Magnetic flux-drag forces for high-T_c superconductors

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According to the high-T_c superconducting bearing experiments, the magnetic flux-drag torque due to the asymmetric magnetic field distribution of the magnet cannot be neglected. A homemade vertical torsion balance has been constructed to directly measure the flux-drag torque acting on a yttrium-barium-copper-oxide (YBCO) superconducting sample due to the off-axis circular motion of a small permanent magnet. It is found that these flux-drag torques, unlike the levitation forces, have no obvious hysteretic effect. Also, these flux-drag torques are larger for a melt-powder-melt-growth YBCO superconducting sample than for a ceramic YBCO sample.

I. INTRODUCTION

Mechanical interaction between high-T_c superconductors in the mixed state and a magnetic field is rather complex due to flux-line pinning and motion in these superconductors.[1-6] Sufficiently strong pinning leads to a continuous range of points of levitation of a permanent magnet by a superconductor.[7-9] The macroscopic dynamics of this levitation have been studied by several groups.[10-15] In superconducting bearing experiments, a flux-drag torque is found to exist.[13-15] This flux-drag torque is assumed to be due mainly to the asymmetric distribution of the magnetic field intensity about the axis of rotation of the spinning permanent magnet.[13-15] The purpose of this investigation is to measure directly these flux-drag torques as a function of the asymmetric magnetic field by a homemade vertical torsion balance.

II. EXPERIMENTAL SETUP

The superconducting YBCO samples were prepared by both the ordinary ceramic method and the melt-powder-melt-growth (MPMG) method.[16] The diameter of the superconducting samples (SS) was 25.4 mm and the thickness was 1.85 mm. A cylindrical permanent magnet (PM) made of Nd-Fe-B, magnetized along the cylindrical axis, was used. The diameter of the PM was 6.35 mm and the height was 6.40 mm. The distribution of both the axial and tangential components of the field intensity Hz and Ht were determined by a Hall probe attached to a microdisplacement system. The maximum field intensity at the surface of the magnet is 4.5 kG. The experiment was performed with a homemade vertical balance as shown in Fig. 1. The tension of the steel wire was monitored by a spring balance. The moving frame was cramped on the steel wire at two positions instead of one to prevent horizontal motion. The torsional constant of the wire was measured by the conventional torsion pendulum method. The relative position of the PM with respect to its rotational axis can be changed by using different holes in the aluminum holder. The distances between the PM and the SS were determined by two traveling microscopes. The disturbances caused by the air bubbles in the liquid nitrogen were reduced to an acceptable level by using a double-beaker container. The angular speed of the PM was monitored by an oscilloscope with a He-Ne laser. The angular positions of the SS were monitored by a second He-Ne laser. The angles of rotation caused by the flux-drag torque were calculated by the difference of the angular positions of the SS between the forward and reverse drive of the electric motor.

III. RESULTS AND DISCUSSIONS

Figure 2 shows the flux-drag torque acting on a ceramic YBCO SS as a function of distance between the PM and the sample. Different curves represent results from different axial distances (R) between the rotational axis and the PM. It is obvious that the more asymmetric the magnetic field one used, the larger the flux-drag torques one got. According to the high-T_c superconducting bearing experiment,[13] the magnetic shear stress acting on their rotor magnet was estimated to be 150 dyn/cm^2. The mag-

