Calorimetric Measurements of AC Losses in BSCCO and YBCO Tapes

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Abstract. *Using of calorimetric method we measured AC losses of commercially available BSCCO and YBCO tapes exposed to external magnetic field with amplitudes up to ~ 100 mT. The evaporation rate of the liquid nitrogen, caused by AC losses, was measured by electronic flow-meter. We studied the losses in single tapes as well as in tapes arranged in stacks of several tapes. The losses measured with single tapes are compared with the data calculated using the theoretical model of Brandt. The calibration procedure, measurement accuracy and detection limits of this method will be also discussed.*

Keywords: Calorimetry, superconductor, BSCCO, YBCO, AC losses.

1. Introduction

Measurements of AC losses of high temperature superconductors are of high importance for the design of electro-magnetic devices operating in AC regimes. Electrical methods of AC loss measurements are often used [1], however, the results are affected by various errors and the experimental set-up is quite expensive. Moreover, the measurements are difficult in the case of an non-regular shape of the sample.

Calorimetric measurements are less sensitive and less precise, however, the results are quite reliable. Schmidt [2] presented a set-up for calorimetric ac loss measurements at 4.2 K. A slight temperature increase of the sample in an ac-field, thermally insulated from the liquid helium bath, is used as a measure of losses. Okamoto et al. [3] developed a measurement set-up based the measurement of the nitrogen boil-off method with the sensitivity limit of ~ 0.5 W, using a wet gas counter. The sensitivity of their set-up is determined by the background flow rate, which is about 100 mW on a 5 hour average.

2. Subject and Methods

For measurements of AC losses in superconducting tapes and pancake coils we developed a simple measurements set-up using a sensitive electronic flow-meter to measure the evaporation rate of LN_2. The measured sample is placed in a calorimeter box and the evaporation rate of the cooling medium (nitrogen) is proportional to the sample losses. The evaporation rate is measured by an electronic flow-meter Setaram [4]. The calibration of the system using a resistor is quite easy and reliable.

AC magnetic field is generated by a copper magnet. To illustrate the properties of the set-up we measured AC losses of BSCCO tapes (American superconductors) in AC magnetic field with frequency 256.4 Hz at 77 K.

The sketch of the calorimeter is shown in Fig. 1. It is a cylindrical vessel made of a glass-fibre epoxy material. The evaporated nitrogen flows through a glass - fibre epoxy tube to the flow-meter. The measured samples are fixed to the bottom plate of the calorimeter using polystyrene spacers, as shown in Fig.1.

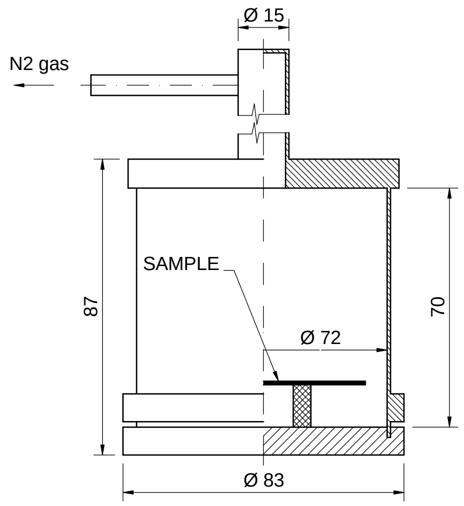

Fig. 1. The sketch of the calorimeter.

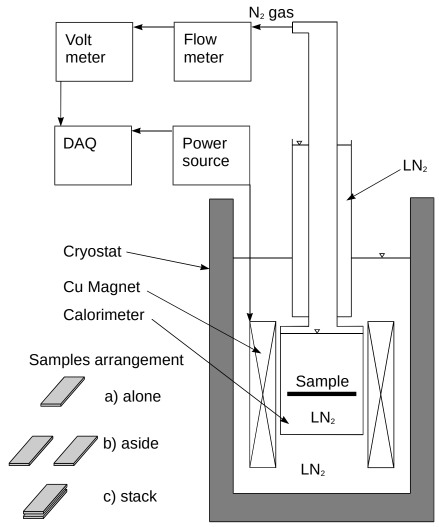

Fig. 2. Schematic view of experimental set-up and samples arrangement in the calorimeter.

