USE OF METALLIC STRAIN GAUGES FOR TORQUE MAGNETOMETRY: APPLICATION TO THE CONTACTLESS CHARACTERIZATION OF LARGE MAGNETIZED SUPERCONDUCTING SAMPLES

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1. Introduction

The context of this research is the need of non-destructive characterization techniques for magnetized samples of relatively large size (> 10 mm). The magnetic materials of interest are either permanent magnets or bulk superconductors. Due to the ability of superconductors to carry large electric currents with no loss when cooled at cryogenic temperature (typically $T < 100$ K), they are able to trap large permanent current loops generating a strong magnetic field. A bulk magnetized superconducting material, therefore, behaves like a quasi-permanent magnet, also called 'trapped flux magnet'. Such trapped flux magnets may generate flux densities of several teslas [1], which is well beyond the flux density generated by conventional ferromagnets. Since the magnetic properties are due to macroscopic current loops, they depend on the size of the superconductor. A suitable characterization of the magnetic moment cannot be carried out on small samples cut out of the trapped field magnet. This requires the design of magnetometers that are able to accommodate samples of large size, typically above 10 mm in diameter. In this work we show how this can be achieved with torque measurement based on metallic strain gauges.

Magnetometry using torque measurements has been applied successfully in the last decades to measure accurately the magnetic moment of small samples (see e.g. [3]). The method usually relies on magnetizing the sample and then applying a magnetic field tilted at a given angle with respect to the magnetization direction. The resulting torque, measured experimentally, is used to determine the magnetization of the trapped field magnet. This technique, however, was demonstrated on samples of a few mm^3, with torques typically smaller than 10^{-5} Nm. The purpose of the present work is to demonstrate that it can be applied to the measurement of torques up to 1 Nm.

2. Experiment

A bespoke torque magnetometer was constructed for operation either at room temperature or at liquid nitrogen temperature (77 K) [3]. The torque is measured with a metallic strain gauge bridge (HBM 1-VY43-3/350) mounted on an aluminum transmission shaft, as shown schematically in Fig. 1a. The shaft allows the sample to be located between two poles of a water-cooled electromagnet, the poles are 46 mm apart. The sample holder can accommodate samples up to 17 mm in diameter. The sample can be placed at two orthogonal directions with the applied field, namely with (i) the main axis parallel to the field during the magnetization procedure and (ii) the main axis perpendicular to the field for the generation of the torque to be measured. In so doing the sample is subjected to a field perpendicular to its main magnetization, which can lead to a demagnetization effect [4]. This effect is also worth to be investigated in view of engineering applications. When the magnetometer is operated at 77 K, the strain gauge bridge is maintained within its recommended operating temperature range (here ~ 242 K) using a Lake Shore temperature controller, a thermofoil heater and a Pt 100 temperature sensor thermally anchored to the shaft (Fig. 1b). The output signal of the bridge fed at 63 Hz is measured with an EG&G 7260 DSP Lock-in amplifier, allowing a relative bridge sensitivity down to $\sim 2 \times 10^{-8}$ to be achieved.

3. Results

Figure 1c shows the bridge output voltage as a function of the magnetic field, perpendicular to the axis of a calibration coil fed with a known DC current. The data are compared to the theoretical voltage expected from the bridge sensitivity, shear modulus and shaft diameter. Figure 1d shows the magnetic moment of a bulk sample made of a stack of $YBa_2Cu_3O_7$ superconducting tapes (12×12 mm) at 77 K, measured experimentally with the torque magnetometer, and being slightly affected by the transverse applied field. Successful operation of the device was also demonstrated with a 15 mm diameter Nd-Fe-B magnet. The latter leads to measured magnetic moments > 1 Am^2, i.e. two orders of magnitude above what can be achieved with off-the shelf magnetometers.