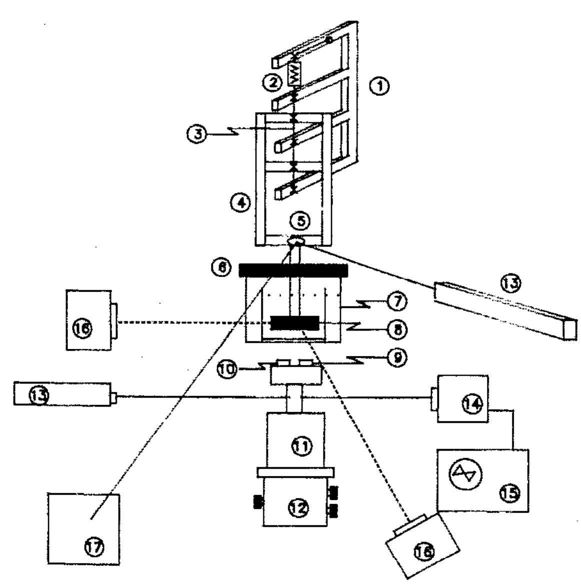

FIG. 1. Experimental setup: 1. Fixed frame; 2. Spring balance; 3. Steel wire; 4. Moving frame; 5. Mirror; 6. Styrofoam cover; 7. Double-beaker container; 8. SS; 9. PM; 10. Counterweight of PM; 11. Motor; 12. *X-Y-Z* micrometer; 13. He-Ne lasers; 14. Photodetector; 15. Oscilloscope; 16. Traveling microscopes; 17. Screen.

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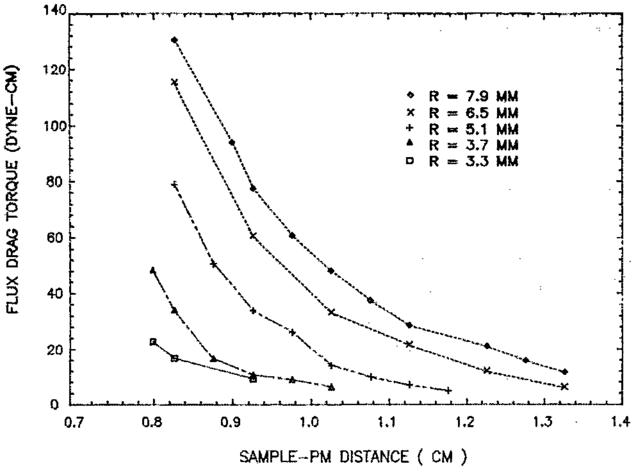

FIG. 2. Flux-drag torques as a function of perpendicular distances between the ceramic YBCO SS and the PM for different off-axis distance R.

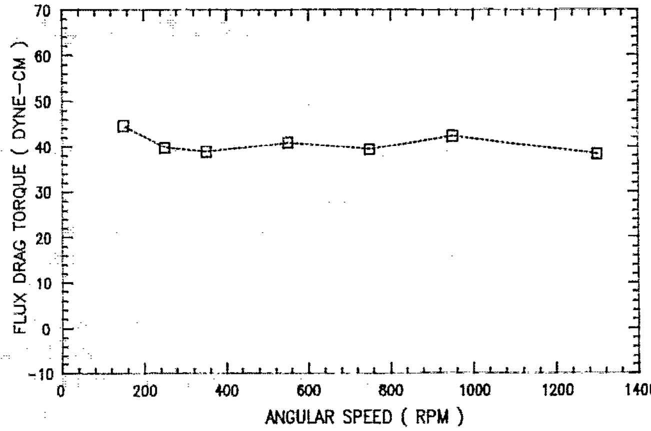

FIG. 4. Flux-drag torques for the ceramic YBCO SS as a function of angular speeds of the PM at a vertical distance of 0.95 cm and an off-axis distance $R=6.5$ *mm*.

netic shear stress, calculated from our data for the most symmetric magnetic field ($R=3.3$ mm) at the closest vertical distance (8 mm), was estimated to be 220 dyn/cm^2. Taking into account that our magnetic field is much more asymmetric but weaker than the magnetic field used by the superconducting bearing experiment, it seems nothing unreasonable can be found between the above two magnetic shear stress data.

Figure 3 shows the hysteretic curves of the flux-drag torques for both ceramic and MPMG YBCO SS at a fixed axial distance $R=6.5$ mm. In obtaining these hysteretic curves, the SS was first cooled to its superconducting state by liquid nitrogen while it was far away from the PM (zero-field cooling), then it was moved close to and then away from the PM. One can see that the flux-drag torques are always larger for the MPMG YBCO SS than for the ceramic sample. Also, from the almost zero enclosed areas of the two curves, one can conclude that there is no obvious hysteretic effect for the flux-drag torques.

