VSM measurements in thin filaments NbTi wires

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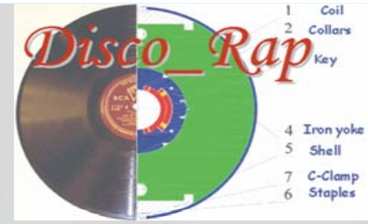


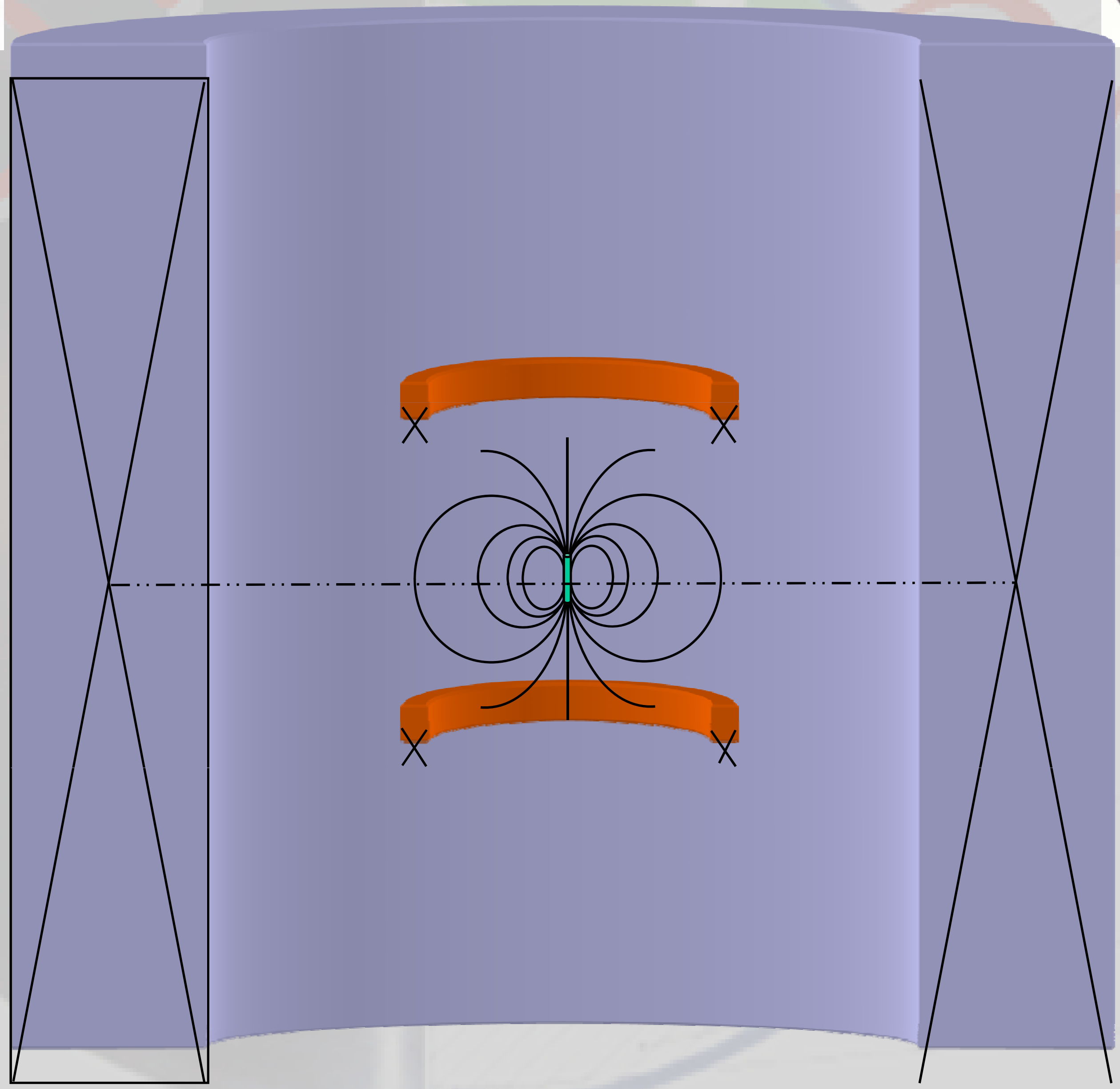
Outline:

1. **VSM working principle of and its weak points**
2. **features of a low losses** *(i.e. thin filaments)* **NbTi wire**
3. **VSM vs SQUID**
4. **conclusions**

What is a VSM

- **The mechanical movement of a sample magnetized in a uniform background magnetic field is translated into a voltage;**
- **Thus, among other problems, it NEEDS of calibration.**

Two VSM equipments (Oxford MagLab) are available, a 12 T (ENEA Frascati) and a 16 T (INFM Salerno). In addition cross checks with a SQUID magnetometer (INFM Genova) are also performed routinely.



