Design and construction of a torque magnetometer for large size superconductors

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Introduction and motivation

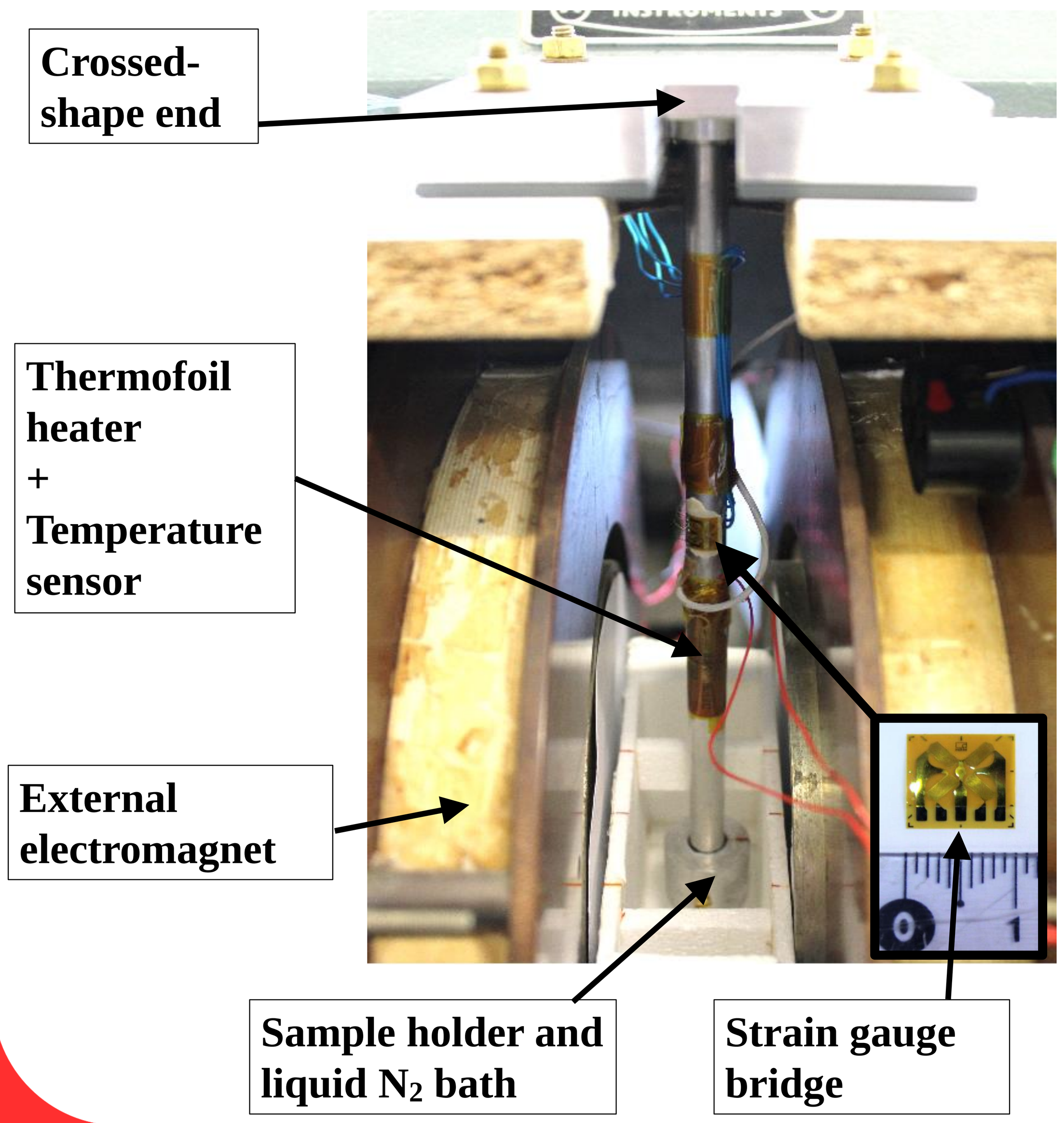
- Current commercial magnetometers working at cryogenic temperatures accommodate very small samples (<< 1 cm³).
- We need **non destructive** characterization methods of the magnetic properties for the **whole volume** of the sample.
- Recently, we have designed a simple torque magnetometer able to accommodate sizable samples [1].
- ***Principle of operation:***

  Magnetic torque: $\boldsymbol{\tau} = \boldsymbol{m} \times \boldsymbol{B}$
  for a hysteretic or non isotropic material under an external field $\boldsymbol{B}$

- **In crossed-fields configuration ($\boldsymbol{m} \perp \boldsymbol{B}$) [2]:**

