

## Calorimetric measurements of AC losses in Bi-2213/Ag multifilament tape

M. Ramos<sup>a</sup>, J. Schwartz<sup>b</sup>, U. Trociewitz<sup>b</sup>, S. Pamidi<sup>c</sup>, and S. Flores<sup>d</sup>

<sup>a</sup>Materials Research and Technology Institute, University of Texas at El Paso,  
e-mail: maramos1@miners.utep.edu

<sup>b</sup>National High Magnetic Field Laboratory Tallahassee, Florida.

<sup>c</sup>Center for the Advanced Power Systems, Tallahassee, Florida.

<sup>d</sup>Departamento de Ciencias Básicas, Universidad Autónoma de Ciudad Juárez.

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We present research work collaboration between the University of Texas at El Paso and The National High Magnetic Field Laboratory. This work presents a series of measurements of AC losses in multi-filamentary Bi-2223/Ag tapes using a calorimetric method as described by *Ashworth and Suenaga*. The AC losses were investigated at liquid nitrogen temperatures (77 K) for different AC currents and in frequency range from 50 Hz to 500 Hz. The results are compared with the Norris ellipse model for calculating self-field loss in high temperature superconducting tape.

**Keywords:** AC losses; superconductor; nitrogen; calorimetric.

Presentamos un trabajo de investigación en colaboración con la Universidad de Texas en El Paso y El Laboratorio Nacional de Altos Campos Magnéticos. Este trabajo presenta una serie de mediciones de pérdidas de potencial (AC) en una cinta multi-filamentaria de Bi2223/Ag utilizando un método calorimétrico descrito por *Ashworth and Suenaga*. Las pérdidas de corriente (AC) son investigadas en bajas temperaturas usando nitrógeno líquido (77 K) para diferentes corrientes AC en un rango de frecuencia de 50Hz a 500 Hz. Los resultados son comparados con el modelo de elíptico Norris para calcular las pérdidas por campo directo en cintas superconductoras de alta temperatura.

**Descriptores:** Perdidas AC; superconductor; nitrógeno; calorimétrico.

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### 1. Introduction

The superconductor materials of the powder in tube method (BSSCO-2223, HTS tapes) are available now in long lengths with a higher quality that ever seen before [1]. However one of the obstacles to having a superconductor is the power loss in a heat form ( $Q$ ) due to magnetic and transport currents. To understand more about heat losses in an HTS we need to measure the heat losses. The standard technique for measuring losses in an HTS tape, due to AC transport currents is the utilization of the phase sensitive voltmeter or lock-in amplifier (LIA) [2], which measures the voltage generated along the HTS tape in phase with the current. Recent publications [1,2] show a new technique for calculating the AC losses in an HTS tape when it is carrying a transport AC current and under an external magnetic field, the mentioned losses are obtained by considering the power supplies driving both the current and the field and carefully measuring the energy losses of these two supplies to the HTS samples. In our research, we used a similar technique to measure transport AC losses with our available devices.

### 2. Experiment

An eight-centimeter long sample of 64 filament Bi-2223/Ag tape was studied. The width and thickness of the sample are 4 and 0.21 mm respectively. The I-V curve of the sample at 77 K was measured and shown as in figure 1. From this curve, we obtained the  $I_c$  of the sample at 77 K is 115 A.

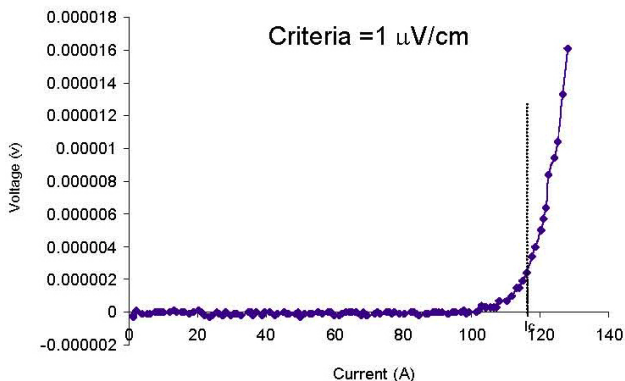


FIGURE 1. I-V curve of the HTS sample, showing the critical current cutoff criterion near 120 A.