Figure 4 shows the flux-drag torques as a function of angular speeds of the rotating PM. Within our experimental error, we consider that the flux-drag torque is a constant with respect to the angular speed. This proves that our measured flux-drag torques are mainly due to hysteretic losses and not caused by the viscous losses of the flux line flow inside the SS.[12]

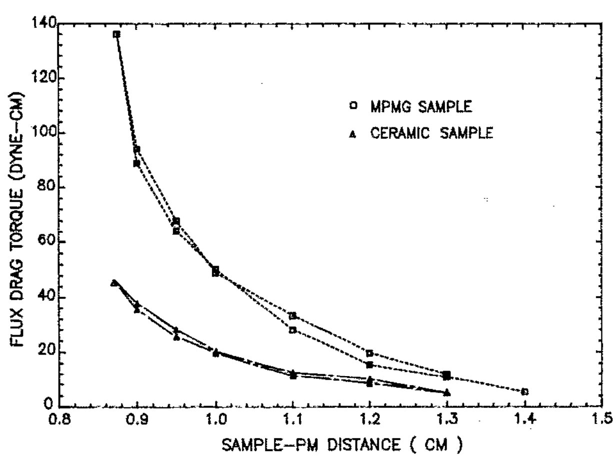

FIG. 3. Hysteretic curves of the flux-drag torques for both the MPMG and ceramic YBCO SS at an off-axis distance $R=5.1$ mm.

IV. CONCLUSION

The flux-drag torques in a superconducting sample caused by the rotation of an asymmetric distribution of magnetic field intensity of a permanent magnet were measured directly by a homemade vertical torsion balance. It is found that these flux-drag torques, as a function of the vertical distances between the PM and the SS, unlike the levitation forces, have no obvious hysteretic effect. It is also found that these flux-drag torques are larger for a MPMG YBCO superconducting sample than for a ceramic sample.

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[1] F. Hellman, E. M. Gyorgy, D. W. Johnson, Jr., H. M. O'Bryan, and R. C. Sherwood, J. Appl. Phys. **63**, 447 (1988).
[2] L. C. David, F. M. Logothetis, and R. E. Soltis, J. Appl. Phys. **64**, 4212 (1988).
[3] F. C. Moon, K. C. Weng, and P. Z. Chang, J. Appl. Phys. **66**, 5643 (1989).
[4] S. Takamura, M. Kobiyama, and T. Hoshiya, Physica C **170**, 254 (1990).
[5] D. X. Chen, A. Sanchez, T. Puig, L. M. Martiner, and J. S. Munoz, Physica C **168**, 652 (1990).
[6] J. Kober, A. Gupta, P. Esquinazi, and H. F. Braun, Phys. Rev. Lett. **66**, 2507 (1991).
[7] P. N. Peters, R. C. Sisk, E. W. Urban, C. Y. Huang, and M. K. Wu, Appl. Phys. Lett. **52**, 2066 (1988).

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[8] E. H. Brandt, Appl. Phys. Lett. **53**, 1554 (1988).
[9] M. Murakami, T. Oyama, H. Fujimoto, T. Taguchi, S. Gotoh, Y. Shiohara, N. Koshizuka, and S. Tanaka, Jpn. J. Appl. Phys. **29**, L1991 (1990).
[10] L. C. Davis, J. Appl. Phys. **67**, 2631 (1990).
[11] T. H. Johansen, Z. J. Yang, H. Brataberg, G. Helgesen, and A. T. Skjeltorp, Appl. Phys. Lett. **58**, 179 (1991).
[12] V. V. Nemoshkalenko, E. H. Brandt, A. A. Kordyuk, and B. G. Nikitin, Physica C **170**, 481 (1990).
[13] F. C. Moon and P. Z. Chang, Appl. Phys. Lett. **56**, 397 (1990).
[14] D. E. Weeks, Rev. Sci. Instrum. **61**, 195 (1990).
[15] A. N. Terentiev, E. O. Kutukova, and A. A. Kuznetsov, Physica C **193**, 110 (1992).
[16] M. Murakami, M. Morita, K. Doi, and K. Miyamoto, Jpn. J. Appl. Phys. **28**, L1125 (1989).

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