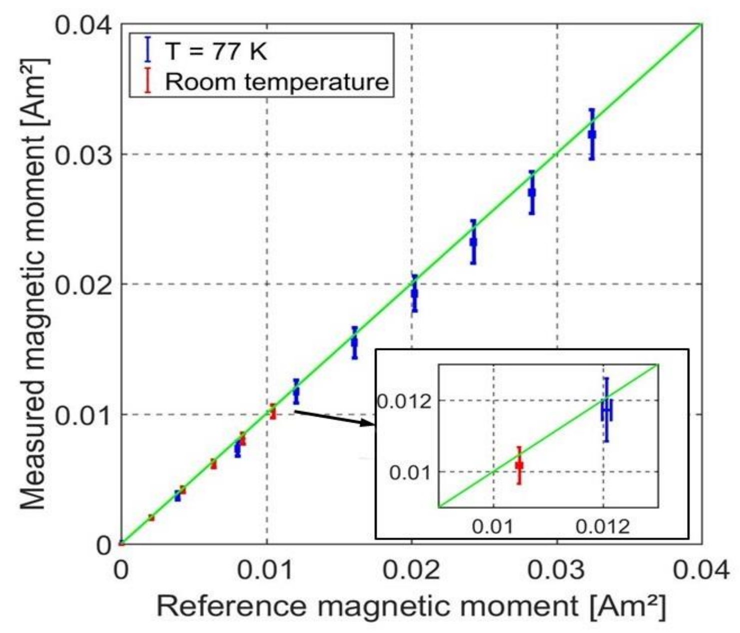
$$m = \frac{\tau}{B}$$

Experimental set-up



- Aluminium **cylindrical transmission shaft.**
- **Strain gauges** mounted in a **full bridge configuration** and placed at **45° w.r.t. the shaft axis.**
- Gauge bridge supplied with an **AC voltage** (6.08 V_{RMS}, 63 Hz) and output signal measured with a **lock-in amplifier.**
- **Thermofoil heater and Pt100 sensor** to control the temperature of the bridge.

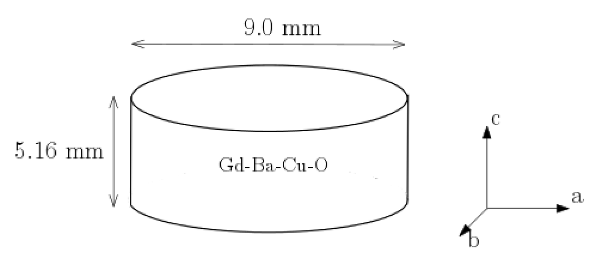
- Calibration by a **small coil fed with a DC current.**
- **Magnetic moment is known** and compared with **measured value.**

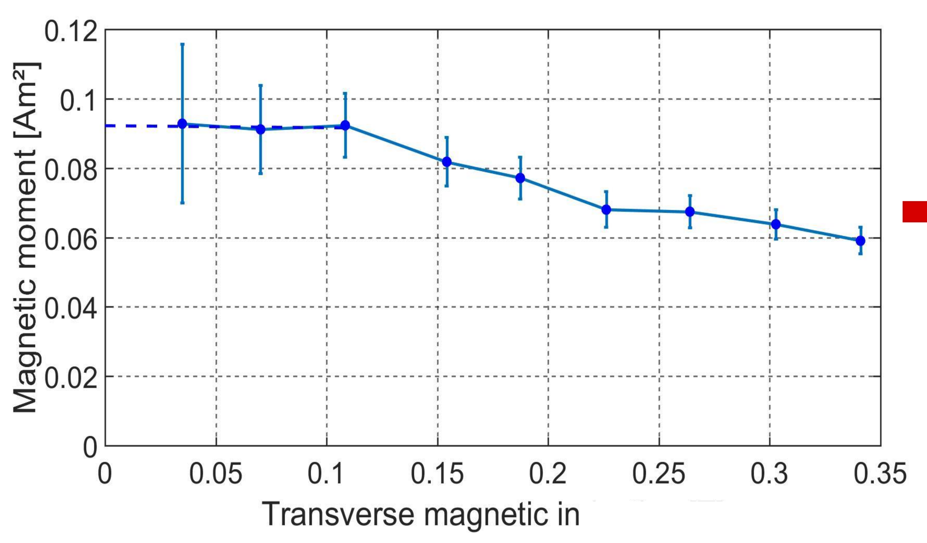


Results and discussion

Test on a bulk $GdBa_2Cu_3O_7$ sample

- Magnetization under 670 mT (**Field Cooled**). The **magnetic moment** is recorded as a function of the **transverse applied field**. The **initial magnetic moment m_0** is obtained by **linear extrapolation**.



