HIGH-TEMPERATURE SUPERCONDUCTORS

Raised to a higher plane

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ONE of the more popular tricks to play with the new high-temperature superconductors is to levitate a magnet over a sample cooled in liquid nitrogen. Indeed, researchers at one Japanese laboratory, having used the levitation force to raise a goldfish in its fish bowl (reported in News and Views last year[1]), have now proceeded to raise their director in the same way (see Fig. 1). For practical purposes, however, the important parameter is the stiffness of the force, both vertically and laterally. New work by Johansen *et al.*[2] at the University of Oslo shows that the high-temperature superconductors are much more stable laterally than had been predicted theoretically.

As is often the case with new discoveries, such as the high-temperature superconductors, the most obvious applications are not always the first to have the greatest industrial impact. This may become the case with the emerging field of superconducting magnetic bearings. With practical, high-current, wire-wound, high-temperature devices still years away, some laboratories are beginning to look at levitation applications using new bulk superconducting materials. Although not as glamorous in the public's mind as, say, magnetic resonance imaging, these applications include passive, magnetically levitated (and hence friction-free) machine elements such as high-speed rotors (Fig. 2) for gyros, energy or momentum storage, cryopumps, cryocoolers and even high-speed machine tools. New discoveries in materials processing of bulk superconducting materials, especially the melt-quenched or melt-textured yttrium–barium–copper oxide (YBCO), have led to increased research on the nature of magnetic levitation forces between superconductors and permanent magnets.

ISTEC/High-T_c Update

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FIG. 1 Levity in superconductivity research: S. Tanaka, director of the Superconductivity Research Laboratory at ISTEC in Tokyo, raised a centimetre above a superconductor at a recent meeting. The total mass of Tanaka and the magnetic disk supporting him was 120 kg.

Although countless laboratories have used levitation of small magnets (usually of the high-field rare earth element type) to demonstrate the phenomenon of superconductivity, very few have actually measured the forces and stability characteristics of these magnetic forces. For a levitated rotor made of a cylindrical rare earth magnet to be stable, it should have positive magnetic stiffness in five senses: one for vertical heave, two for lateral motions, and two more for pitch and yaw stability. In our experiments of 1988, we found[3] that the equivalent magnetic pressure on the face of the levitation magnets produced by sintered YBCO was quite low, of the order of 0.2 newtons (N) cm^{-2}. Currently available gas bearings provide a much higher fluid pressure of the order of 5–15 N cm^{-2}. Progress in the past two years in the processing of YBCO using so-called melt-quench or melt-textured techniques have pushed the levitation pressures up to 5 N cm^{-2} at 78 K and more than 10–20 N cm^{-2} at 20 K. It was these developments that permitted the Japanese workers at the ISTEC institute to levitate their director on a floating platform using 250 samples of melt-quench processed YBCO. However, engineers say that bearing stiffness is often the critical factor for many applications – thus the shift in focus in superconducting bearings from lift to magnetic stiffness, particularly lateral stiffness.

The Oslo group now show that, for a flat superconductor, the lateral stiffness seems to be independent of the position. A small lateral displacement of a test magnet yields a restoring force which is believed to be related to the pinning of magnetic flux lines to features in the superconductor. Davis has developed a model[4] for calculating this stiffness using Bean's critical-state model[5] in which the flux penetration into the superconductor is determined by the critical current of the material. The model predicts correctly the qualitative behaviour of the lateral force as seen by Johansen *et al.* But the model predicts a magnetic stiffness that is at least 50 per cent too small. Independent observations[6] show that the vertical stiffness depends on the incremental displacement: the stiffness for small displacements of a few micrometres is as much as twice that for displacement of 100–1,000 μm. The Oslo measurements were made with displacements of 500–1,000 μm.

Johansen *et al.* also find a lateral magnetic drag force when the displacement exceeds 1–2mm. This force might be interpreted as breaking the flux pinning forces when the test magnet is moved too far relative to the surface of the superconductor. In practical superconducting magnetic bearings, these drag forces can provide damping for lateral motions of the rotor. My colleagues and I find[7] that the lift force and magnetic stiffness are related by a power law. A similar law was derived for this magnetic drag force which also relates magnetic lift and drag by a power law. Since the lift force is proportional to the magnetic field, increasing the applied field of the levitation magnet will also increase magnetic stiffness and drag. Quadrupole and multipole arrangements for the levitating magnets also increase the magnetic stiffness (W.C. Chu, personal communication).

FIG. 2 Frictionless bearings could be an early use of high-temperature superconductors. Here, a half-kilogram magnetic disk suspended over three melt-quenched YBCO pellets is spinning 15,000 times a minute.

Although wire and thin-film research still garner the bulk of the superconducting research funds, NASA is taking a special interest in magnetic levitation, looking at applications for machines which require long-life bearings (for use on missions to Mars and the Moon, for example) and have natural cryogenic environments such as liquid H_2 and O_2 propellents. Given the potential for high-speed, contactless, no-wear, stable levitation of small and large rotors, superconducting magnetic bearings may become the first 'sleeper' application of the high-temperature revolution. □

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