Literature background

These questions have been addressed in many papers with different approaches.

Detection coil, sensitivity function, and sample geometry effects for vibrating sample magnetometers

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A general description based on the sensitivity function is presented for the effects of detection coil geometry and sample geometry on the output of a vibrating sample magnetometer (VSM). This harmonic function gives the VSM output versus position of a vibrating dipole. Calculations of the sensitivity function for axial and transverse detection coil configurations are presented using exact results and approximations including a spherical harmonic expansion. For axial, thick, rectangular cross-section coils, the design yielding the output with a minimum sensitivity to sample position, sample shape, and sample size is presented. For the transverse geometry the small coil approximation is used. Various designs yielding maximum output and output insensitive to variations of sample geometry are reviewed. The signal-to-noise for various coil configurations is also discussed. Corrections for the VSM output are derived for "large" samples with regular geometries (thin rod, circular cylinder, cube, and rectangular parallelepiped). The calculations were verified experimentally for a rod-like sample for different orientations. The effects of applied field homogeneity, sample position errors, and sample support contributions are also discussed. Finally, applications of the analysis to other types of induction and force type magnetometers are discussed briefly.

Rev. Sci.Instrum. **53** *9* (1982) 1344

Non-uniform magnetisation and the vibrating sample magnetometer

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Received 12 September 1977

Abstract. A general treatment is given of the response of vibrating-sample magnetometer pick-up coils to non-uniformly magnetised specimens. It is shown that the nth term in a multiple expansion of the sample magnetisation gives rise to a component of the induced EMF at the oscillation frequency, proportional to the $(n+1)$th derivative of the 'pick-up field', h, along the direction of the sample motion (h is the field such that $h.m$ is the flux produced in the coils by a magnetic moment m). The analysis has been tested by observations of the signals produced by systems of small coils carrying a DC current. To illustrate the method, experiments on the remanent states of several ordered magnetic materials are described. Application of the method, using a SQUID magnetometer, to the possible measurement of the sublattice magnetisation of antiferromagnetic materials is described.

J. Phys. C: Solid State Phys. **11** (1978) 1635

Harmonic calculations and measurements of the irreversibility field using a vibrating sample magnetometer

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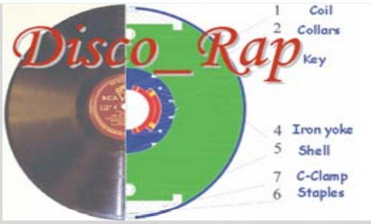
(Received 17 September 1999)

The effect of the field inhomogeneity of the magnet on a vibrating sample magnetometer (VSM) measurement of a superconductor is calculated using Bean's model and Mallinson's principle of reciprocity. When the sample is centered in both the magnetic field and the VSM pick-up coils, the hysteretic signal obtained in a VSM measurement, associated with the critical current density (J_C), is reduced to zero when the effective ac field caused by the sample movement penetrates the entire sample and not, as is commonly assumed, when the critical current density becomes zero. Under these conditions, an apparent phase transition is observed where the magnitude of the hysteresis drops to zero over a small field range. This apparent transition is solely an artifact of the measurement and cannot correctly be compared to theoretical calculations of the irreversibility field (B_{IRR}), which is the phase boundary at which J_C is zero. Furthermore, the apparent reversible magnetization signal in high fields includes two contributions. In addition to the usual diamagnetic contribution from the thermodynamic reversible magnetization of the superconductor, there is a reversible paramagnetic contribution from the nonzero J_C. Hence values of the Ginzburg-Landau parameter (κ) cannot be reliably obtained from standard reversible magnetization measurements using a VSM unless it is confirmed that J_C is zero. Harmonic measurements using a VSM are reported. They confirm the results of the calculations. By applying a large field gradient, the hysteresis in the magnetization signal at the drive frequency of the VSM is found to drop to zero more than 3 T below B_{IRR}. We propose methods to improve measurements of B_{IRR} and κ. The implications of results presented for superconducting quantum interference device measurements are also briefly discussed.

Phys. Rev. B **61** (2000) 6982



Our purpose is to get the widest information from magnetization

a. Low field measurements
   - superconducting volume
   - critical temperature, lower critical field

