Magnetization measurements and analyses on thin filament NbTi wires for SIS300 synchrotron superconducting dipoles[*]

U. Gambardella[†], INFN Frascati, Italy
G. De Marzi, ENEA Frascati, Italy
P. Fabbricatore, S. Farinon, R. Musenich, INFN Genova, Italy
F. Alessandria, G. Bellomo, M. Sorbi, G. Volpini, INFN Milano, Italy
J. Kaugerts, G. Moritz, GSI Darmstadt, Germany

Abstract

In order to minimise the heat generation in the fast cycled superconducting dipoles foreseen for the synchrotron SIS300 at FAIR, thin filaments NbTi wires must be developed (see presentation of G. Volpini). Following the previous efforts carried out many years ago in SSC developments, we have analyzed some thin filament NbTi wires obtained either from laboratories or industry. These wires give us the opportunity to set up suitable metodology for studying the wire needed to the manufacturing of SIS300 dipoles. We use a magnetic characterization, by means of vibrating sample magnetometer, to get important informations in the wire performances. Rather than the usual critical current density computation, this presentation will deal with typical aspects of thin filaments NbTi wires which can be experimentally derived: the transverse resistivity, the presence of magnetic materials, and the proximity effect.

INTRODUCTION

The requirement of low dissipation superconducting wires for fast ramped dipoles, such us the one under development within the INFN project NTA-DISCORAP, supports measuring techniques able to provide fast and reliable data from wires under investigation. In order to reduce hysteretic losses of the superconducting material it is customary to reduce the superconducting filament size in the wire but this increases the filament number and consequently reduces the filament spacing[1][2]. In fact in a superconducting cylinder the hysteretic losses Q_h in one cycle may be computed from its radius a and the critical current density J_c with eq.1:

$$Q_h = \frac{8}{3\pi} J_c a B_m \qquad (1)$$

where B_m is the maximum value of the ramping magnetic field. These parameters may have noticeable drawbacks both in the wire manufacturing process, and in the wire superconducting features. In this paper we summarize the experience we made using two Vibrating Sample Magnetometer (VSM), MagLab 2000 by Oxford Instruments, to analyze the superconducting features in thin filaments NbTi wires formerly developed in previous projects.

EXPERIMENTAL ANALYSIS

We shall divide the experimental analysis in three ranges of the applied magnetic field: a) low field region; b) high field region; c) cycles to compute losses.

Low magnetic field

It is a good practice to have a detailed behavior of the $M(H)$ curve from the zero field cooling (ZFC) state of a wire. Although the measure is time consuming we consider that this curve reflects the first full diamagnetic response of a wire, thus it is a signature of the superconducting volume, effective or apparent, we are dealing with. In this curve is reflected the size of filaments and eventually the weak coupling among them.

The experimental curves of the magnetization M

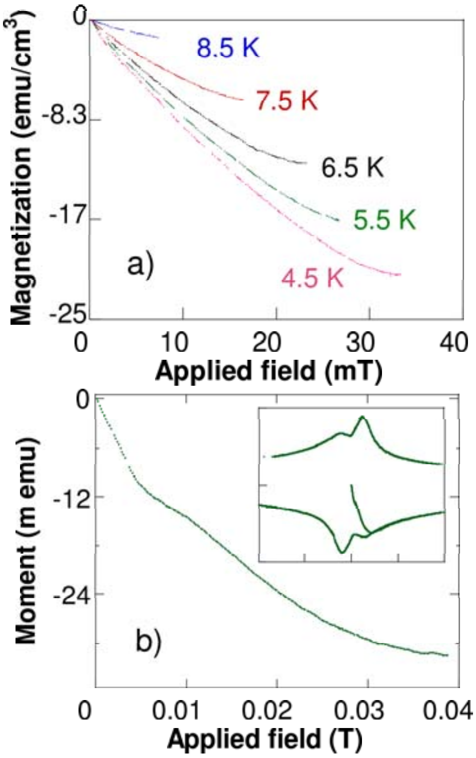

Figure 1: a) low field virgin magnetization for IGC944; b) low field virgin magnetization for SC357, in the inset is shown the $M(H)$ cycle ±0.2T.

