a steel core on the mover side, a steel core and a superconducting coil on the fixed side, which are all in the shape of simple torus. Figure 2 shows the vertical cross section of the Ax_SMB. The C-shaped movable and fixed cores form a main magnetic circuit. It generates strong restoring force in the axial direction. The bearing uses this restoring force for levitation (Yamauchi et al. 2006). In the radial direction, however, it has negative stiffness. It needs Ra_AMB to obtain non-contact levitation.

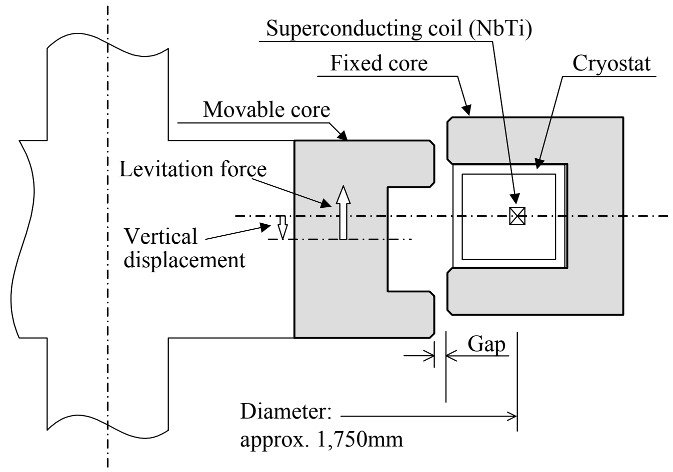

Figure 2: Configuration of the Ax_SMB

2.3 Specifications of the flywheel system

Table 1 shows the specifications of the 50kWh-Class flywheel system that we are developing. The system can suspend 25t mass of flywheel which storages large energy of 50kWh in relatively low rotational speed from 1000rpm to 2000rpm.

Table 1: Specifications of the 50kWh-Class flywheel system

Energy storage capacity	50 kWh
In/Out electric power	1000 kW
Maximum rotational speed	2000 rpm
Mass of flywheel	Approx. 25 t
Diameter of flywheel	Approx. 2 m

3 BASIC STUDY OF ELECTROMAGNETIC CHARACTERISTICS OF THE AX_SMB

3.1 Basic characteristics of axial magnetic force

Figure 3 shows a typical example of electromagnetic characteristics of the bearing. It is important to understand that the electromagnetic force works mainly on both movable and fixed cores, as a result, the total force working on the superconducting coil is very small (Yamauchi et al. 2006). It means that the superconducting coil can be supported inside the cryostat with very low thermal conduction.

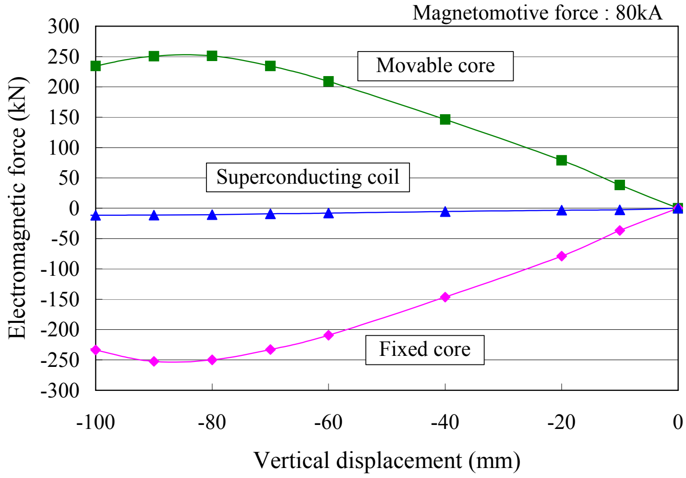

Figure 3: Relations between electromagnetic forces and vertical displacements

3.2 R&D equipment for basic study

The Ax_SMB theoretically makes it possible to support very large loads. However, toward its practical application, it is essential to obtain ideas for the design by both numerical analysis and experimental study. For this purpose, we made small R&D equipment. Figure 4 shows its photograph. Figure 5 shows structure of the equipment. It is composed of 800kg mass of flywheel, steel movable core, fixed core of steel core and copper coil cooled by water, and so on. In this equipment, copper coil is used instead of superconducting coil, because the mass of the rotor is not so heavy. And, mechanical bearings are used for stabilizing in radial direction.

