Physica C 495 (2013) 182–186

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Experimental study of magnetization AC loss in MgB_2 wires and cables with non-magnetic sheath

Ján Kováč*, Ján Šouc, Pavol Kováč, Imrich Hušek, Fedor Gömöry

Institute of Electrical Engineering, Slovak Academy of Sciences, Dúbravská cesta 9, 84104 Bratislava, Slovakia

ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 12 September 2013
Accepted 22 September 2013
Available online 4 October 2013

Keywords:
AC loss
MgB_2
Superconductor

ABSTRACT

The influence of MgB_2 wires design on the magnetization AC loss was studied. AC loss in external AC magnetic field perpendicular to the wire axis was measured in the temperature range from 18 K up to 40 K and at the frequencies of 72 Hz and 144 Hz, respectively. For this purpose the experimental apparatus combining magnetization measurement system and non-magnetic vacuum vessel with two-stage crycooler for sample cooling has been used.

To clarify the influence of wire architecture on the AC loss in non-magnetic GlidCop sheathed MgB_2 composites experiments on a single-core, 30-filament un-twisted and also twisted samples were performed. MgB_2 cables containing 7 mono-core strands and 30 filament strands were also measured. While in the cable containing single core strands the hysteresis loss was dominant, in the un-twisted wire and the cable with un-twisted filaments the coupling loss prevailed. The effect of decoupling was observed in all twisted filamentary wires. The obtained results show that in 7 strands cable the AC loss of strands is crucial to the overall AC loss of a cable.

1. Introduction

Increasing interest in MgB_2 wires results from their low cost and possibility to produce long lengths (km scale) wires. Important is also that its critical temperature is high enough to use cryocoolers for keeping this superconductor at operating conditions.

In the case of possible AC applications e.g. power transmission cables, transformers, fault current limiters, etc.; AC loss plays an important role because any dissipative process generates a heat, which directly increases the operating cost.

In the recent years, several works presenting magnetization AC losses of MgB_2 wires at various temperatures have been published. Young et al. [1] measured self-field and in-field AC loss in the stabilized multifilament MgB_2 tapes at various temperatures. They have found that while the self-field loss of Ni sheathed Cu stabilized filamentary MgB_2 tape is dominated by the loss generated in ferromagnetic material, the coupling currents are major factor for the losses in applied field. The temperature, field and frequency dependences of magnetization AC losses of bulk MgB_2 and Ni sheathed wires were measured by Yang et al. [2]. They stated that the loss behaviour of bulk MgB_2 samples strongly depends on the conductor's geometry. In superconducting wire the losses consist of contributions from MgB_2 and from the ferromagnetic sheath. Two types of 6 filament MgB_2 wires were measured by Tanaka et al. [3] and experimental results were compared with the results of loss estimation for a filamentary conductor model and a hollow cylinder model. AC losses in MgB_2 filamentary strands with Nb barriers, Cu-inter-filamentary matrix with non-magnetic GlidCop and/or magnetic Monel sheath were investigated by Majoros et al. at liquid helium temperature [4]. They have found that for samples with no ferromagnetic elements there is a reasonable agreement of the losses with the critical state model in low frequency region $f < 150$ Hz. At higher frequency the eddy currents in Cu matrix generate bulk of AC losses. Polak et al. have measured and analyzed AC losses of MgB_2 tape with 19 filaments surrounded by Ti barriers and embedded in copper stabilization, exposed to external magnetic field with frequencies from 30 mHz up to 1.4 Hz and amplitudes up to 0.8 T at 4.2 K. They have determined the contribution of hysteresis and coupling losses using the measured frequency dependence of the total AC losses [5]. The temperature and magnetic field dependence of AC magnetization losses of single and six filaments untwisted MgB2 wires were measured and the difference between hysteretic and coupling current losses were presented in our previous article [6]. Selected properties of non-magnetic GlidCop sheathed MgB_2 wires including the magnetization AC losses were presented by Kováč et al. [7]. The AC losses of the coil manufactured from Cu-sheathed MgB_2 composites with Nb barriers were studied by Funaki et al. [8]. It was found that the observed experimental results cannot be explained by the theoretical prediction and they discuss the discrepancy from the viewpoint of the coupling among the filaments with the Nb barrier.

---

* Corresponding author.
E-mail address: elekjkov@savba.sk (J. Kováč).

0921-4534/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.physc.2013.09.011

The AC losses in twisted multifilamentary MgB_2 wire and tapes with Nb barrier and CuNi matrix were studied by Kawagoe et al. [9]. They observed that coupling losses in the tape with aspect ratio of 6.6, when the magnetic fields were applied in parallel to the flat faces of the tapes were ten times smaller than those of the round wires.

In our work, experimental results of AC magnetization loss measurement of various MgB_2 wires with non-magnetic sheath are presented and the influence of different constructions on their behaviour in AC conditions is discussed.

2. Experimental details

2.1. Apparatus

The measurement apparatus used for our studies consists of two parts: the cooling system and the device for magnetization loss measurement. Two-stage cryocooler Sumitomo and a heater power supply controlled by PC were used for managing of the sample temperature from 15.5 K up to 300 K. The vacuum vessel is made from non-magnetic fibreglass. For manufacturing of the sample holder we have used the aluminium nitride, which is non-magnetic electrically insulating and well machinable ceramic material with high thermal conductivity. More details about the sample holder arrangement are described in our previous article [6]. Thermal shielding made from copper plate and super insulation was fixed to the first stage of cryocooler in order to eliminate a thermal radiation from the vessel walls.

