Superconducting Magnetic Bearings Using High Tc Superconducting Bulks and Coils, and The Application

Mochimitsu KOMORI*, Riku NAKATSUKA*, Kaoru NEMOTO*,
Tsunemasa FUNATSU*, Yangbo DONG**, Satoshi UENO**
*Department of Electric and Electronic Engineering, Kyushu Institute of Technology, Japan
E-mail: komori_mk@yahoo.co.jp
**Department of Mechanical Engineering, Ritsumeikan University, Japan

Abstract
Superconducting magnetic bearings (SMBs) are usually composed of superconductors and permanent magnets (PMs). These SMBs are based on pinning forces between superconductors and PMs. In this paper, new types of SMB-I and SMB-II are proposed. These SMB-I and SMB-II are composed of superconductor and superconducting coils. To compare SMB-I with SMB-II, impulse responses in the vertical and horizontal directions are studied. Then, natural damped vibration curves for impulse responses are observed. The damping coefficient for SMB-II is larger than other SMB-I.

Keywords:Superconducting magnetic bearing, High Tc superconductor, Superconducting coil

1. Introduction

In There are many reports about superconducting magnetic bearings (SMBs) using pinning forces (Moon and Chang, 1990), (Komori and Kitamura, 1992), (Nagashima et al., 2009). The dynamic characteristics of SMBs are based on materials applied to SMBs. On the other hand, high Tc superconducting coils are also useful for SMBs (Komori et al., 2018), (Komori et al. 2020). Superconducting coils are used for adding stiffness and damping to SMBs. Superconducting coils are used for adding stiffness and damping to SMBs.

In this paper, SMBs composed of superconductor and superconducting coils are studied. And the dynamic characteristics in the vertical and horizontal directions are discussed.

2. SMB Structure

Fig. 1 shows two types of arrangements for (a) SMB-I and (b) SMB-II. SMB-I is composed of a superconductor and four superconducting coils The superconducting coils (20 turns) are yttrium type with $I_c \approx$ 150A, and measures 52 mm in outer diameter, 45 mm in inner diameter and 5 mm in width. SMB-II is composed of four superconductors and four superconducting coils, although the doughnut-shaped superconductor is divided into four pieces. The superconducting coils of SMB-II are the same as those of SMB-I. The same mechanical model in Fig. 2 is adopted for SMB-I and SMB-II. Fig. 2 shows a photo of SMB-II showing that PM is levitated at distance of 6 mm. Impulse forces are applied in the vertical and horizontal directions to the levitated PM at various distances.

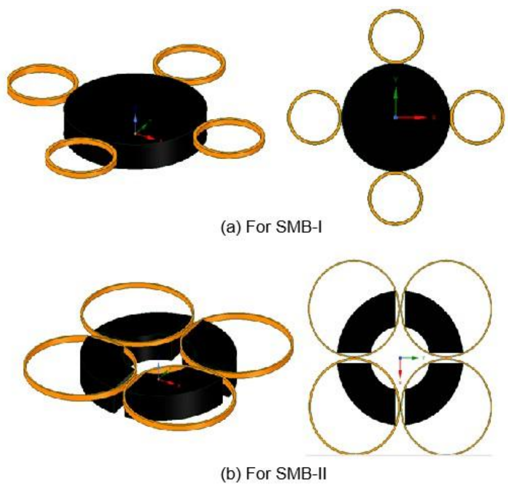

Fig.1. Two types of arrangements for (a) SMB-I and (b) SMB-II.