Figure 4: Photograph of R&D equipment

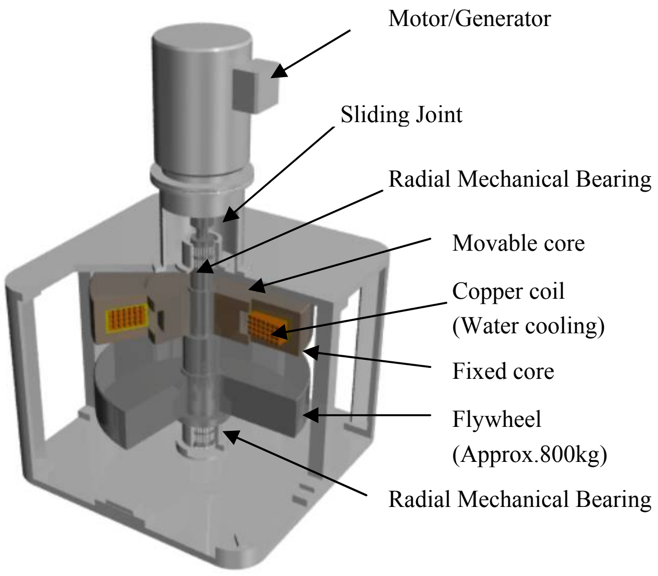

Figure 5: Structure of the R&D equipment

We have measured vertical displacement of the rotor on various magnetomotive forces. We also analyzed the characteristics of the equipment by the finite element method (FEM). Figure 6 shows the comparison between result of experimentation and analysis. They agree in each other (Uchiyama et al. 2005).

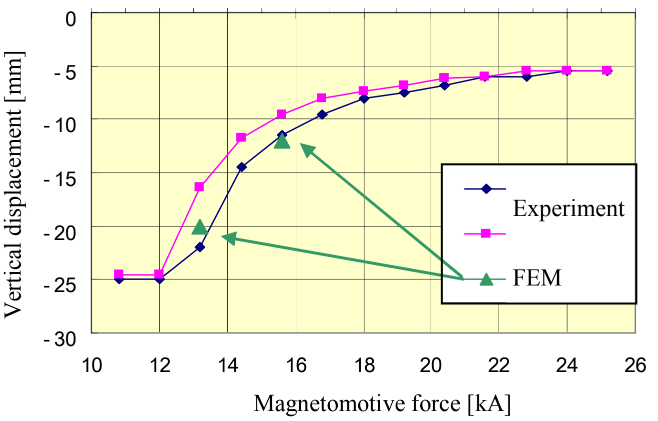

Figure 6: Comparison between experimentation and analysis

3.3 *FEM analysis about influences in the case of rotating in eccentric position*

We have studied parameters that can generate 250kN of stable levitation force by FEM analysis. The shape of analysis model is shown in Figure 2. Figure 7 shows the result of analysis, relationship between vertical displacement and levitation force. Each parameter can generate stable levitation force of 250kN(Kubota et al. 2006).

In these cases, we analyzed influences in the case of rotating in eccentric position, disturbance of flux density between movable and fixed core in axial symmetry, and unstable force in radial direction. Disturbance of flux density increase rotational losses. Unstable force in radial direction requires Ra_AMB to have more capacity.