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[†] P.O.Box 13, 00044 Frascati, Italy - e-mail gamba@sa.infn.it

recorded in sample IGC 944b (a 2.6 μm filaments wire) are shown in Fig. 1a) as a function of the applied magnetic field $\mu_0 H$ at different temperatures. The linear slopes of the curves are related to the superconducting volumes by

$$V = -\frac{1}{\chi_0}\frac{dm}{dH} \qquad (2)$$

where m is the magnetic moment and χ_0 the susceptibility.

This analysis is widely applied to wires, taking into account of the proper demagnetization factor, but in the case of thin filaments wires the results is quite far from the nominal volume expected from geometry (typically lower). In addition the temperature behavhior does not follow the penetration depth temperature behavior $(1-t^4)^{-1/2}$, being t the reduced temperature. The problem arises when the filament radius r becames comparable to the magnetic penetration depth λ: in this occurence the χ deviates from its bulk value. This dependence of χ with the ratio r/λ has been computed for simple geometry[3] and can be used to correct the χ value to be used in eq.2.

In thin filament wires the number of filaments increases thus reducing spacing among them. At a certain point, due to proximity effect (PE) superconducting coupling among filaments occurs[4]. This weak superconductivity has a clear signature: usually low field strength is enough to break the coupling. However weak couplings induce an excess of irreversible magnetization at low field values. Its occurence is revealed by a changing slope of the $M(H)$ curve at low field, starting from a ZFC condition, as shown in Fig. 1b) for SC357 (a 5 μm filaments wire with pure Cu matrix). In the inset of the same figure it is shown how this phenomena may also affect the $M(H)$ cycle which appears similar to a flux jump phenomena.

High magnetic field

There are no large differences between standard NbTi wires and thin filaments wire from the point of view of VSM critical current measurements. One peculiarity of thin filament wires is that, to avoid weak coupling phenomena, magnetic impurities, like Mn, are diluted in the Cu matrix. The presence of magnetic impurities in the wire is observed in the $M(H)$ curve, being more and more evident as the magnetic field increases. In Fig. 2 it is reported the $M(H)$ curve for the sample SC356 (a 5 μm filaments wire with CuMn matrix), where the presence of Mn is detectable at 15K (in the normal state) from the linear slope of $M(H)$ curve, which adds to the regular magnetization shape in the superconducting state (at 4.5K) of the wire. Though this contribution does not affects the ΔM value, used for the critical current computation, there are difficulties in computing the reversible and irreversible parts of the curve as the $M(T)$ behavior of the CuMn matrix cannot be measured independently and canceled. This hinder some specific feature, like the Ginzburg-Landau parameter κ which could be derived from the reversible magnetization near the upper critical field[5].

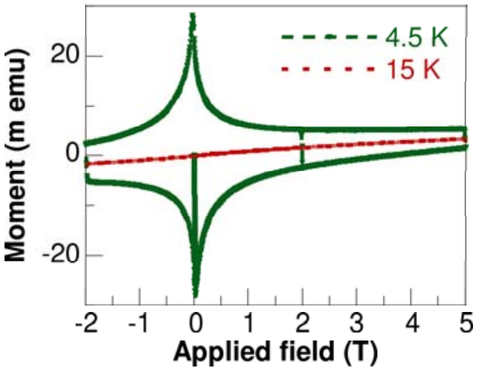

Figure 2: $M(H)$ cycle for SC356: normal (15K) and superconducting (4.5K) states.

Finally it is worth noting that the excess of reversible magnetization due to the magnetic impurities could also affect field quality, if not considered, when designing magnets with wires made of CuMn matrix.

Magnetic cycles and losses

The low loss wires have strategic applications in fast ramped magnets, where, in addition to the irreversible magnetization losses, the coupling losses among filaments became relevant. The lucky fact is that the magnetic impurities increase the local Cu resistivity, reducing the coupling currents between adjacent filaments, which arise under changing transverse magnetic fields.