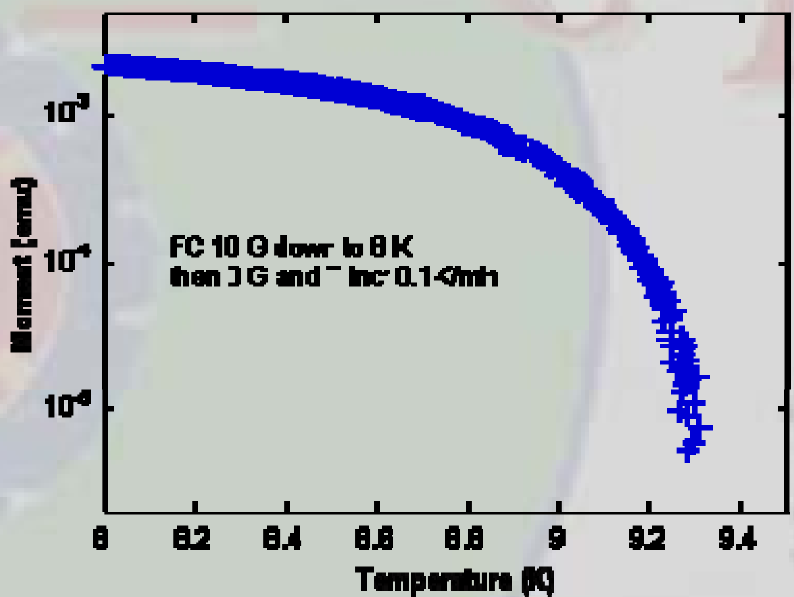
b. High field measurements
   - Critical current value (F_p, etc.)
   - Upper critical field (H_{c2}, H_{irr}, etc)
   - G-L parameter κ

c. Magnetization cycle
   - magnetization losses
   - time constant of the wire (ρ_{et})

a. Low field measurements

- ***superconducting volume***
- ***critical temperature, lower critical field***

From FC state (few G), the residual magnetization disappears at the critical temperature.



From ZFC state, the first magnetization slope is proportional to the sample volume.

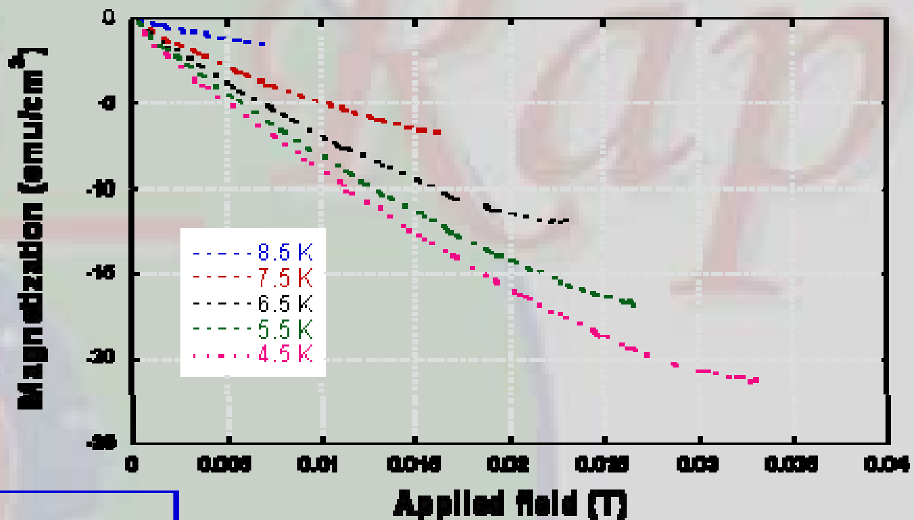
$$\text{Superconducting volume} = -\frac{1}{\chi_0}\frac{dm}{dH}$$