3. Experiments and Results for SMB-I and II

3.1 SMB-I

Fig. 3 shows the impulse responses in the vertical direction for SMB-I at various distances of 6, 8, 10 and 12 mm. The results show that natural damped vibration curve for each distance of 6, 8, 10 and 12 mm is observed. For each vibration curve, the displacement amplitude gradually decreases to ≈ 0 mm. The decreasing time to ≈ 0 mm decreases with decreasing distance. The relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the vertical direction for various distances are shown in Fig. 4 as black circles. White circles represent the results of SMB-I shown in Fig. 4. Each stiffness decreases gradually with increasing distance from 6 mm to 12 mm, and each damping

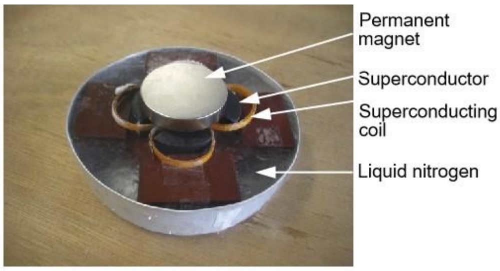

Fig.2 Photo of SMB-II showing that PM is levitating at distance of 6 mm.

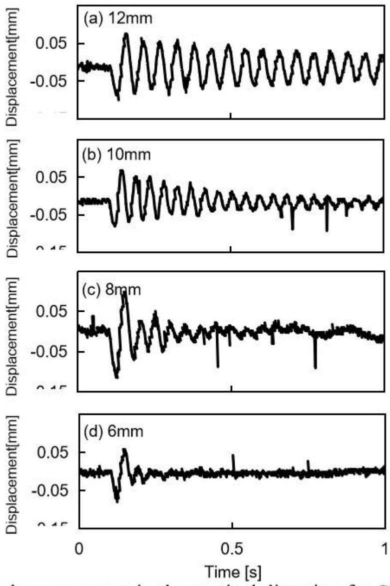

Fig.3 Impulse responses in the vertical direction for SMB-I at various distances of 6, 8, 10 and 12mm

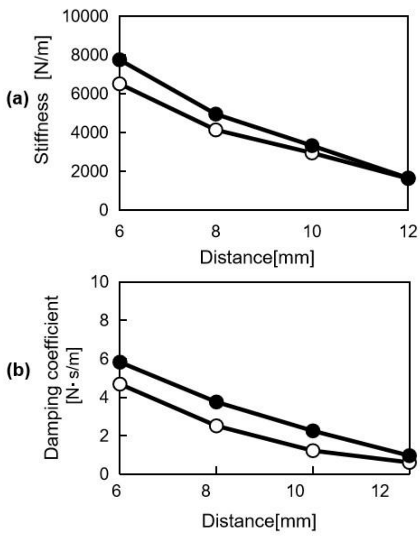

Fig.4 Relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the vertical direction for SMB-I at various distances.

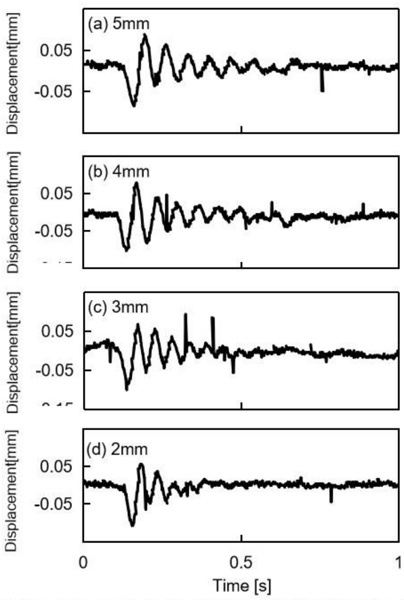

Fig. 5 Impulse responses in the horizontal direction for SMB-I at variou distances of 2, 3, 4 and 5 mm

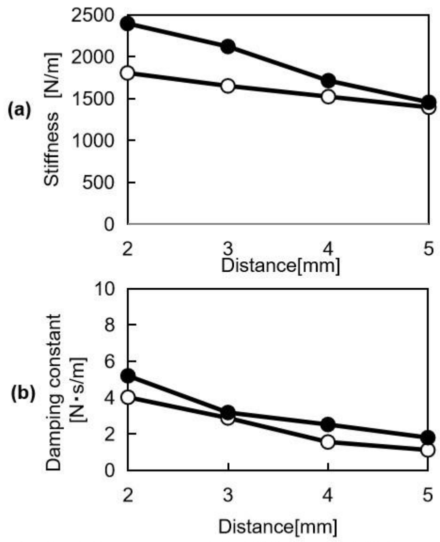

Fig. 6 Relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the horizontal direction for ISMB-I at various distances.

coefficient also decreases gradually with increasing distance. The difference between black circles and white circles are caused by the superconducting coils of SMB-I. It seems that there is a little difference between them in stiffness and damping coefficient in the vertical direction.