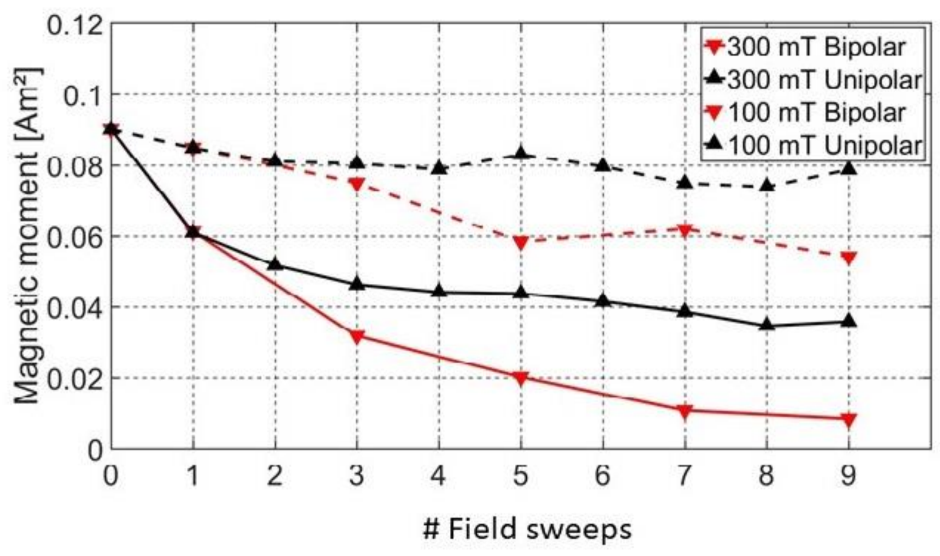


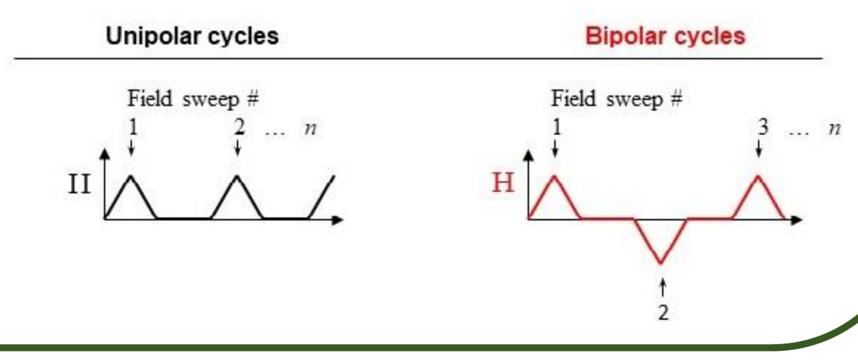
$m_0 = 0.092\ \mathrm{A\,m^2}$
$J_c \approx 2 \times 10^4\ \mathrm{A/cm^2}$

Flux extraction magnetometer:
$m_0 = 0.089 \pm 0.01\ \mathrm{Am^2}$ [3]

- **Demagnetization effect** observed by applying triangular cycles (unipolar and bipolar).
- Demagnetization amplified for **bipolar cycles**.
- **Advantage of this technique:**

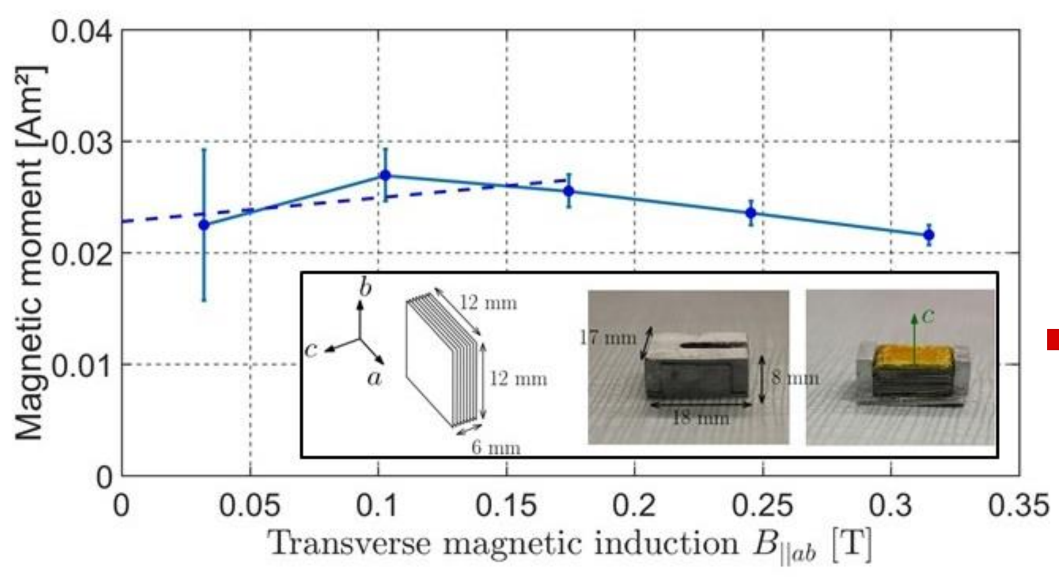
  The sample can be inserted in the narrow band gap of a **strong electromagnet** which is not always possible with techniques based on **sensing coils.**



