CHARACTERIZATION
OF
SUPERCONDUCTING MAGNETIC BEARINGS

Ryoichi Takahata and Hirochika Ueyama
Koyo Seiko Co., Ltd., Kashiwara, Osaka, Japan

ABSTRACT

High-temperature superconductor YBa$_2$Cu$_3$O$_{7-x}$ with strong pinning force has allowed the realization of stable magnetic suspension with no control. Superconducting magnetic bearing (SMB) using YBCO and permanent magnet, and SMB operation system were assembled. Two SMB cooled down in a field cooling state by liquid nitrogen were proved to support a rotor weighing 2.5kg up to 42,000rpm. A radial run out of the rotor was 8μm or less. The value can be considered for practical application. The rotating performance at high speed has disclosed by an active control assist in radial direction during accelerations.

INTRODUCTION

High temperature superconductor such as bulk YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) with pinning effect[1,2] has created many possible applications. A superconducting magnetic bearing (SMB) utilizing strong pinning force has been able to levitate stably heavy machinery without active control systems.[3,4] However in lower rotational speed a radial run out of rotor shaft supported by SMB was large compared to that by conventional bearing. Therefore it is necessary that the rotating shaft is assisted by means of certain method at a resonant frequency of SMB in order to accelerate up to high speed. It is considered that the SMB is able to support stably the rotor without any additional control at high rotational speed. In this paper, we present a hybrid SMB operation system (Fig. 1) and properties of radial run out with the SMB at high speed rotation. An rotational center point of rotor supported by SMB was discussed.

EXPERIMENT

A drawing and structure of this SMB system are shown in Fig.2. The SMB unit was constructed with bulk YBCO as a stator and permanent magnet NdFeB as a rotor. The surface field of ring permanent magnet (Ø60×Ø30×12mm) had magnetic induction of 0.4T. The bearing members were five pieces of bulk YBCO (Ø50×18mm) which were sealed to cryostat (170mm OD, 22mm ID, 20mm length). The cryostat was full filled by liquid nitrogen and was provided with a thermocouple and a heater. The rotor shaft, weighing 2.5Kg, containing two permanent magnets was supported by two SMB serving an attractive force at upper bearing and a repulsive force at lower one. An air cylinder was installed under the lower end of shaft for initial gap positioning of SMB transiting superconductivity in a field cooling state at 77K. A induction motor was used to drive the rotor. While radial run out of the rotor shaft was monitored by remote sensing and radial stiffness of SMB was assisted by control system with an active magnetic bearing (AMB). Touch down bearings were also provided to protect stator members in case of emergency. The entire SMB assembly was immersed in a vacuum chamber and liquid nitrogen was supplied to SMB cryostats from an external liquid gas dewar.