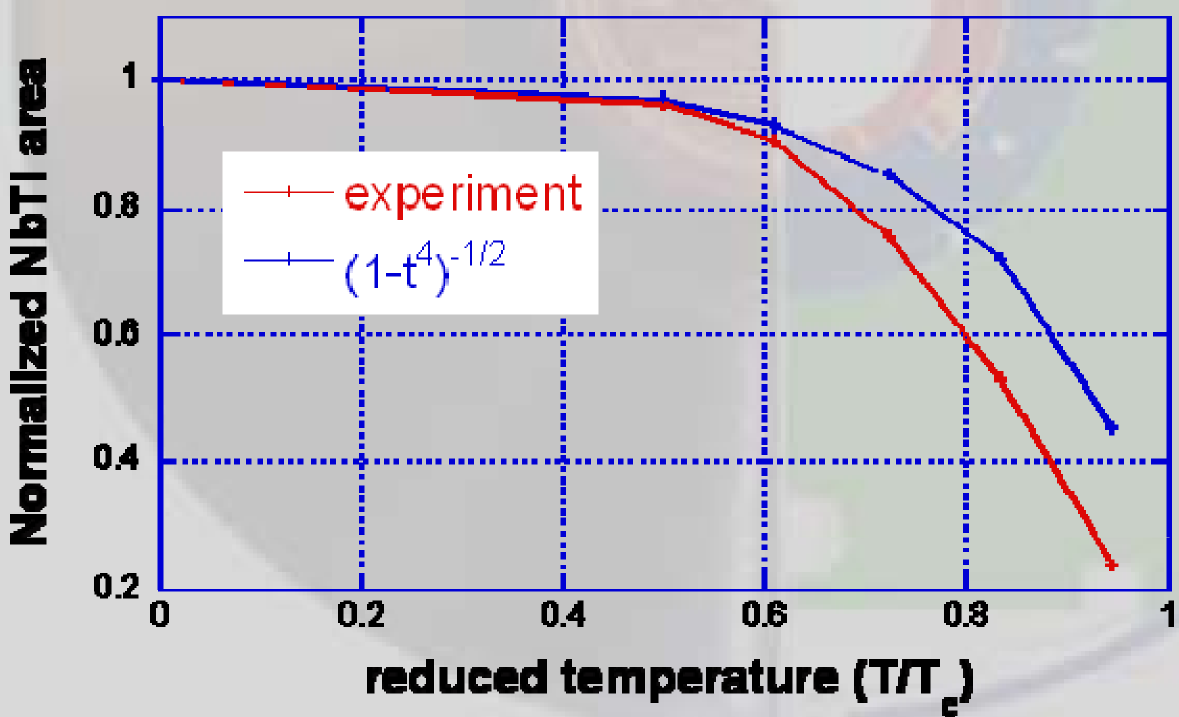
wire IGC 944 - Cu/Mn - 2.6 μm

nominal NbTi section 0.123 mm^2

From the 4.5 K *m*(H) slope we have 0.066 mm^2

From a SQUID measure we have 0.046 mm^2





Thin filaments wires

It is known that a χ_0 correction must be considered when the ratio λ/R, being R the filament radius, is not negligible