Fig. 5 shows the impulse responses in the horizontal direction for SMB-I at various distances of 2, 3, 4 and 5 mm. The results in Fig. 5 show that natural damped vibration curve for each distance of 2, 3, 4 and 5 mm is observed. For each vibration curve, the displacement amplitude gradually decreases to 0 mm within 1.0 s. The decreasing time to ≈ 0 mm decreases with decreasing distance from 5 mm to 2 mm. The relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the horizontal direction for various distances are shown in Fig. 6 as black circles. White circles represent the results of SMB-I shown in Fig. 6. Each stiffness decreases gradually with increasing distance, and each damping coefficient also decreases gradually with increasing distance. In the horizontal direction it seems that there is a little difference between them in stiffness as shown in Fig. 6(a) and there is not so difference between them in damping coefficient as shown in Fig. 6(b).

In other words, in the case of SMB-I the arrangement for SMB-I is a little effective on stiffness and damping coefficient in the vertical and horizontal directions.

3.2 SMB-II

Fig. 7 shows the impulse responses in the vertical direction for SMB-II at various distances of 6, 8, 10 and 12 mm. The results in Fig. 7 show that natural damped vibration curve for each distance of 6, 8, 10 and 12 mm is observed. For each vibration curve, the displacement amplitude gradually decreases to ≈ 0 mm. The decreasing time to ≈ 0 mm decreases with decreasing distance from 12 mm to 6 mm. The relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the vertical direction at various distances are shown in Fig. 8 as black circles. White circles represent the results of SMB-II shown in Fig. 8. Each stiffness decreases gradually with increasing distance, and each damping coefficient also decreases gradually with increasing distance. The stiffness of SMB-II (black circles) is larger than that of SMB-II (white circles), and the damping coefficient of SMB-II (black circles) is also larger than that of SMB-II (white circles). In other words, the superconducting coils of SMB-II are effective on the stiffness and the damping coefficient in the vertical direction.

Fig. 9 shows the impulse responses in the horizontal direction for SMB-II at various distances of 2, 3, 4 and 5 mm. The results in Fig. 9 show that natural damped vibration curve for each distance of 2, 3, 4 and 5 mm is observed. For each vibration curve, the displacement amplitude gradually decreases to ≈ 0 mm within 0.5 s. The decreasing time to ≈ 0 mm decreases with decreasing distance from 5 mm to 2 mm. The relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the horizontal direction for various distances are shown in Fig. 10 as black circles. White circles represent the results of SMB-II shown in Fig. 10. Each stiffness decreases gradually with

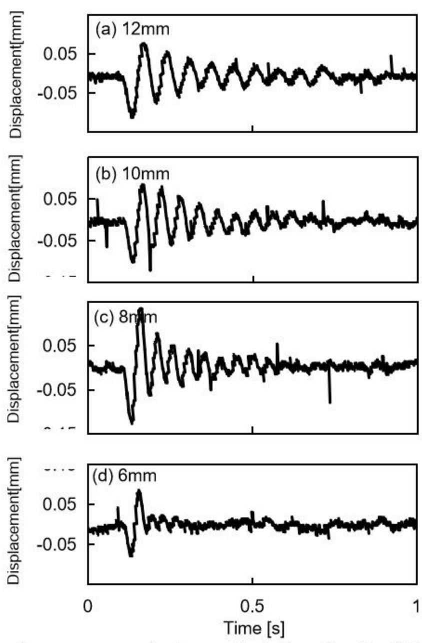

Fig. 7 Impulse responses in the vertical direction for SMB-II at various distances of 6, 8, 10 and 12 mm