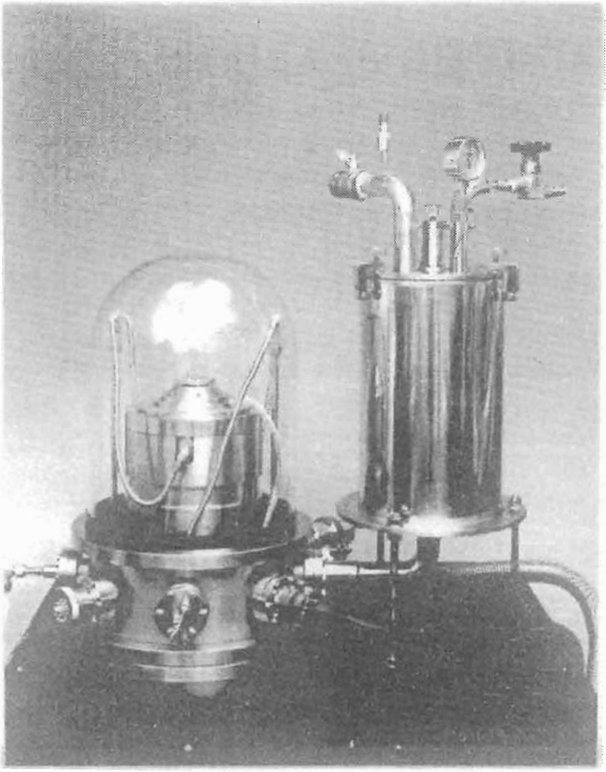

FIGURE 1: Photograph of the SMB operation system

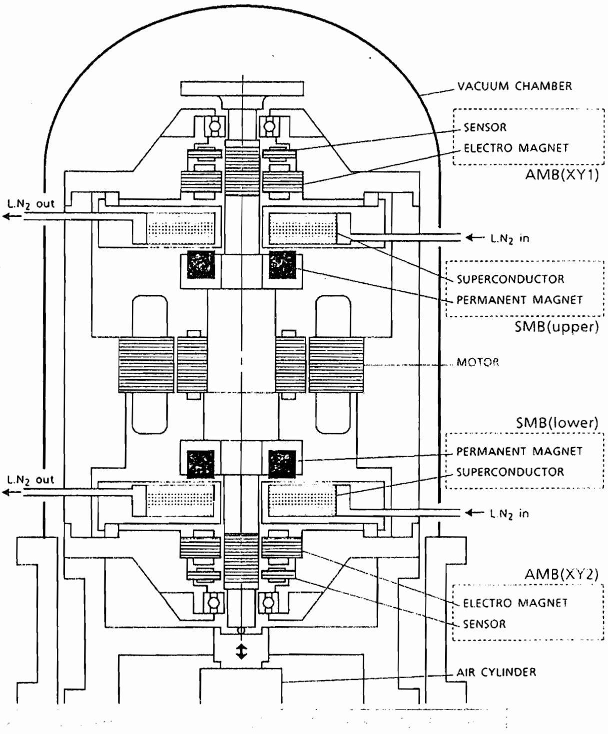

FIGURE 2: Drawing of the SMB operation system

A operation procedure of this SMB system is as follows :

① Positioning of rotor shaft (Axial : Air cylinder, Radial : AMB)
② Field cooling of SMB (Flowing liquid nitrogen to cryostats)
③ Releasing from axial positioning by air cylinder
④ Driving shaft by induction motor
⑤ Releasing from radial assisting by AMB (XY1 or XY2)

Then rotational property of each SMB unit at high rotational speed was measured by means of displacement sensor.

RESULTS AND DISCUSSION

At first the rotor shaft was positioned initially with air cylinder in axial direction and with AMB in radial direction, and each SMB was cooled down in a field cooling state by liquid nitrogen. Axial gaps were 0mm at upper SMB unit and 1.8mm at lower SMB. After the SMB transited superconductivity, the axial positioning was released. Then the shaft was supported with no mechanical contact by a repulsive force of lower SMB and an attractive force of upper SMB. The equilibrium axial gap of upper SMB unit was 1.0mm and lower one was 0.8mm. The shaft was driven by induction motor with additional radial control of AMB. Because the run out of the shaft supported by only SMB was so large, more than 200 μm, that the shaft was not able to driven without radial control in the lower frequency region. It was considered that a radial dynamic stiffness of SMB unit was smaller than an attractive force of induction motor.

The shaft was accelerated up to 42,000rpm which was limited value by tensile strength of rotor magnet under centrifugal stress. After one active control (XY1 or XY2) was turn off at 42,000rpm, rotational run out of the shaft supported by the passive SMB without control was measured by means of displacement sensor. Orbit diagrams of radial run out were shown in Fig.3. The rotational run out of the shaft supported by upper SMB was 8μm on XY2 at 40,000rpm. And that by lower SMB was 6μm on XY1. These were considered as a property of each SMB unit. These values increased with an decrease in rotational speed. At 20,000rpm or less, there are large whirling (Fig.3 (c)(f)). When the rotor began to whirl, SMB was assisted by AMB in order to break the rotor safely in this test. On the basis of this result, it is necessary to increase a dynamic stiffness of SMB by a mean of some kind in lower rotational speed ranging under 20,000rpm. Particularly an advent of strong pinning force in bulk YBCO has led SMB to large spring constant but not improved damping factor. [5,6] Therefore damping factor of SMB should be increased with another additional damping factor.