$$\chi_0 = -\left[1 - \frac{2\lambda}{R}\frac{\frac{1}{\pi}\int_0^{\pi} e^{\frac{R}{\lambda}\cos t}\cos t\;dt}{\frac{1}{\pi}\int_0^{\pi} e^{\frac{R}{\lambda}\cos t}dt}\right]$$

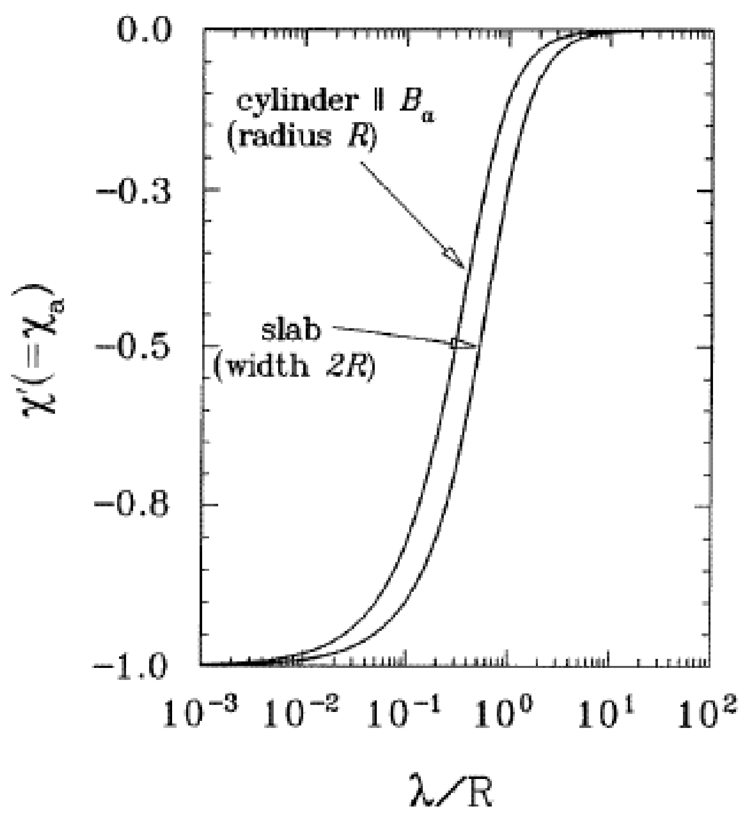
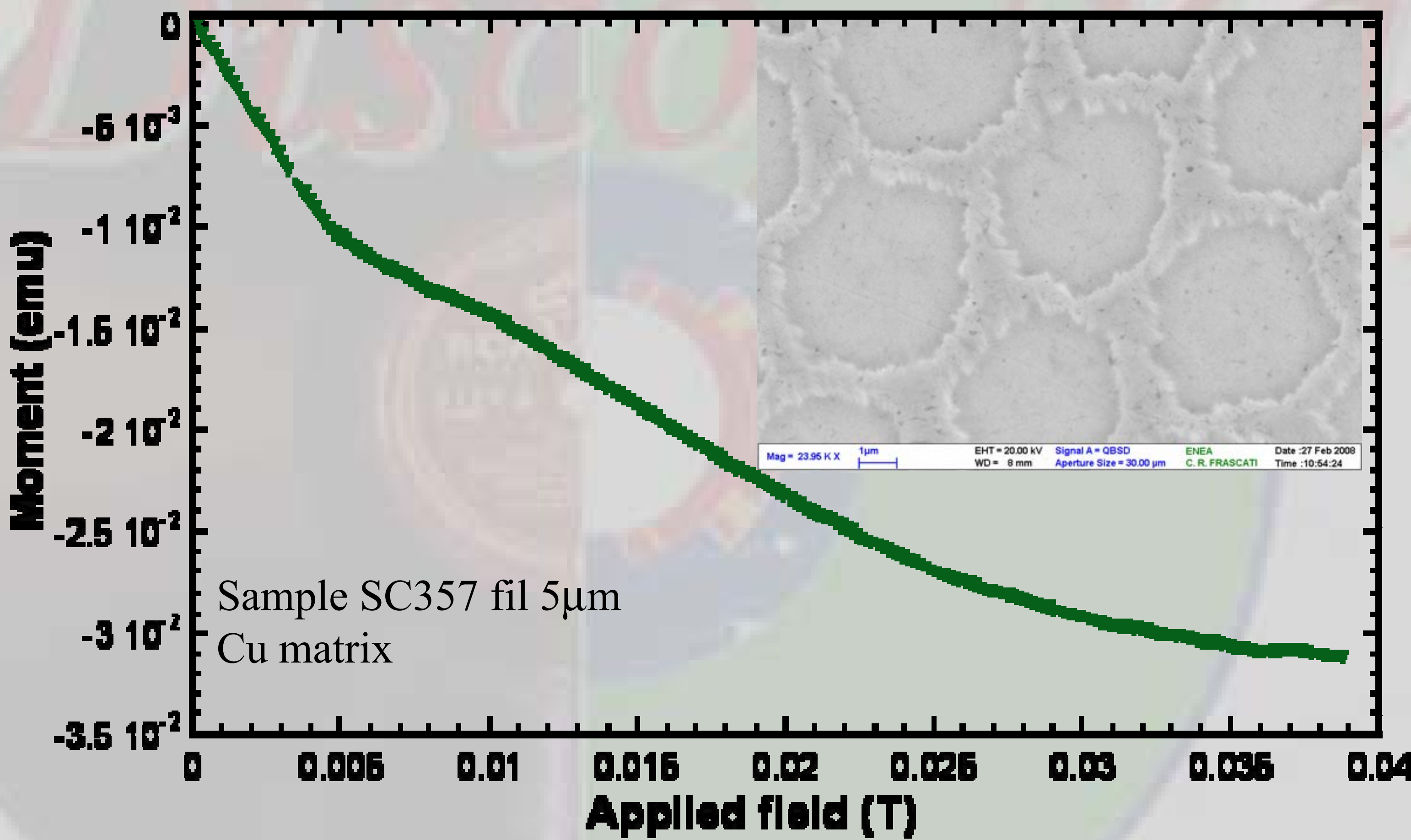


