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APPLICATIONS OF BULK HIGH-TEMPERATURE SUPERCONDUCTORS*

by

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DISCLAIMER

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ABSTRACT

This paper describes major applications of bulk high-temperature superconductors. Current leads and magnetic bearings are discussed in detail.

INTRODUCTION

The development of high-temperature superconductors (HTSs) can be broadly generalized into thin-film electronics, wire applications, and bulk applications. We consider bulk HTSs to include sintered or crystallized forms that do not take the geometry of filaments or tapes, and we discuss major applications for these materials. For the most part applications may be realized with the HTSs cooled to 77 K, and the properties of the bulk HTSs are often already sufficient for commercial use.

A non-exhaustive list of applications for bulk HTSs includes trapped field magnets, hysteresis motors, magnetic shielding, current leads, and magnetic bearings. These applications are briefly discussed in this paper.

TRAPPED-FIELD MAGNETS

HTSs have the ability to replicate the multipolarity of an activation magnet and in some samples have exhibited maximum field intensities that are higher than that achievable by permanent magnets at room temperature [1]. Their use in electric motors where permanent magnets are replaced by the trapped-field HTSs would result in power densities much higher than in contemporary motors and would allow motor topologies unsuitable to wires. Means to energize the trapped fields and the study of losses in these designs are still active areas of research. In this application larger magnetic field in the trapped-field HTSs result from larger diameter single-domain samples and from stronger flux pinning. Typically, samples for this application are made from melt-textured Y-Ba-Cu-O.

HYSTERESIS MOTORS

The same melt-textured Y-Ba-Cu-O that enables trapped-field magnets can also be used in hysteresis motors [2]. In this application, however, the HTS acts as a passive element, and its ability to stably trap a field is not as critical. There is an analogous relation for power scaling that desires larger diameter single-domain samples, however the advantages and limitations of these machines are still not widely understood.

MAGNETIC SHIELDING

Bulk HTS has received considerable attention for use in shielding of magnetic fields. A near-term application of this type is for shielded core reactors, e.g. [3]. Such reactors can be used for fault-current limiters. Below a certain current, the magnetic core is shielded from the coil. Above some threshold current, the magnetic field penetrates to the core and the impedance of the reactor significantly increases, thus helping to reduce further increases in current.

CURRENT LEADS

The use of HTSs in cryostat current leads, delivering electrical power from ambient-temperature supplies to devices operating in liquid helium, is a near-term HTS application [4]. The advantage of HTSs in this application is that because joule heating is eliminated in the HTS part of the lead, heat leakage into the liquid helium is reduced, resulting in longer operating times for open systems and reduced refrigeration requirements for closed systems. Because the thermal conductivities of HTSs are relatively low, lead lengths can be relatively short. Current densities of 100-1000 A/cm^2 (at $T \leq 77$ K and $B \leq 20$ mT), obtainable with present bulk-sintering methods, allow the use of leads that occupy a reasonably small volume and are not overly expensive in many designs. Lower current densities are also advantageous in providing a longer transient response time if part of the HTS becomes normal.

HTS current leads are already in use in several commercial devices, and HTS leads of several kA have been successfully tested. In this application, powder-in-tube (PIT) HTS can also be used, and PIT typically performs better than bulk HTS in higher magnetic fields. The preference of bulk to PIT in this application will probably depend on mechanical integrity and cost.

MAGNETIC BEARINGS

Magnetic bearings constitute another near-term application for HTSs. Considerable effort has been expended to elucidate much of the basic levitation phenomena associated with permanent magnets interacting with HTSs. As flux pinning has steadily improved and grain size in good quality specimens has increased, magnetic pressures have also increased, so that magnetic pressures of

100 kPa are now obtainable with a variety of processing methods based on melt processing of Y-Ba-Cu-O.

A cylindrical permanent magnet levitated over an HTS becomes a good bearing when the magnet rotates easily about its axis of symmetry but exhibits high stiffness to lateral and vertical displacements. It is sometimes stated that such magnets are frictionless, probably because there are no contacting parts. Strictly speaking, there will always be some rotational drag caused by eddy currents, magnetic hysteresis, or air friction, and thus there will always be an effective coefficient of friction.

With a low coefficient of friction, HTS bearings have the potential for use in low-loss energy-storage flywheels. State-of-the-art conventional magnetic bearings typically have an effective coefficient of friction of about 10^{-4}. Conventional roller bearings have even more friction. Even considering the refrigeration losses at 77 K, low-loss HTS bearings should have lower loss and allow flywheels to spin longer than with any other bearing technology. We consider the low-loss HTS bearing an enabling technology for many flywheel applications and are presently pursuing a project in this area with Commonwealth Research Corporation. In that collaboration, we have reduced the coefficient of friction to 2×10^{-7} [5].

A new type of HTS bearing, using mixed-mu levitation is also under development. In this bearing the levitated object contains magnetic steel. The levitation force on the steel is provided by a stationary set of permanent magnets, and stability is provided by stationary HTSs. Low-speed experiments have exhibited a coefficient of friction as low as 5×10^{-9}, and the speed dependence indicates it is possible to obtain a coefficient of friction less than 10^{-6} at a bearing speed of over 100 m/s.

CONCLUSIONS

Bulk HTS have already developed to the point that some commercial applications are in place. As the materials properties continue to improve, more applications are expected to become a commercial reality. The main applications areas include trapped-field magnets, hysteresis motors, magnetic shielding, current leads, and superconducting bearings. Superconducting bearings are expected to enable high-efficiency flywheels.

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