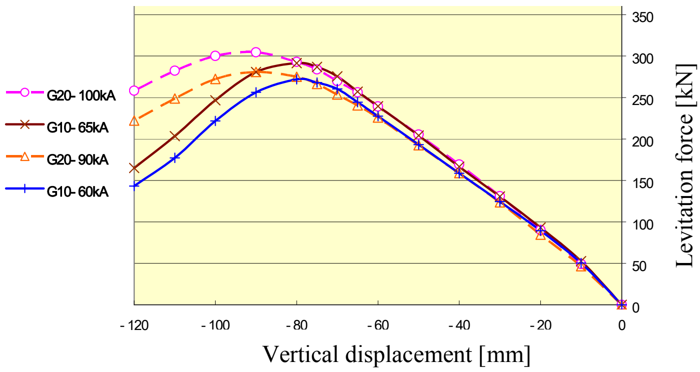

Figure 7: Characteristics of levitation force on the parameters, which generate stable levitation force of 250kN

Movable core can move within 0.250mm in radial direction, limited with radial touch down bearings. Figure 8 shows the disturbance of flux density between movable and fixed core in axial symmetry in one case. The disturbance is very small compared with absolute flux density. We assume rotational losses caused by the disturbance will be very small.

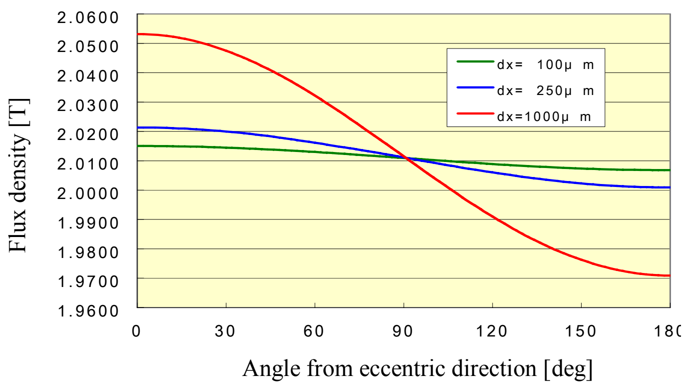

Figure 8: Disturbance of flux density in axial symmetry

Figure 9 shows unstable forces in radial direction. The maximum unstable force caused by Ax_SMB is less than 3kN in the case of 0.25mm of eccentric distance. We should consider the unstable force into design of the Ra_AMB capacity.

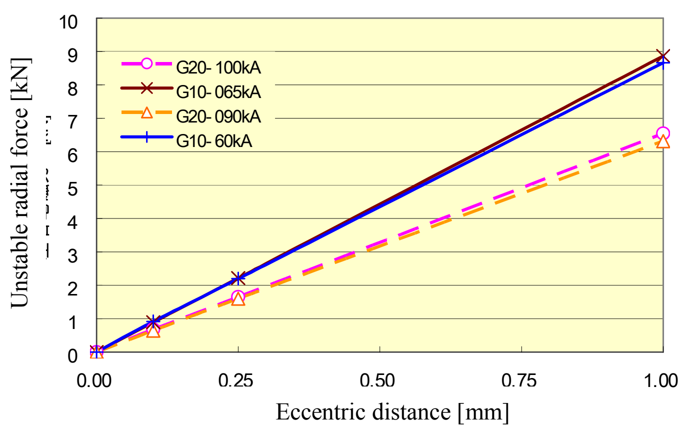

Figure 9: Unstable force in the case of rotating in eccentric position

4 TESTING DEVICE FOR EVALUATION OF BASIC CHARACTERISTICS

4.1 *Outline of the device*

A testing device was fabricated for evaluation of basic characteristics of the axial bearing. Figure 10 shows the appearance of the testing device. This device is composed of the axial bearing, a motor, a clutch mechanism, and active magnetic bearings for non-contact support in the radius direction. There is no flywheel in this device. The device has some sensors, for example, a torque meter, load cells, and hall sensors, for measurement of levitation force, magnetic field distribution, rotation loss, etc. (Yamauchi et al. 2006).