Figure 5. AC susceptibility in the regime of reversible screening.

F. Gomory, Supercond. Sci. Technol. **10** (1997) 523–542

Proximity effects



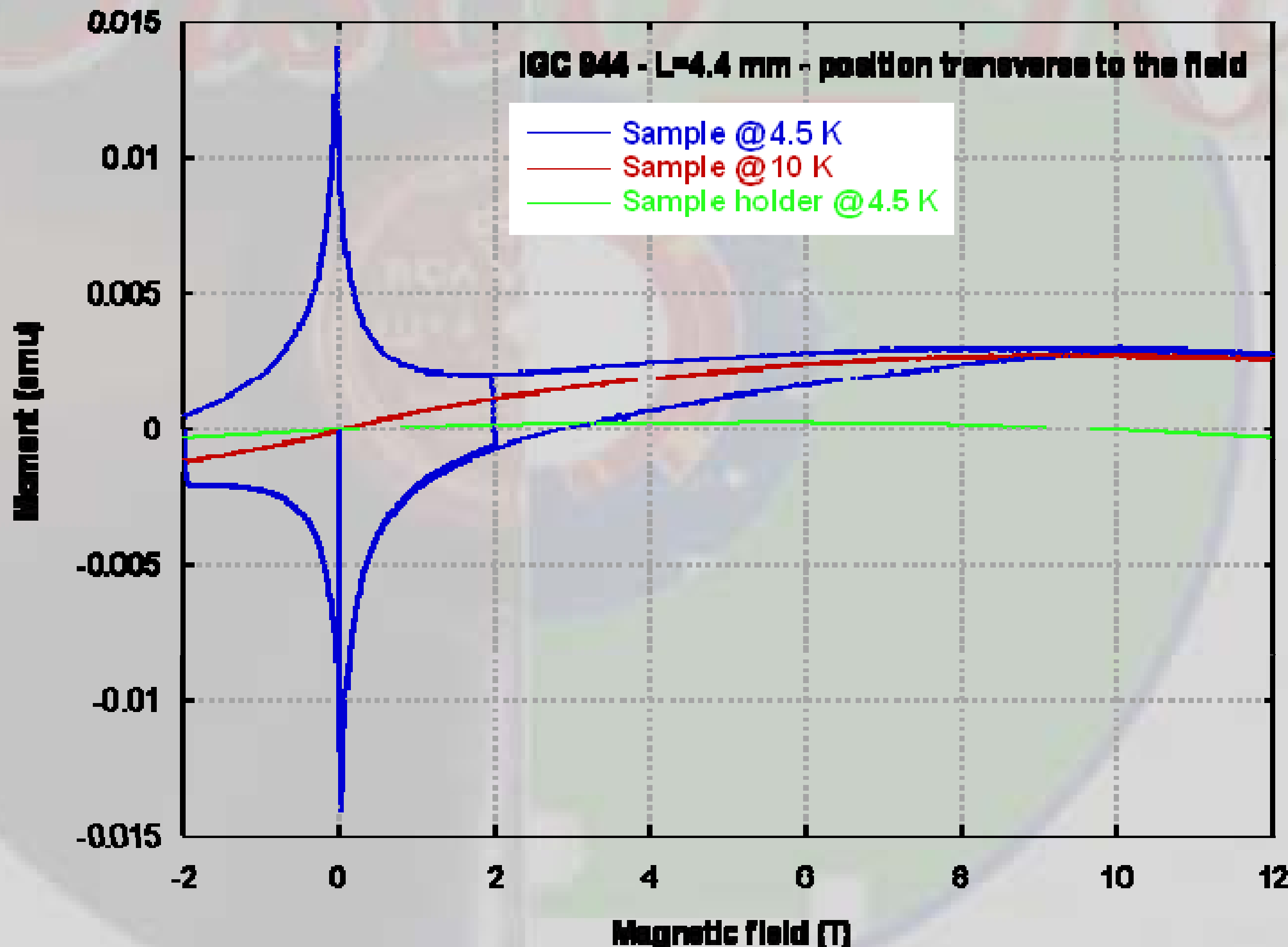
The linear fit in the range [0÷50] G gives a slope of -2.26 emu/T, while in the range [100÷200] G the slope is -0.896. Assuming a demagnetization factor ≈2 the estimated volume/length (1 emu=$4\pi 10^{-10}$ Wb m) of superconducting NbTi considering the two slopes is ≈0.37 mm^2 or ≈0.15 mm^2, respectively (the nominal one is 0.21 mm^2)