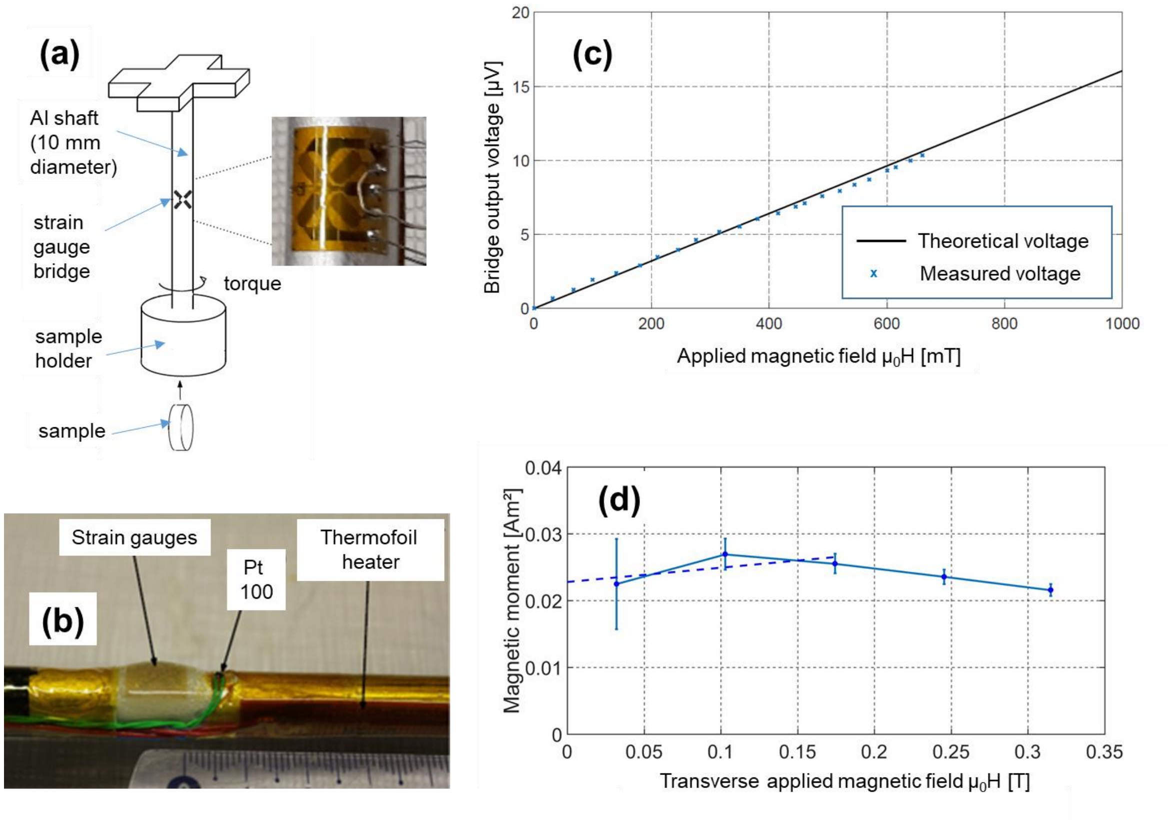

Figure 1. (a) Schematic illustration of the torque transmission system (b) Photograph of the fully mounted bridge (c) Output signal measured at room temperature; the sample is a copper coil fed with DC current for absolute calibration (d) Magnetic moment at 77 K of a magnetized bulk stack of $YBa_2Cu_3O_7$ superconducting tapes as a function of the transverse applied magnetic field.

4. References

[1] J. H. Durrell et al. (2018). Bulk superconductors: a roadmap to applications, *Supercond. Sci. Technol.* **31**, 103501.

[2] S. Kohout, J. Roos and H. Keller (2007). Novel sensor design for torque magnetometry, *Rev. Sci. Instrum.* **78**, 013903.

[3] S. Brialmont, J. F. Fagnard and P. Vanderbemden (2019). A simple torque magnetometer for magnetic moment measurement of large samples: Application to permanent magnets and bulk superconductors, *Rev. Sci. Instrum.* **90**, 085101.

[4] Z. Hong et al. (2008). The numerical modeling and measurement of demagnetization effect in bulk YBCO supercond. subjected to transverse field, *IEEE Trans. Appl. Supercond.* **18**, 1561.