Measurement of AC Losses in Superconducting Tapes subjected to both AC Current and Magnetic Field using a Bolometric technique

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Abstract

AC losses have been measured on HTS tapes in presence of both AC transport current and AC magnetic field, by using an extended bolometric technique. Tapes as long as 10 cm are thermally anchored at its ends to the 77 K bath, and are placed in a chamber where the spurious effects due to thermal instabilities are strongly reduced. The AC power losses are rapidly obtained by measuring the resulting temperature gradient between the centre and the extremities of the sample, with a sensitivity of $\sim$1 μW/cm. In this way, the losses can be measured at various frequencies, phases and amplitudes of the AC current (up to $\sim$40A) and field (up to $\sim$600 mT), which are in fact completely independent of each other.

Key words: AC Losses; Superconducting Tapes; Bolometric Technique

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1. Introduction

In the last year good quality multifilamentary BSCCO/Ag tapes have been produced, with critical current densities (J_c) high enough to compete, in terms of reduced power losses, with the traditional material in various electrical power applications. In typical applications like transformers, power transmission lines or motors, the tapes carry an AC current (I_{AC}) and are exposed to AC magnetic fields (H_{AC}), both longitudinal and perpendicular to the tape itself, which produce AC power losses (ACL). For the HTS tapes to be really competitive, tolerable values of the ACL at 77 K should be $\sim$100 times lower than in conventional conductors (like Cu or Al), i.e. in the range [0.15 - 0.6 mW/A m][1]. To carefully measure these losses different techniques (inductive, tap potential-transport, magnetic, calorimetric...) have been developed, but the calorimetric technique appears to be intrinsically the most reliable one, due to its sensitivity to the dissipation alone. The bolometric approach to the ACL measurements has been already discussed in detail elsewhere [2]. Here we report some results obtained with an improved experimental setup, based on the bolometric approach, in which the sample is put in operative conditions by applying simultaneously an AC transport current and an AC magnetic field.

2. Experimental setup and results

The main part of the experimental setup is a cylindrical sample space ($\sim 10^4 cm^3$ of volume) immersed in the liquid nitrogen bath, contained in a dewar which is connected to a vacuum pump in order to have the possibility of changing the temperature of the bath T_b. In the sample space, a massive copper block is present, and it is in thermal contact with the external cryogenic bath by thick copper rods passing through a wall of the sample space. Only the two extremities of a 10 cm long sample are in contact with the copper block, sol-

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dered on it to reduce the contact resistance below 0.5 $\mu\Omega$ at room temperature ($\sim$90 nΩ at 77 K). When I_{AC} and/or H_{AC} are turned on, the produced ACL create a thermal gradient between the center and the two extremities (still at the temperature T_b) of the sample. Three constantan wires, each one acting as one leg of a thermocouple, are then soldered to the sample Ag sheath (which is in fact the second leg of each thermocouple) in correspondence to these 3 positions, and the temperature differences between the center and the two ends, proportional to the power dissipation per unit length P, are measured by reading the relative voltage differences by means of a nanovoltmeter[2]. An AC magnet is placed inside the sample space, and the field is applied perpendicular to the tape. With this system, the ACL can be measured with a sensitivity of $\sim$1 μW/cm, for applied I_{AC} up to $\sim$40A (RMS) and H_{AC} up to 600 mT (RMS), at frequencies from $\sim$20 Hz to $\sim$1 kHz, and with any phase angle between I_{AC} and H_{AC}. A special care has been devoted to avoid any spurious thermal contribution and instability. The current carrying wires are passed through the cryogenic bath before reaching the tape and the magnet, in order to dissipate in it all the heat generated in the wires by the current. The constantan wires are thermally anchored to several places at $T=T_b$ before reach the sample, to stop the heat flow from the external ambience at room temperature. A massive copper block has been used to stabilize the temperature of the extremities of the tape. Moreover, the sample space is evacuated to minimize the heat losses due to the gas conduction, to neglect the effect due to gas convection currents, and to avoid in the sample space any influence coming from superheating and from convection currents within the bath.