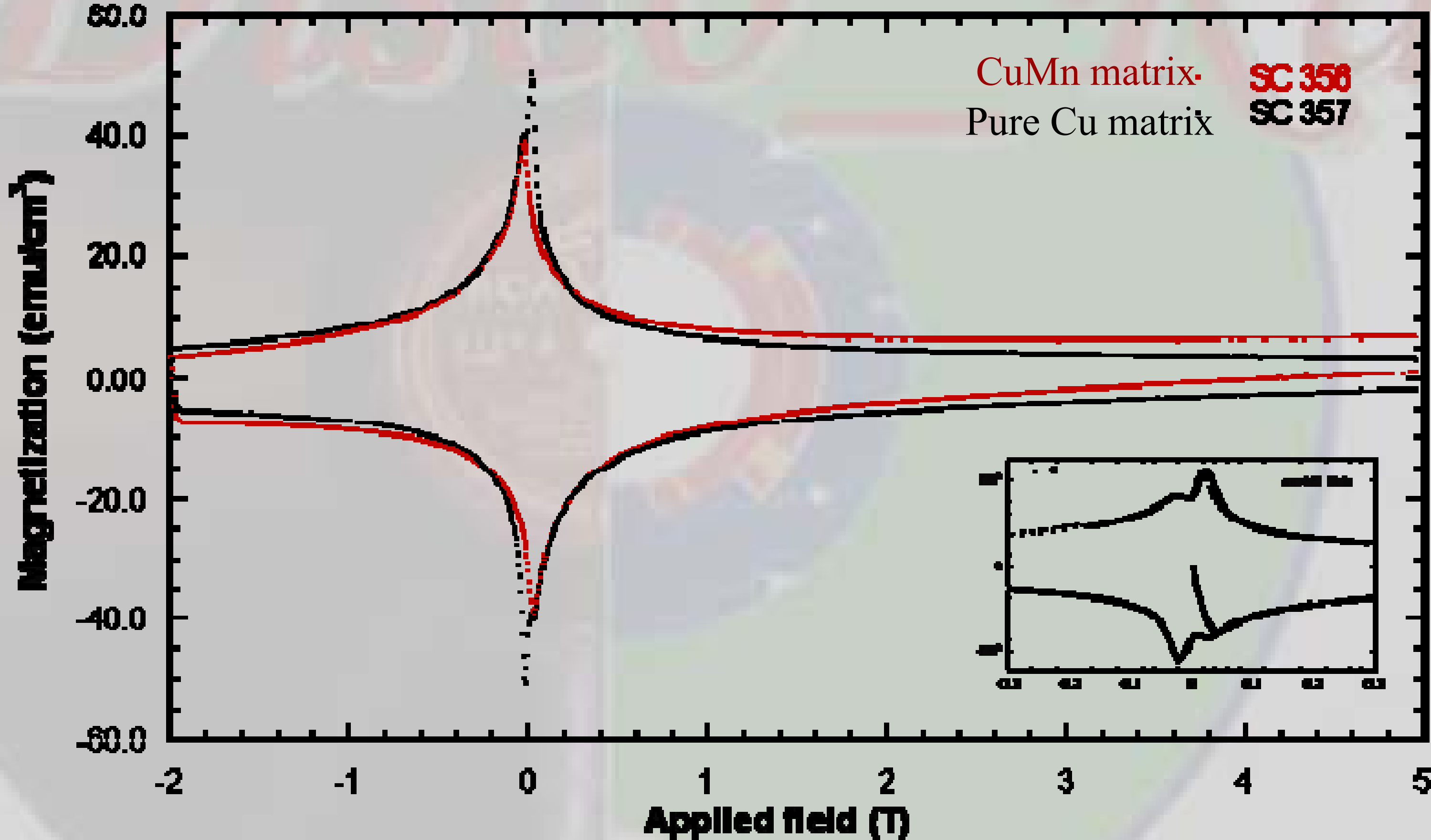
b. *High field measurements*

Critical current value (J_c, F_p, etc.)

Upper critical field (H_{c2}, H_{irr}, etc)

G-L parameter κ



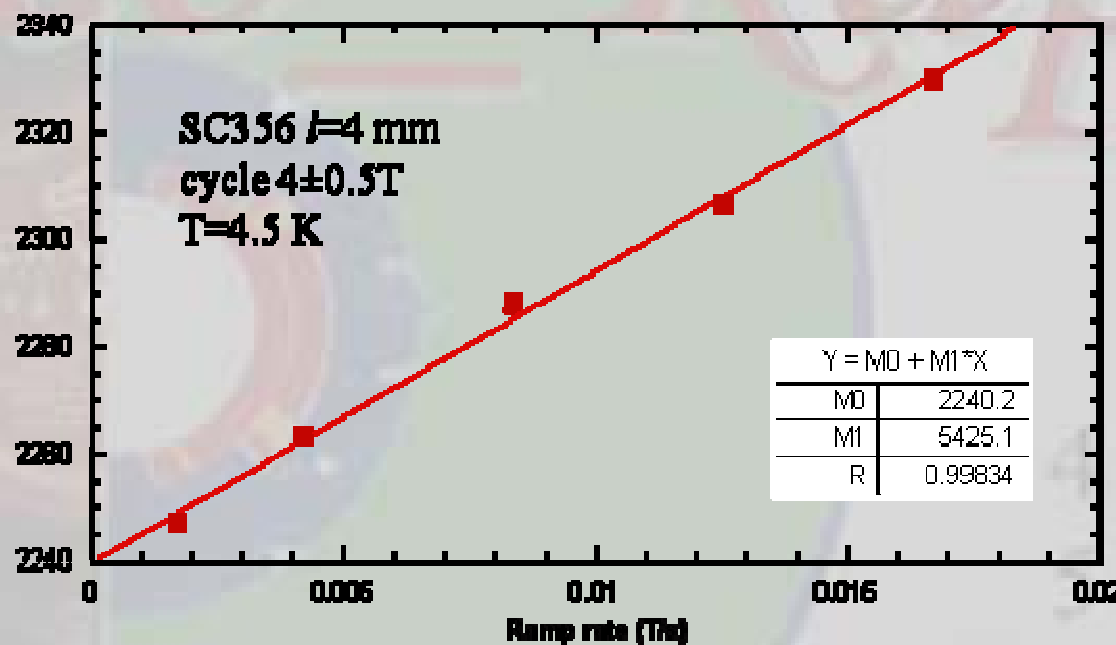

CuMn matrix
Pure Cu matrix
SC 358
SC 357
Magnetization (emu/cm^3)
Applied field (T)
60.0
40.0
20.0
0.00
-20.0
-40.0
-60.0
-2
-1
0
1
2
3
4
5

c. <u>*Magnetization cycle*</u>

- *magnetization losses*
- *time constant of the wire (ρ_{et})*

$$Q_c = Q_h + \frac{8B_m^2\tau}{2T_m\mu_0}$$

(linear ramp rate)



