A Novel Approach to Characterizing Superconducting Joints

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January 16, 2015 (HP88). In a recent article [1] with our industrial collaborators at Agilent Technologies, we proposed a novel technique for measuring the superconducting properties of persistent current joints in a commercial magnetic properties measurement system (MPMS). As was seconded by Jan Jaroszynski of the National High Magnetic Field Laboratory (NHMFL) in the associated viewpoint article [2], joint development is a highly active field of research and widely regarded as a key stepping stone for next-generation magnet manufacture.

The inability to easily characterize the superconducting properties of joints over a wide range of operational conditions may inhibit our ability to identify key performance-limiting factors. This is chiefly because inductive resistance testing (IRT) based on measuring field decay in small coils is traditionally subject to a number of constraints. These typically include limited resistance sensitivity (i.e., slow data acquisition) and single temperature operation (LHe at 4.2 K) with the joint situated in relatively low fields. Whilst such limitations can be overcome by establishing a test system with advanced field sensors, measurement electronics and home-built cryomagnetics, this requires specialized technical expertise. Without a comprehensive test system, IRT is little more than a litmus test for acceptable quality, yielding only limited insights into the underlying physics of joint operation.

Commercial magnetometers (such as the Quantum Design MPMS that we have used) are able to make very high sensitivity magnetic measurements over a wide range of temperatures and fields. With some modifications to the traditional IRT setup and measurement procedures, we have provided a first principle demonstration that such systems are in-fact capable of serving as versatile “out-of-the-box” joint testing kits.

In this demonstration, a single-turn sample coil was wound from monocoreNbTi wire, terminated with a PbBi soldered joint and loaded axially into an MPMS XL-7 in a standard Ø5 mm straw (as shown in Figure 1). The MPMS magnet serves the dual role of inducing currents in the coil (by changing the field) and sustaining a persistent mode background field on the coil and joint during decay measurements.

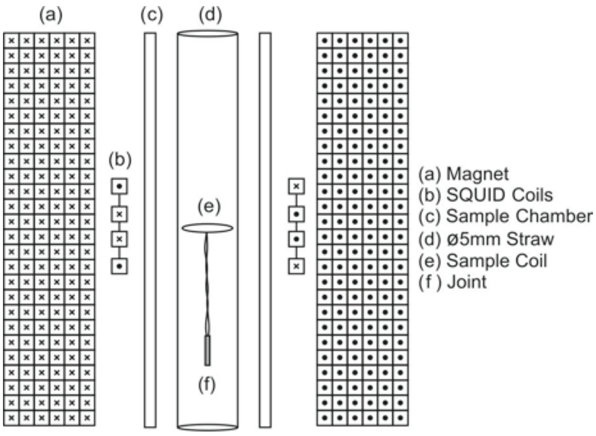

Fig. 1. A schematic illustration of the experimental setup, with the jointed sample coil loaded axially in the MPMS, centered on the SQUID pickup coils.

The current in the coil is measured indirectly from high sensitivity SQUID voltage scans obtained by DC extraction magnetometry. The single turn sample coil geometry produces a magnetic field of almost ideal dipole form, allowing quantitative measures of magnetic moment (μ) to be obtained from these voltage scans. Current can then be inferred by a simple single-turn assumption. Our paper demonstrates two useful features of the technique.

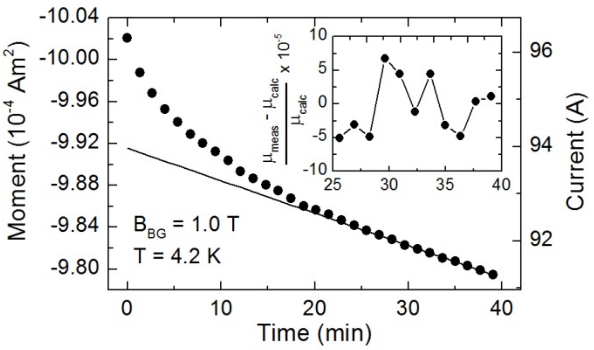

Fig. 2. The decaying magnetic moment of the sample coil as an induced current is attenuated across the joint. The current was generated by raising the field from 0.7 T to 1.0 T at 4.2 K. The solid line is an exponential fit to the settled trend with resistance R = 39.6 ± 0.5 x 10^{-15} Ω. The inset shows the noise level on measurements in the fitted portion.

Firstly, by measuring the current induced in the coil as the MPMS field is ramped (in a fashion analogous to standard hysteresis loop measurements), joint $I_C(B,T)$ can be rapidly determined. Moreover, upon critical failure of the joint, current flow through the joint ceases altogether and the field produced by the sample coil changes in form. This is evident from changes in the characteristic shape of the measured voltage scans. Identifying the precise fields and temperatures at which a joint fails gives us $B_{c2}(T)$ of the materials along the critical current path through the joint. By this method, joints can be characterized over a wide range of fields and temperatures in a few hours, providing a highly effective tool for screening of joint quality.

The second feature is inductive resistance testing. By monitoring the decay of currents induced in the coil (such as that shown in Figure 2), the joint resistance can be inferred as usual from R=L/τ, where τ is the settled exponential decay constant and L is the coil self-inductance (in this case calculated to be ~7.55 nH). By varying the field applied on cooling, followed by ramping to a desired background field value (B_{BG}), $R(I,B,T)$ can be obtained over a wide range of operational conditions. Measurements made to-date show resistance to rise significantly towards the critical surface, and typical values are in the commonly found range for persistent joints of 10^{-15}-10^{-12} Ω. Whilst much work remains to fully understand the data we generate in this way, including potential influences of the measurement process itself on decay behavior, the results are consistent with dissipation originating in the joint. Resistance sensitivity is very high on account of the low sample coil inductance and low noise level in the decay data, and a 20 minute period of steady state decay is theoretically sufficient to distinguish resistances at the 10^{-17}-10^{-16} Ω level.

It is hoped that this technique will serve as a useful tool to the applied superconductivity community in allowing for effective development of jointing techniques, as well as allowing for more fundamental studies of joint performance by virtue of the ability to rapidly characterize their superconducting properties in unprecedented detail. With some modifications to the coil design, it should also be possible to test joints between (RE)BCO coated conductors by this method.

References

[1] G. D. Brittles, P. Noonan, S. A. Keys, C. R. M. Grovenor and S. Speller, "Rapid characterization of persistent current joints by SQUID magnetometry", *Supercond. Sci. Technol.*, **27**, 122002 (2014)

[2] J. Jaroszynski, "Race against time: resistance of superconducting joints measurements", *Supercond. Sci. Technol.*, **28**, 010501 (2015)