

A HIGH-TEMPERATURE SUPERCONDUCTOR CRYOGENIC CURRENT COMPARATOR

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Abstract

NIST is developing a cryogenic current comparator (CCC) to operate at 77 K, using high-temperature superconductor (HTS) ceramic shields and a HTS-based superconducting quantum interference device (SQUID) detector. HTS shielding at low magnetic field levels is probably sufficient for high accuracy measurements. Unshielded sections of the ratio windings may produce a significant error.

Introduction

The original CCC proposed by Harvey [1] was constructed by passing the ratio windings through a superconducting tube; the current ratio balance was sensed by coupling the induced external magnetic field to a SQUID detector. In order to implement available HTS technology we propose using a CCC design with ratio windings enclosed in two parallel HTS tubes. The HTS-based SQUID will be directly coupled to the induced field by placing the SQUID between the tubes.

HTS Magnetic Shielding

Meissner effect shielding of magnetic fields in HTS ceramic materials has been shown to be similar to shielding in Nb-based superconductors [2]. In metallic type-II superconductors, flux is expelled completely if the field is below the lower critical field (H_{c1}) of the bulk sample. The ceramics differ from the metals in that ceramic superconducting grains form Josephson junctions at grain boundaries. This allows a magnetic field to penetrate between the grains if the Josephson lower critical field (H_{jc1}) is exceeded. Above this critical field value, HTS ceramics exhibit flux creep, and the shielding is strongly dependent on thickness [3]. The H_{jc1} for ceramics has been shown to depend on the grain size [4], and rises with the critical current density [5]. Both the $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) and

$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ compounds are effective as magnetic shields [6,7]. YBCO ceramic tubes can have a shielding efficiency at 77 K of at least 10^6 for weak magnetic fields.

CCC Design

The current-linkage error [8] of a CCC is defined as $E = \epsilon/N_1 I_1$, where a main ratio winding has N_1 turns and carries current I_1 . The current-linkage signal ϵ is proportional to the current I_1 . Precision measurements are possible with overlapped-tube type CCC devices [9] because E can be made very small (0.0001 ppm or less). Continuous overlapped-tube shielding is not practical for HTS ceramics.

The HTS CCC will use a commercial rf SQUID sensor positioned between two HTS tubes. We have built and characterized a prototype CCC using a conventional SQUID (fig. 1) which is coupled via a flux transformer and two 16 mm (inside diameter) tubes of a conventional superconductor (Nb). The dimensions are fixed with the separation of the Nb tubes equal to the diameter of the flux transformer (6 mm). The lengths of the tubes are 150 mm. Using a 14-turn circular flux transformer, the resulting sensitivity of the SQUID is 14.3 μA of one-turn winding current for one

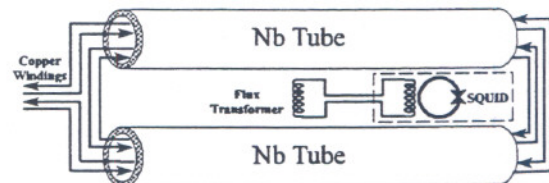


Fig. 1. A diagram of a prototype conventional CCC consisting of two shield tubes and a SQUID detector, with two insulated copper windings.

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flux quantum of detected field. Several sets of ten-turn windings were tested with currents of 10 μ A to 100 mA to determine the range of errors. A loosely twisted pair of windings gives a current-linkage error E of less than five ppm, while several sets of separately wound wires give an error of order 100 ppm. The error E should be at worst inversely proportional to the square of the tube length L if the length is much greater than the tube separation. Tube extensions made of a non-superconductor resulted in a much larger value of E for both twisted and untwisted winding pairs.

Conclusion

HTS ceramics appear to have sufficient shielding capability to provide effective magnetic shields for constructing a HTS CCC at the sub-ppm ratio accuracy. However, since the materials are brittle and cannot be formed into complex shapes, it is impractical to use conventional shielding and winding geometries. We plan to investigate different shielding geometries in order to reduce the current-linkage error of HTS CCC systems. At the conference, we will discuss our latest experimental results and future possibilities.

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