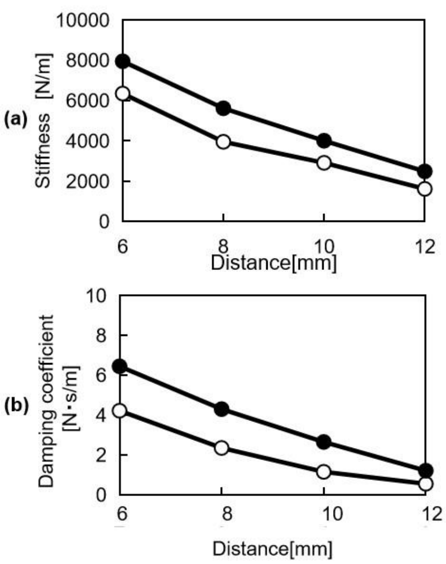

Fig. 8 Relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the vertical direction for SMB-II at various distances.

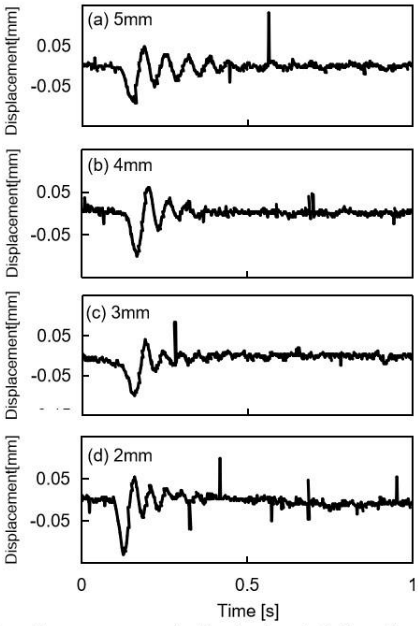

Fig.9 Impulse responses in the horizontal direction for SMB-II at various distances of 2, 3, 4 and 5 mm

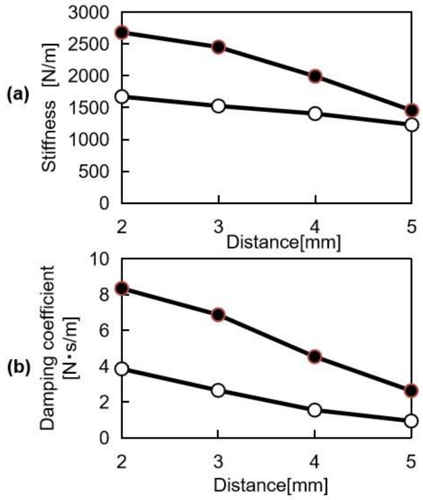

Fig. 10 Relationship between (a) stiffness and distance and between (b) damping coefficient and distance in the horizontal direction for ISMB-II at various distances.

increasing distance, and each damping coefficient also decreases gradually with increasing distance. The stiffness of SMB-II (black circles) is much larger than that of SMB-II (white circles).

4. Levitated Conveyor system

A magnetically levitated conveyor system is shown in Fig. 11 representing (a) the schematic illustration of levitated conveyor system and (b) the photo with a levitated stage. As shown in Fig. 11(a), The conveyor is composed of a magnetically levitated stage and a conveying stage. The levitated stage moves following the conveying stage due to flux pinning forces. The conveyor is composed of two SMB-II for levitating the conveying stage. Each SMB-II is the same as that discussed in Figs. 7-10.