The measurement set-up is shown in Fig.2. The calorimeter is placed in the working space of the copper coil with the working diameter of 85 mm.

The coil is supplied by an AC power supply (FUG) controlled by a signal generator. Due to large inductive voltages across the coil (coil inductance is 22.15 mH, its reactance at 256.4 Hz is 1610 Ohm) the coil must be supplied via a battery of condensers. If $\omega L = 1/\omega C$, the total voltage across LC circuit is small, as the voltages across L and C are in antiphase.

Calibration

To calibrate the calorimeter we used a resistor R = 100 Ohm inserted in the liquid nitrogen. A current I flowing through the resistor generates heat $W = RI^2$, which evaporates the liquid nitrogen. The output voltage of the flowmeter, V_f, is proportional to the evaporation rate of LN_2. In Fig.3 we show the dependence of V_f on the power $W=RI^2$ dissipated in the liquid nitrogen.

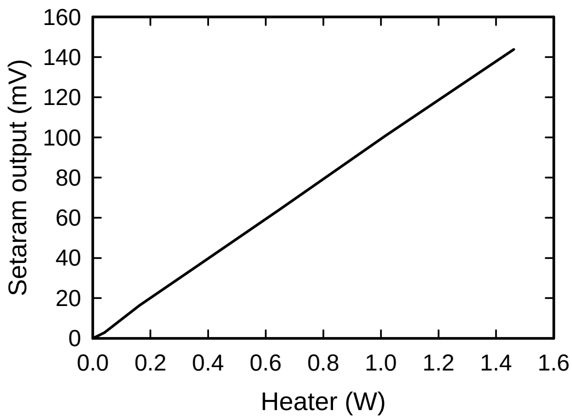

Fig. 3. The calibration curve of the calorimeter. The calibration constant is K_c= 98.84 mV/W.

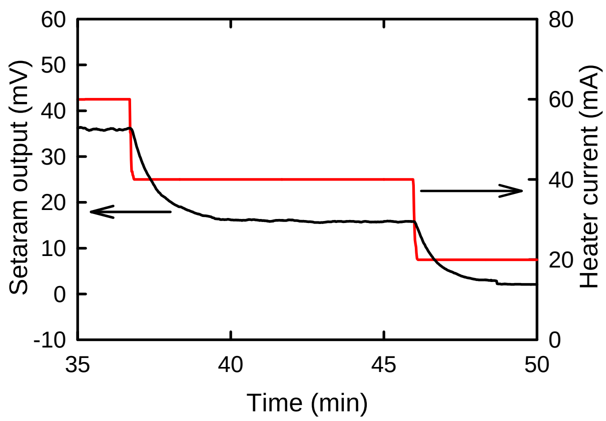

Fig. 4. The dependence of V_f on time recorded during the change of the heating current I_h from 60 mA to 40 mA and from 40 mA to 20 mA.

To measure the saturated evaporation during the calibration, we have to wait of about 5 minutes, as it follows from the measured dependence of V_f on time (see Fig.4).

The stability of the backround nitrogen flow measured during 1 hour is illustrated in Fig.5. The signal change was less than ~ 0.2 mV, which corresponds to losses of about 2 mW. We believe that measurement set up is able to detect losses about 10 to 20 mW approximately.