This resistivity is called transverse resistivity $\rho_\perp$, and is intimately connected to the current distribution in the complicated geometry of a twisted multifilamentary wire. To be more precise $\rho_\perp$ is not only a material property but it includes the current flow path determined by the local shielding currents. One of the way to determine this parameter is to measure $M(H)$ cycle under controlled field ramp rate. In the approximation of wire time constant $\tau \ll T_m$, being T_m the time required to ramp the field to the highest value B_m the specific loss per unit cycle is[6]:

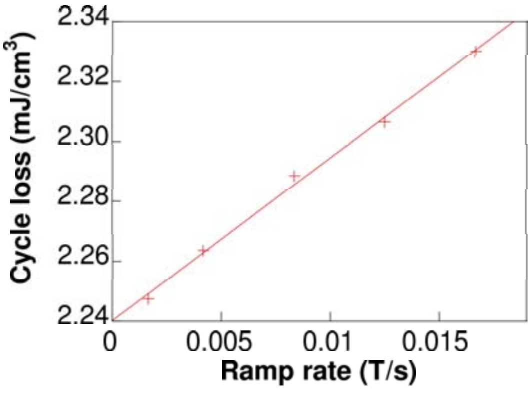

Figure 3: Loss computed at different ramp rates for SC356.

$$Q_{tot} = Q_h + \frac{B_m^2}{2\mu_0}\frac{8\tau}{T_m} \quad (3)$$

As the hysteretic losses are independent of the ramp rate the relationship between ramp rate and losses is related to τ. Though the VSM has maximum ramp rate of 1 T/min, thus it is not designed to investigate dynamical losses, the above mentioned relationship is still detectable. In Fig.3 the loss value computed in one cycle ($4 \pm 0.5T$) as a function of the ramp rate is shown for the sample SC356 at 4.5 K. A linear fit can be easily found, giving a value for $\tau \sim 2ms$. The time constant can then be used to estimate the transverse resistivity, once the geometrical conditions are known. In our case the sample length is much lower than the filament twist pitch thus the relationship between τ and $\rho_\perp$ is[7]:

$$\tau = \frac{1}{2\pi^2}\mu_0\frac{l^2}{\rho_\perp} \quad (4)$$

Being the sample length $l \sim 4mm$ from eq.4 we obtain the value $\rho_\perp \sim 3.5 \times 10^{-10}\Omega \cdot m$. Such value is not far from values obtained by using ac analysis in different NbTi wire also made of CuMn matrix[8].

CONCLUSION

Magnetic measurements performed by using a VSM equipments can be a fast and reliable method for studying superconducting features of low losses NbTi wires. Among others, the analysis of key features of low loss wires, such as the transverse resistivity, can be approached. To finalize our work in this field, we are extending the ramp rate capabilities of our VSM to extend investigations up to 3 T/min. In this way we shall have more dynamic range to analyze for a better estimation of $\rho_\perp$.

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REFERENCES

[1] E.W. Collings, proc. ECOMAG Workshop, Frascati, Oct 26-28, 2005, `http://ecomag-05.web.cern.ch/ecomag-05/`

[2] M. N. Wilson, proc. ECOMAG Workshop, Frascati, Oct 26-28, 2005, `http://ecomag-05.web.cern.ch/ecomag-05/`

[3] F. Gomory, Supercond. Sci. Technol. 10 (1997), p. 523-542.

[4] M.D. Sumption, S. Takacs, E.W. Collings, Adv. Cryogenic Eng. (Materials) 44, edited by Balachandran $etal.$, Plenum Pless, New York 1998, p. 1085-1092.

[5] M. Tinkham, “Introduction To Superconductivity”, Second Edition, McGraw-Hill 1996, p. 160.

[6] M. N. Wilson, ” Superconducting Magnets”, Clarendon Press 1983, §8.3

[7] G. Witz, X. D. Su, K Kwasnitza, R. Flukiger, Physica C 384 (2003) 334

[8] P. Fabbricatore, private communication