By the way, when the radial control was turn off, a rotational center point of the rotor departed from a control point by AMB. It was at about 50μm away on XY2 as shown in Fig. 3(a). In the case of XY1, the action of the shaft was similar. But rotational point on XY1 was clearly different from that on XY2 in a direction. It seems that each SMB unit rotates at its inherent rotational center point. It may be decided at field cooling of SMB but not necessarily equal to center of configuration of rotor ring magnet. Because flux density of ring permanent magnet is slightly nonuniform in the circumferential direction.

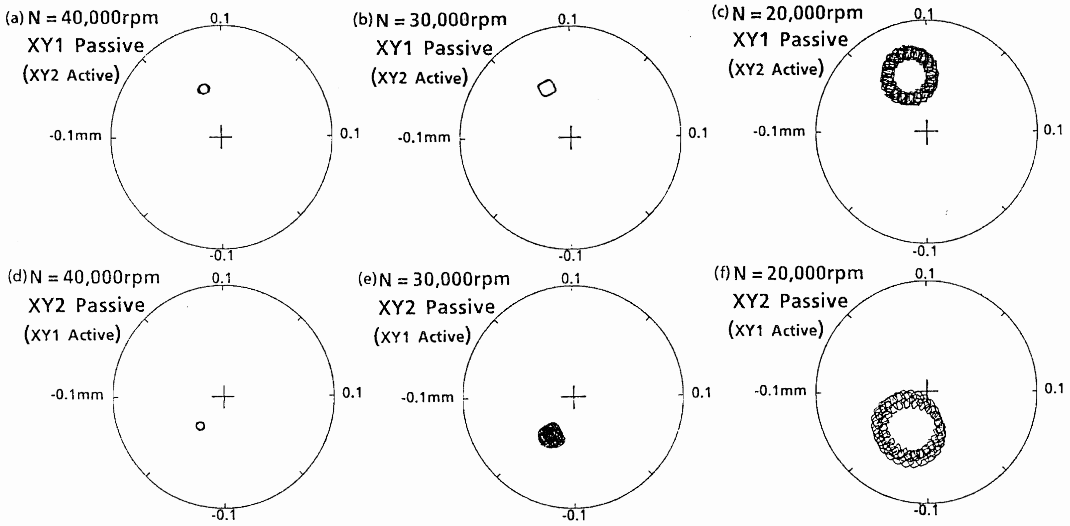

FIGURE 3: Orbit diagrams of rotor supported by the SMB unit without control

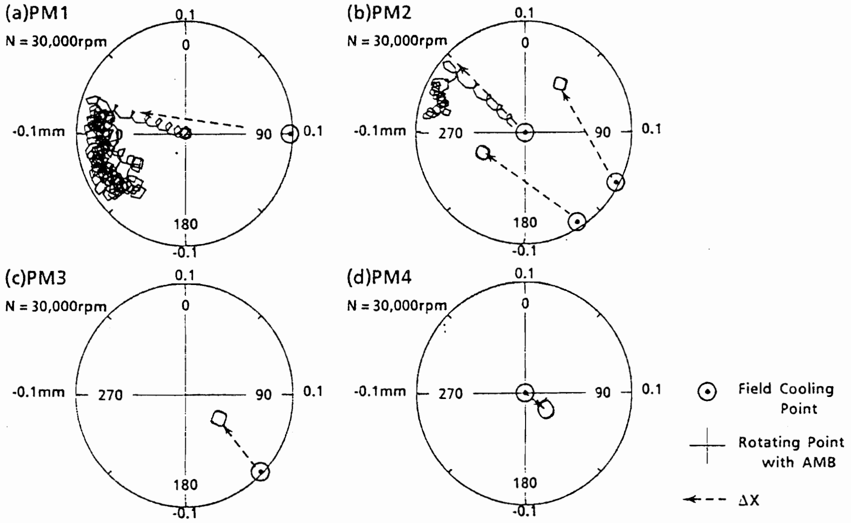

FIGURE 4: Orbit diagrams of rotor supported by the SMB in case of (a)PM1, (b)PM2, (c)PM3, (d)PM4