A multifilamentary (55 filaments) BSCCO/Ag tape has been characterized both in DC and in AC, at T=77 K. First an I-V characteristic has been performed in DC, and the value of the critical current I_c =23.8 A in zero field has been estimated. The Power Losses P(I) as function of I_{AC} have been measured with the sinusoidal AC current, at a frequency f=51 Hz, modulated in amplitude with a square wave having a frequency of $\sim$0.027 Hz. The resulting plot, compared with the expected Norris line [3] $P(I)\propto I^3{}_{AC}$ for a sample with I_c=23.8 A, indicates an elliptical effective cross section of the sample. In presence of an AC field, the field is applied with the same phase and frequency as the AC current, and its amplitude is also square wave modulated with the same frequency as for the I_{AC}.

Measurements of P vs H_{AC} have been performed at different I_{AC}, from I_{AC}=0 to I_{AC}=0.97 I_c. In general, the curves show a plateau at the lowest fields, presumably because the losses are too small there to be sensed. At I_{AC}=0, the P vs H_{AC} curves (not reported) show, after the plateau, a $H^3{}_{AC}$ dependence turning over to a $H^2{}_{AC}$ and then to a H_{AC} dependence as the field is

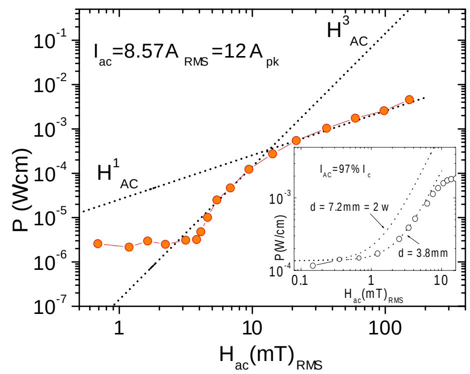

Fig. 1. Power losses P as function of the AC field, at $I_{AC} \simeq 0.5 I_c$. The two dotted lines indicate the cubic and the linear field dependencies respectively. Inset: P vs. H_{AC} (symbols), at I_c= 23 A amplitude, and the relative fits corresponding to the measured and to the effective width of the sample

increased. These correspond to different mechanisms producing the losses [4–7]. At intermediate currents (I_{AC}=0.5 I_c) the losses are hysteretic and follow the behavior predicted by the Bean model, as reported in Fig. 1, i.e. they are proportional to $H^3{}_{AC}$ at low fields, and to H_{AC} at higher fields, where the effect of the applied field determines the condition $I_{AC}=I_c(H_{AC})$ [8]. Finally, for I_{AC}=0.97 I_c= 23 A (RMS) (see inset in Fig. 1), the power losses can be fitted with the help of the Bean model, using the expression suggested for high currents [5,9]. It is worth to notice that, although the measured width of the tape is w = d/2 = 3.6 mm, from the fit an effective width w = 1.9 mm results. This value is also confirmed if the $P(H_{AC})$ curve at I_{AC}=0 is converted into a plot of $\chi''(H_{AC})$ and the full penetration field is estimated from the position of its peak.

Acknowledgements

This work is supported financially by EPSRC.

References

[1] N. Magnusson, A. Wolfbrandt, Cryogenics**41** (2001) 721.

[2] N. Chakraborty, A.V. Volkozub, A.D. Caplin, Supercond. Sci. Technol**13** (2000) 1062.

[3] W.T. Norris, J. Phys. D: Appl. Phys. **3** (1970) 489

[4] K. Funaki et al., Phys. C **310** (1998) 132

[5] S.P. Ashworth, M. Suenaga, Phys. C **313** (1999) 175

[6] W.J. Carr, IEEE Trans. on Magn. Vol. MAG **15**(1979) 240

[7] M. Staines et al., Phys. C **310** (1998) 163

[8] Y. Fukumoto et al., Appl. Phys. Lett **67** (1995) 3180, and Ref. 2 therein

[9] S.P. Ashworth, M. Suenaga, Phys. C **329** (2000) 149