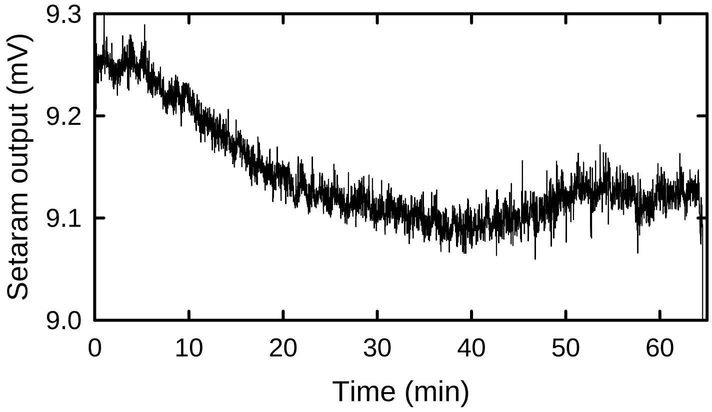

Fig. 5. The measured time variation of the voltage V_f.

3. Results and discussion

In Fig. 6 we show the losses measured for 1 and 2 pieces of 50 mm long BSCCO tapes vs. the amplitude of the external magnetic field with frequency of 256.4 Hz at 77 K. The filamentary tape with the cross-section of 0.25 mm x 4 mm was manufactured by American Superconductors, its critical current at 77 K is I_c ~ 110 A in zero field. The mean value of I_c in magnetic field interval from 0 to 30 mT is ~ 70 A. Due to silver matrix the filamentary tape behaves like a monocore tape. The samples were placed parallel in parallel arrangement at the distance of about 15 mm, so that the mutual influence of the tapes is negligible. For comparison, we show also the results for copper clad YBCO tape 4 mm wide with the total thickness of 0.1 mm (manufacturer Super Power).

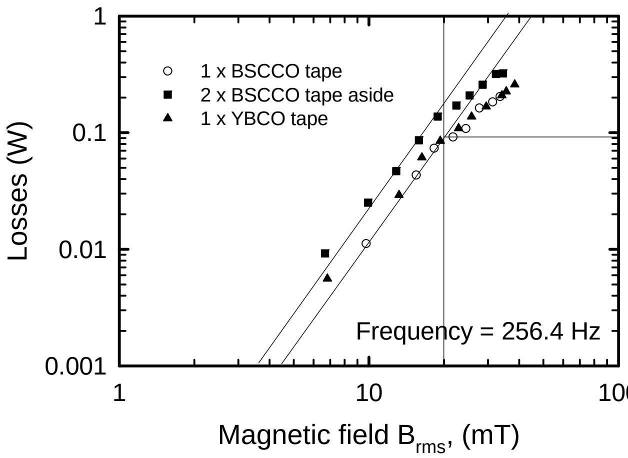

Fig. 6. The AC losses of one and two pieces of BSCCO tape 50 mm long. Also losses of 4 mm wide YBCO tape are shown for comparison.

At low values of the external magnetic field B the losses are proportional to ~ B^3 as predicted by the theory of Carr [5]. The measured AC losses are quite well proportional to the number of tapes supposing they are in the sufficient distance to avoid the mutual influence of the tapes.

We calculated hysteresis losses, P_h, using Carr formula $P_h=2\cdot f\cdot a\cdot I_c\cdot B_m$ [W/m], where f – frequency, a – half tape width, I_c – mean value of critical current of the tape in the measured field interval from 0 to B_m, B_m – magnetic field amplitude. For parameters f = 256.4 Hz, a = 2 mm, I_c = 70 A, B_m = 28.3 mT (B_{rms} = 20 mT), losses are 2.1 W/m, we measured losses 0.09 W for 50 mm long tape, which corresponds to 1.8 W/m. This difference is reasonable.

4. Conclusions

In the calorimeter described above we were able to detect losses above 20 mW approximately. The calibration constant of the calorimeter is ~ 100 mV/W and the stability of the signal for zero losses is of about +/- 1 mV, which corresponds to the loss of ~ 10 mW. Further improvement will be focused on the reduction of the zero loss signal and its stability.

Acknowledgements

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References

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