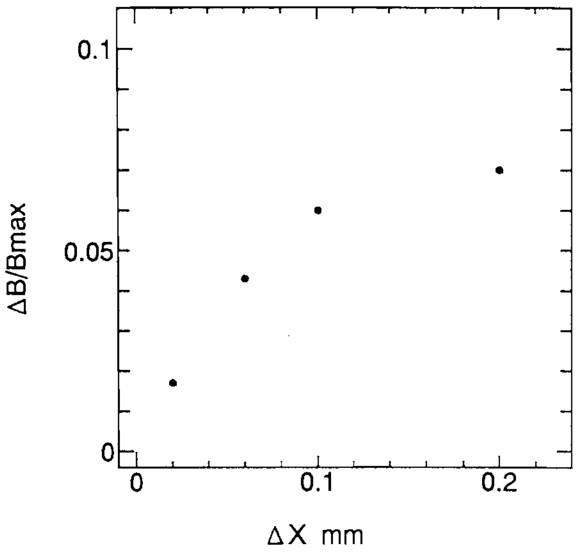

FIGURE 5: Magnetic field fluctuation ratio of magnet versus distance between rotational center and field cooling center in SMB

The causes of the problems can be shown in a comparison of another four ring magnets, PM1,2,3,4. When the AMB(XY1) was turn off at 30,000rpm, the shaft supported by upper SMB having PM1 was shifted in the direction of 290degree and touched inside face of the inner race of upper ball bearing, hereafter referred to simply as a touch down, as shown in Fig. 4(a). In this test, the touch down of the shaft can be avoid, if field cooling point of SMB is shifted 0.1mm away from rotating point with control by AMB in opposite direction of the touch down. In the case, the distance ΔX between rotational center and field cooling center was not less than 0.2mm. When the mounted angle of PM1 on the shaft was shifted 180degree. The touch down direction of the shift was opposite the results in Fig. 4(a). Thus it was considered that this shifting of rotating point of SMB was due to in permanent magnet side. The results of the same tests of another magnets, PM2,3,4 are shown in Fig. 4(b),(c),(d). In case of PM4, the shift of the SMB rotating center point for field cooling and rotating point with AMB was 0.02mm.

By the way, fluctuation of concyclic magnetic field at seven circles over each permanent magnet were measured. These value were calculated to ratio of fluctuation value ΔB/Bmax. ΔB means a value subtracted Bmin. from Bmax. An average value of seven fluctuation values (ΔB/Bmax) of PM1 was 7.3%. That value of PM4 was 1.7%. PM4 has a very low fluctuation ratio. Each average value of ΔB/Bmax. in PM1,2,3,4 can as shown in Fig. 5. It is clear that the value of ΔX is decreased with the value of ΔB/Bmax.

CONCLUSIONS

A superconducting magnetic bearing (SMB) of bulk $YBa_2Cu_3O_{7-x}$ having strong pinning force was assembled. Properties of rotational run out on the SMB at high speed rotation were measured in SMB operation system.

(1) This SMB operation system was composed of basic function, *i.e.* initial positioning device, remote sensing of rotor, electro magnets for additional damping assistance of SMB stiffness, liquid nitrogen filling controller and vacuum chamber.

(2) Two SMB units in the system supported a rotating shaft weighing 2.5Kg with no mechanical contact.

(3) The SMB has achieved a rotational speed exceeding 42,000rpm and a radial run out of 8μm or less.

The authors would like to thank Nippon Steel Corporation for supplying bulk $YBa_2Cu_3O_{7-x}$

REFERENCES

1. M.Morita, K.Miyamoto, K.Doi, M.Murakami, K.Sawano and S.Matsuda (1990) Physica C 172 : 383-387
2. M.Murakami, T.Oyama, H.Fujimoto, S.Gotoh, K.Yamaguchi, Y.Shiohara, N.Koshizuka and S.Tanaka (1991) IEEE Trans. magn., 27(2): 1479-1486
3. R.Takahata, H.Ueyama and T.Yotsuya (1992) Electromagnetic Forces and Applications : 347 - 350
4. H.Fukuyama, K.Seki, T.Tanizawa, S.Aihara, M.Murakami, H.Takaichi, and S.Tanaka (1992) Advance in Superconductivity Ⅳ : 1093-1096
5. R.Takahata, H.Ueyama and T.Yotsuya (1992) NASA Conference Publication 3152 : 289-296
6. R.Takahata and H.Ueyama (1992) Advance in Superconductivity Ⅳ : 1089-1092