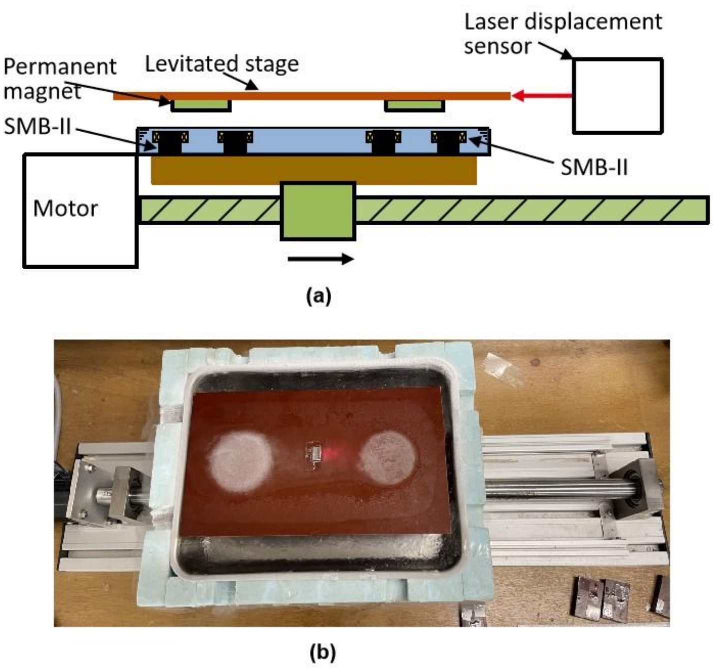

Fig. 11 A magnetically levitated conveyor system showing (a) the schematic illustration of levitated conveyor system and (b) the photo with a levitated stage.

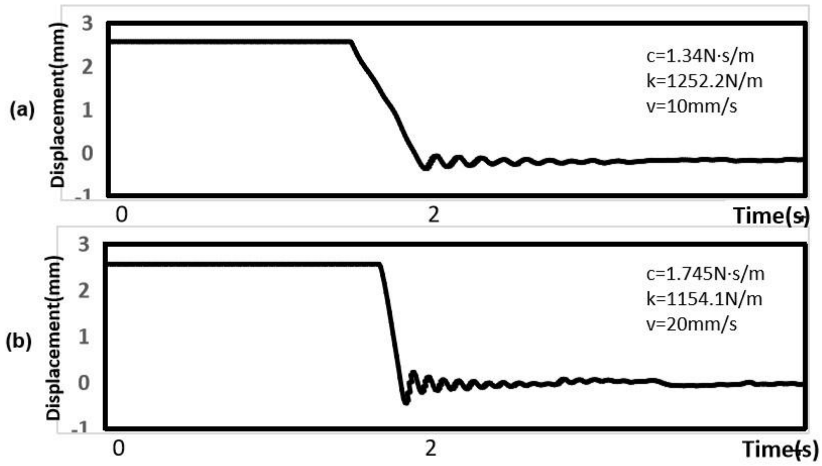

Fig. 12 One of the experimental results showing the displacement of levitated stage at speeds of (a) 10 mm/s and (b) 20 mm/s.

Fig. 12 shows one of the experimental results representing the displacement of levitated stage. In the case of Fig. 12 (a), the levitated stage moves at a speed of 10 mm/s and suddenly stops at a time of 2 s. After the stopping, the vibration of levitated stage occurs and disappears due to the damping effect of the SMB-II. In the case of Fig. 12(b), the levitated stage moves at a speed of 20 mm/s and suddenly stops. In the same manner, the vibration of levitated stage occurs and disappears due to the damping effect of the SMB-II.

4. Conclusion

Two types of SMB-I and SMB-II are discussed, which are composed of superconductor, permanent magnet and superconducting coils. These SMBs are a little different from each other. From some experimental results it is found that the stiffness and the damping coefficient of SMB-II in the vertical direction are larger than those of SMB-I and that the stiffness and the damping coefficient of SMB-II in the horizontal direction are much larger than those of SMB-I. In other words, the superconducting coils of SMB-II are much effective on the stiffness and the damping coefficient in the vertical and horizontal directions.

As an application of the SMB-II, the levitated conveyor system is proposed. the vibration of levitated stage occurs and disappears due to the damping effect of the SMB-II.

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