### 3. Experiment apparatus

In this experiment we used a silver tape with the same dimensions as HTS tape to obtain calibration curves. In order to produce a measurable temperature rise when the tapes carry currents, both tapes were insulated from the surroundings (Liquid Nitrogen bath, 77K) using two Styrofoam blocks as shown in Fig. 2 and using rubber silicon to prevent the penetration of liquid nitrogen inside the samples. The samples were attached to a cooper current lead using a welding solder and immersed into a liquid nitrogen bath taking 5 to 9 minutes to reach the 77 K temperature. We use two differential thermocouples (constantan-chromel “N” type) to measure the rise in temperature due to Seebeck’s effect in the

HTS and Ag tapes. For each tape, one junction of differential thermocouple was bonded to the midpoints of the tape using a GE varnish, the another (reference junction) was kept in LN2 and then both ends of the differential thermocouple were connected to twisted insulated cooper wires to prevent any magnetic inductance. We used Keithley 2001 with option card 1801 to measure the voltage of the differential thermocouples. The symmetry of the differential thermocouple circuit is also considered so that the noise generated by temperature gradient and by junctions between copper wires and thermocouples is canceled.

**4. Results and discussion**

Twenty-second pulses of DC currents in the range from 4A to 15A were passed through the calibration tape (Ag tape). The temperature rise on this tape measured by differential thermocouples is shown in Fig. 3.

The voltage drop from voltage taps in the calibration tape is useful for calculations of power dissipation in a cross-section area of HTS tape located inside the calorimetric box. From the maximum point of the temperature rise-time curves (Fig. 3) and corresponding power dissipation it is possible to obtain the relation between power dissipations and temperature rise that dependence of the temperature rise on power dissipation is presented in Fig. 4.

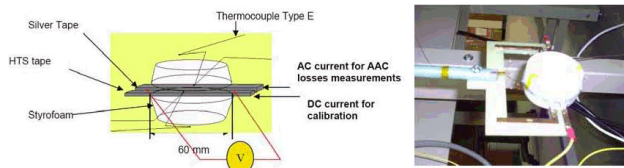


FIGURE 2. Left: Schematic drawing of Styrofoam box, Right: Actual photograph of Styrofoam box used during calorimetric measurements of AC losses.

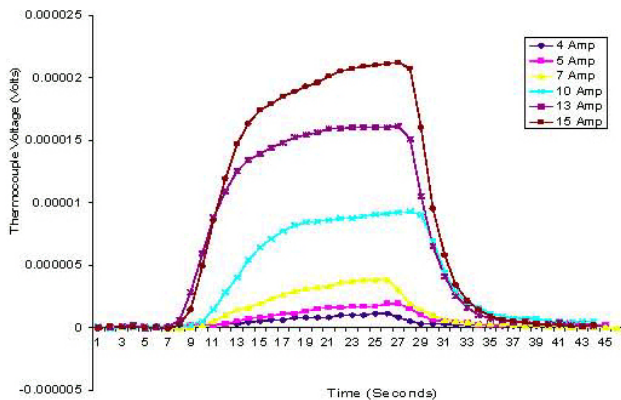


FIGURE 3. Temperature rise measurements for calibration Ag tape at T = 77 K for currents values of 4 to 15 A all measurements were done at a frequency of 500 Hz.

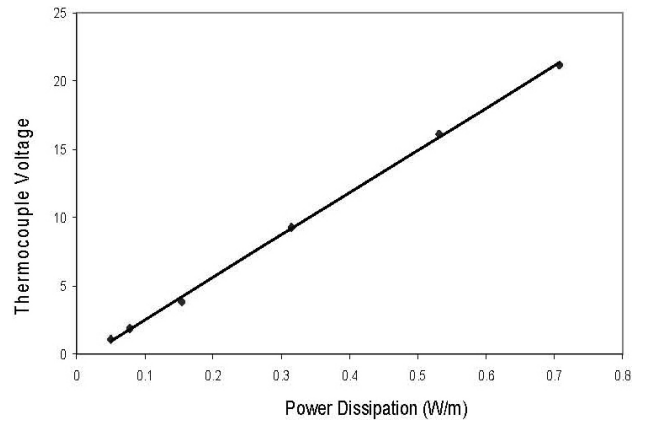


FIGURE 4. Calibration curve for Ag tape measured at T = 77 K, for different current values at 500 Hz. Thermocouple voltage units are mV.