Second part of our apparatus is the system for magnetization AC loss measurement that is based on the original calibration free method [10] with small modifications, which allow a higher sensitivity of measurements. The magnet system consists of two identical racetrack magnets connected in series. The magnets are made from the cooper cable consisting of thin insulated Cu wires in order to eliminate eddy currents. Pick-up coil and compensation coil were wound together with magnets windings and connected in series with opposite polarity. Their signal should be zero when there is no sample placed to one of magnet bores. Because the magnets are not ideal the correction for enhancing of apparatus sensitivity was used. It consists in a small pick-up coil containing a piece of Cu wire. Its position is adjusted until the contribution of its signal to the main pick-up coil output results in the elimination of background signal in the conditions when no sample is present. Fig. 1 shows the magnet system for ac magnetization loss measurement. For determination of AC loss standard lock-in technique was used [11].

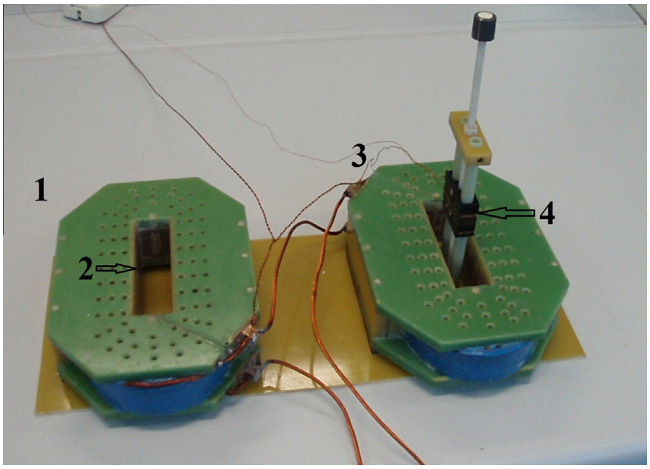

Fig. 1. Magnetization AC loss measurement system 1) Measurement magnet 2) Place for sample 3) Compensation magnet 4) Device for the background signal correction.

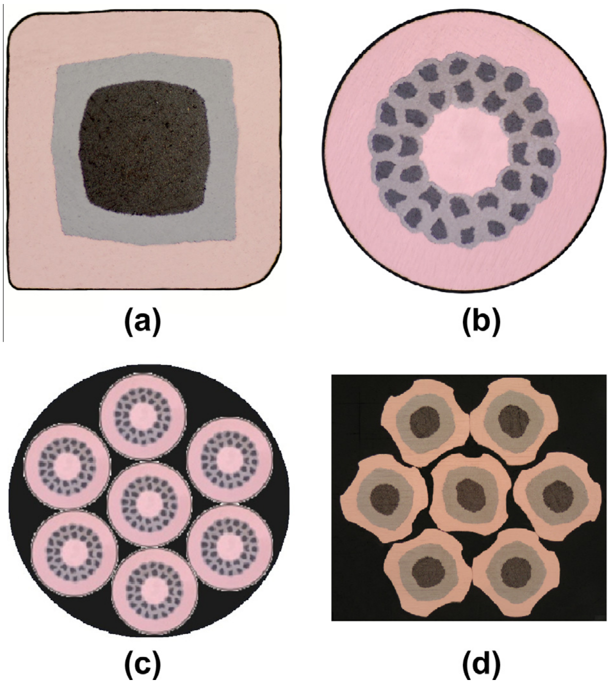

Fig. 2. Cross sections of measured wires and cables a) 1f b) 30f, c) 7 × 30f and d) 7 × 1f.

Standard range of temperatures in our experiment was from 18 K to 40 K, in some cases date were taken down to 15.5 K. External AC magnetic field B_{ext} is ranged from 0.7 mT to 70 mT (rms value used also in the rest of the paper). Frequency dependence of magnetization AC loss was verified by AC loss measurement at two different frequencies f = 72 Hz and 144 Hz.

2.2. Examined samples

To investigate the influence of wire design on AC magnetization loss seven different MgB_2 samples have been examined. None of them contained ferromagnetic material. Their basic design characteristics were as follows: (i) Mono-core wire (**1f**) (Fig. 2a) consisted of MgB_2 core (22%), Nb-barier (23%) and GlidCop AL-60 as outer sheath material [7], (ii) non-twisted filamentary wire (**30f)** (Fig. 2b) contained 30 MgB_2 filaments (12.4%), Ti barriers (24.3%) around a central GlidCop core and the same material as the stabilization outer sheath (63.3%) [12], (iii) filamentary wires with variable twist pitch: 10 mm (**30f-10mm**), 5 mm (**30f-5mm**) and 2.5 mm (**30f-2.5mm**) [13] and (iv) two cables – first one (**7** × **30f**) manufactured from seven 30-filament non-twisted wires of 0.416 mm diameter (Fig. 2c) and second one (**7** × **1f**) made of 7 single core wires with Cu stabilization and Ti barrier (Fig. 2d) [14]. Both cables consist from 6 wires wound around one central wire with 15 mm length of the transposition. The length of all samples was 50 mm. The described above wire's and cable's composition and their critical currents at temperature 20 K and self field are summarized by Table 1.

3. Results and discussion

Fig. 3 shows the temperature dependence of AC magnetization loss (per cycle and m^3 of superconductor volume) for two samples **1f** and **30f** measured at constant external magnetic field B_{ext} = 26 mT and frequencies f = 72 Hz (full line with full symbols) and