$$\tau = (Q_c - Q_h)\frac{2T_m\mu_0}{8B_m^2} \approx 2\ ms$$

The wire time constant is related to the transverse resistivity through filament geometry into the copper matrix:

$$\tau = \frac{\mu_0}{2\rho_{et}}\left(\frac{l}{2\pi}\right)^2$$

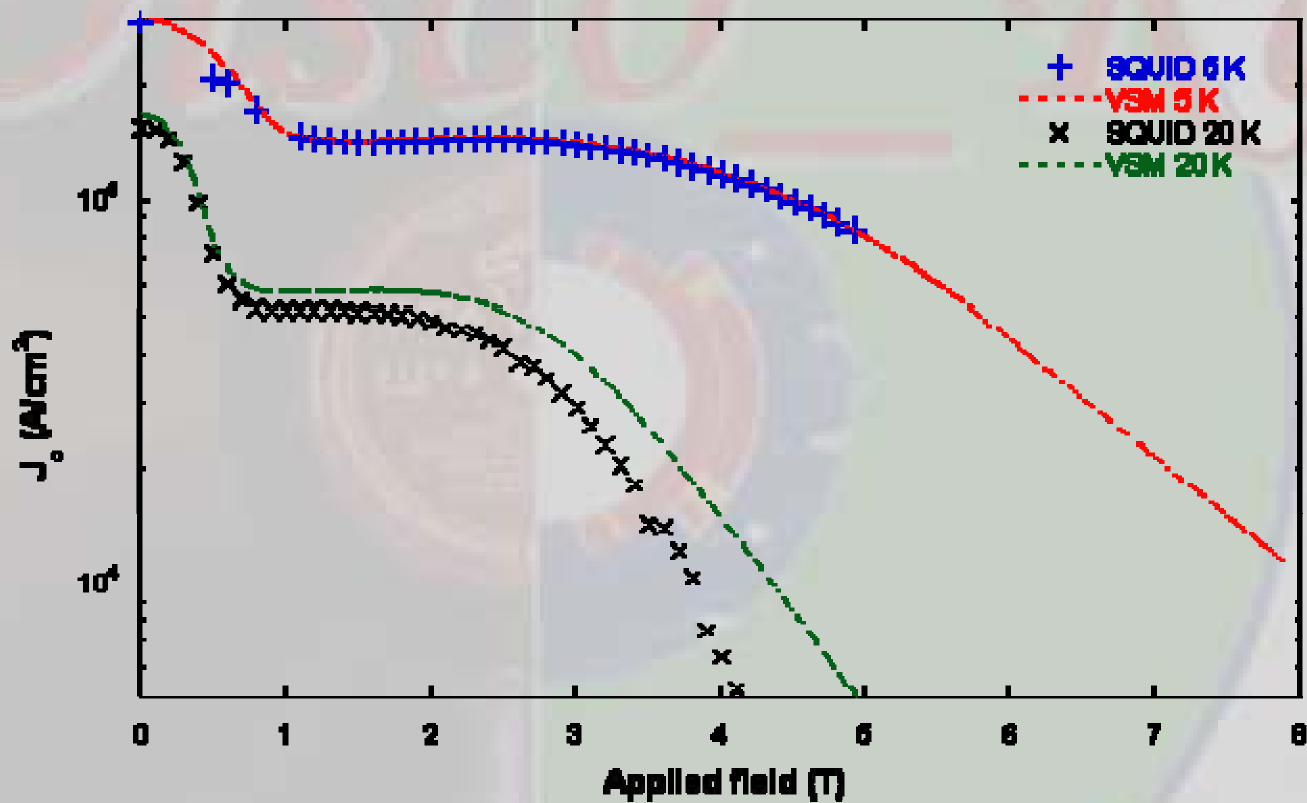
Twisted filaments, M. Wilson

$$\tau = \frac{1}{\pi^2}(1 - N)\mu_0 \frac{l^2}{\rho_{et}}$$

Untwisted filaments (N=1/2 for round wires), G. Witz, X. D. Su, K Kwasnitza, R. Flukiger, Physica C **384** (2003) 334

A factor 4 between twisted and untwisted (with the same length ot the pitch) give a ρ_{et}=3.5 10^{-10} Ωm

VSM vs. SQUID



C. Tarantini *et al*, “Magnetization decays in neutron irradiated MgB_2 bulk”, *J. Appl. Phys.* (2008) to be published

Conclusions

VSM seems a reliable, flexible and fast instrument to get preliminary informations on wires for low losses applications, provided that:

- **special care must be taken when dealing with thin filaments wires, as either penetration depth or filament coupling may affect the magnetic moment measure;**
- **the estimated τ of the wire, due to the sample space limitation, should be considered for an untwisted wire;**
- **faster ramp rates are however needed to improve the accuracy of τ measurement.**