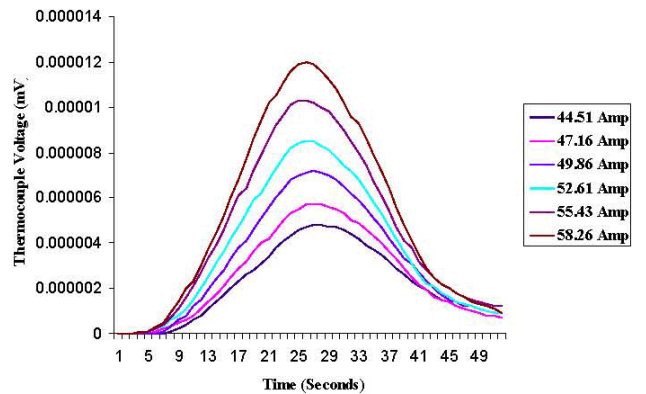


FIGURE 5. Temperature rise on HTS (Bi-2213) tape for different currents, 500 Hz at 77 K.

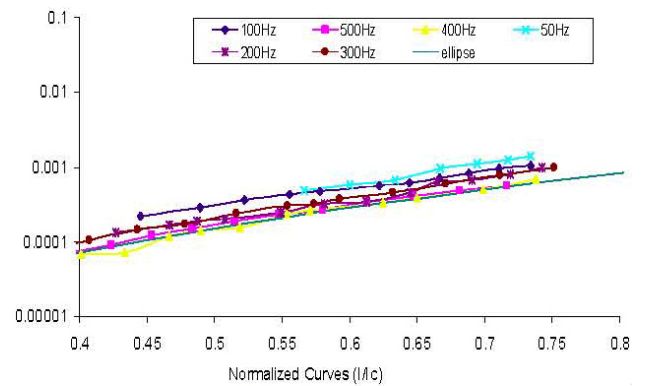


FIGURE 6. AC loss for different currents and frequencies in 64 filament Bi-2223/Ag tape tape measured at T = 77 K as compared with the Norris ellipse [4].

Obviously, one can observe that rises in temperature depend linearly on power dissipation as expected and from that calibration curve, it is possible to determine a relation  $V=AQ$ , where V and Q are the voltage of differential thermocouple and power dissipation on the tape.

A twenty second AC current pulse in the range from  $I_{peak}=45$  A on increments is passed gradually through the

HTS tape. The recordings of measured temperature rises giving by voltage of differential thermocouple are collected. Also measurements were taken at different frequencies (50 Hz to 500 Hz). The temperature rise (Voltage of differential thermocouple) in the HTS tape when carrying AC currents at a frequency of 500 Hz was obtained and is presented in the Fig. 5, as was done for the calibration Ag tape. However, the two curves display slightly different behavior, volcano-like for the HTS and volcano-like with a strong plateau. This is because silver is not a superconductor so the thermocouple will experience more heat generated in the surface than will HTS tape, but also because the current velocity runs faster in an HTS compared to pure conventional Ag. Furthermore, authors are using silver tape so as to obtain a calibration curve because it is necessary to assume HTS has more than 70 percent of silver and just around 30 percent of Bi-2223 material in the matrix of the tape.

Now using the temperature rise at the HTS data maximum point and knowing the relation between temperature rise and power dissipation obtained from calibration curves, one can calculate the AC loss of the HTS tape by using  $V=AQ$ , with  $V$  and  $Q$  as voltage of differential thermocouple and power dissipation on the tape. Data results are presented in Fig. 6.

The AC losses in the sample depend on the normalized current at a frequency of 500 Hz and a temperature of 77 K.

## 5. Conclusion

The calculated result using the Norris model for elliptical cross-section tape is also plotted and presented in Fig. 7 for comparison. Clearly, one can observe that measured results are close to calculated results. This observation can be explained by the fact that the main component in AC transport loss at 500 Hz is self-field loss as indicated by others [5] and also observed at other different frequencies. Transport AC losses per cycle of the sample at different frequencies spreading from 50 Hz to 500 Hz are all close to results calculated from the Norris model.

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