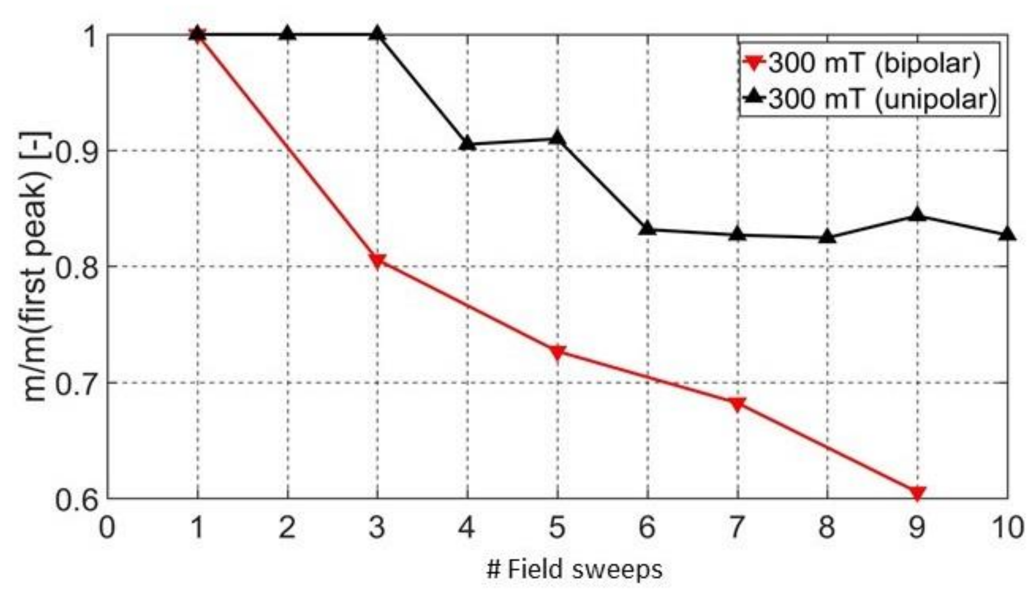


Test on stacked 2G $YBa_2Cu_3O_7$ tapes

- Magnetometer tested on **a stack of 42 superconducting tapes** from Superpower® .
- Magnetization in the *c*-direction under 670 mT (**Field Cooled**). Then the **magnetic moment** is measured as a function of the **transverse field**. The **initial magnetic moment** is then obtained by **linear extrapolation**. From this, the **engineering current density** J_e can be estimated.



$m_0 = 0.022\ \mathrm{A\,m^2}$
$J_e \approx 212\ \mathrm{A/cm^2}$



- **Demagnetization effect** observed by application of triangular field cycles.
- Magnetic moment normalized w.r.t. the magnetic moment measured at the first peak is plotted as a function of the number of field sweeps.
- Demagnetization effect **drastically reduced using stacked tapes** compared to bulk samples.

Conclusions

I. An experimental **magnetic torque measurement system** for the **non-destructive measurement** of magnetic moment of **sizable samples** (up to 17 mm in diameter and 8 mm in thickness) and working at both **room and cryogenic (77 K) temperatures** has been designed, constructed and calibrated.

II. The system is able to measure magnetic moment down to **5×10^{-3} A m² (5 emu)**. It was also shown to be able to probe magnetic moment **exceeding 0.1 A m² (100 emu).**

III. It can be easily inserted in the air gap of a **powerful electromagnet** (not always possible with techniques based on **sensing coils**). However, it is not possible to measure the **field relaxation** (flux creep) with this technique.

[1] S. Brialmont, J. F. Fagnard and P. Vanderbemden , *Rev. Sci. Instrum.*, **90**, 085101 (2019).
[2] P. Vanderbemden, Z. Hong, T. A. Coombs, M. Ausloos, N. Hari Babu, D. A. Cardwell and A. M. Campbell, *Supercond. Sci. Technol.*, **20**, S174 (2007).
[3] R. Egan, M. Philippe, L. Wera, J. F. Fagnard, B. Vanderheyden, A. Dennis, Y. Shi, D. A. Cardwell and P. Vanderbemden, *Rev. Sci. Instrum.*, **86**, 025107 (2015).

Acknowledgements

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