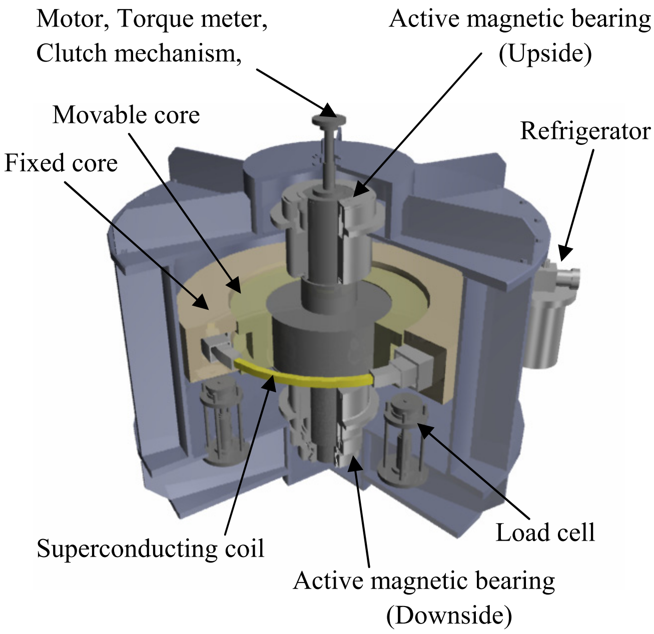

Figure 10: Appearance of the testing device

4.2 *Specification of the superconducting coil*

Table 2 shows the specifications of the superconducting coil (Yamauchi et al. 2006). Figure 11 shows a picture of the superconducting coil unit.

Table 2: Specifications of the superconducting coil

Diameter	1756 mm
Wire material	NbTi
Number of turns	2652 turns
Magnetomotive force	150 kA(Max.)
Cooling system	Conduction cooling

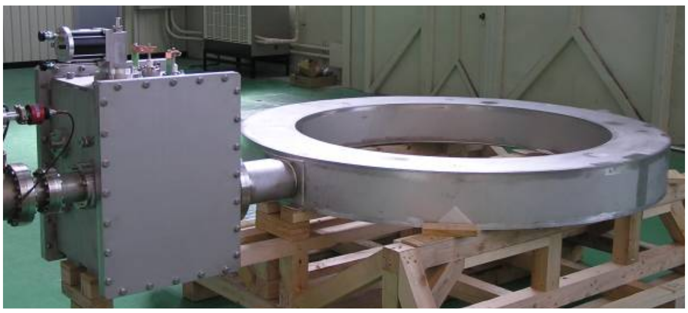

Figure 11: Superconducting magnet unit

5 A PILOT SYSTEM

Based on the evaluation of basic characteristics of the axial bearing by the FEM analysis of electromagnetic fields and the experiments, a pilot system will be fabricated for establishment of 50kWh-class superconducting flywheel energy storage system technology. This system will be electrically connected to the power network of our research facility to perform a characteristic examination of the system (Yamauchi et al. 2006).

Figure 12 shows a location of the research facility, where test site of pilot system of 50kWh-Class flywheel energy storage system exits.

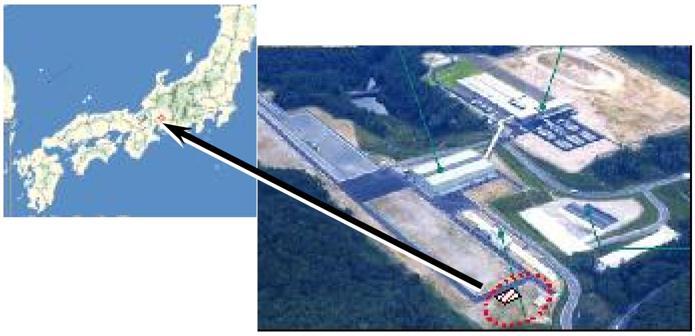

Figure 12: Location of test site

6 CONCLUSIONS

The new type of Ax_SMB, which utilizes strong magnetic force generated by superconducting coil and Fe core, is able to suspend 25t of flywheel stably according to our FEM analysis. However, toward its practical application, it is essential to obtain ideas for the design by precisely measuring and evaluating levitation characteristics of this superconducting thrust bearing, rotational loss and basic characteristics of radial bearing. We have made test device for this purpose, and started to conduct the experimental tests. We are expected to get good result in the experimentation.

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