AC Loss Measurement and Analysis of Ag-sheathed Bi-2223 Conductors in Terms of Eddy Currents and Flux Creep

Mi-Hye Jang

Abstract - Alternating current (AC) losses of two Bi-2223 ([Bi, Pb] : Sr : Ca : Cu :O = 2:2:2:3) tapes [one untwisted (Tape I, twist-pitch of ∞ mm) and the other with a twist-pitch of 8mm (Tape II)] were measured and compared. These samples, produced by the powder-in-tube (PIT) method, are multi-filamentary and have a Ag/Au and Ag matrix, respectively. Susceptibility measurements were conducted while cooling in a magnetic field. Flux loss measurements were conducted as a function of ramping rate, frequency and field direction. The AC flux loss increases as the twist-pitch of the tapes decreased, in agreement with the Norris Equation.

Keywords: flux flow, flux creep, eddy loss, ac loss, magnetization

1. Introduction

Recent achievements in the fabrication of long-length multi-filament (Bi,Pb)-Sr-Ca-Cu-O(BSCCO) high temperature superconductor (HTS) tapes with high critical current have generated considerable interest in applications such as cables, transformers, motors and generators, and energy storage systems. Since BSCCO tapes in most large scale systems are exposed to time-varying fields or transport alternating currents, the tapes exhibit energy dissipation mainly due to AC losses. Thus, much research has been directed toward understanding of the nature of these AC losses and their minimization [1-5]. In general, AC losses are dependent on the geometry of the filaments in the tapes, the magnetic and electrical properties of the superconductor, the type of matrix material, and the amplitude and frequency of the transport current. The total losses, Q, are attributed to hysteretic loss within the filaments (Q_h), eddy current loss and coupling current loss within the matrix (Q_e), and coupling current loss across the matrix (Q_c). The Critical State model has been used extensively to describe the electrodynamics of type II superconductors and to calculate the AC hysteresis loss ([6]-[7]). For Bi-2223 ([Bi,Pb]:Sr:Ca:Cu:O=2:2:2:3)-based tapes consisting of multiple superconducting cores in a silver matrix, the AC loss per cycle was found to be mostly frequency independent ([6]-[8]).

In this paper, the AC losses of two BSCCO tapes were measured by controlling the field magnitude and the incident angles to the *c*-axis of the tape, and external time-varying magnetic field (60Hz). The influence of the different interior structure (i.e. different twist-pitch) of the materials on their transport current and AC loss was also determined.

2. Experimental Set -Up

Multi-filament silver-sheathed $Bi_{1.8}Pb_{0.4}Sr_{2.0}Ca_{2.2}Cu_{3.0}O_{10+}$ (Bi-2223/Ag) tapes of vary twist were made by a powder–in-tube (PIT) technique where a high c-axis alignment of grains is achieved by a combination of pressing, rolling and heating [9]. Appropriate amount a of Bi_2O_3, $SrCO_3$, $CaCO_3$ and CuO were mixed milled for 24h in methanol with ZrO_2 ball. The milled slurry was dried and then calcined at 700 °C for 12h, 800°C for 8h, and 835°C for 8h,and 855°C for 8h in an ambient atmosphere. The calcinations and grinding procedures were repeated three times. Phase composition of the powders was confirmed by x-ray diffraction. To make Ag-sheathed tape, BSCCO powder was loaded into a silver tube (6.35 mm outer diameter, 4.35mm inner diameter). And a specific characteristic of heat treatment is table 1. In most cases, and additional heat treatment in absence of oxygen is used to sinter or react the precursor powders

The measured samples are 37-core Bi-2223 tapes with Ag matrix, untwist and twist pitch, respectively. The heat treatment condition is listed in table1, and each specification of the samples is given in table 2. And Microstructure was evaluated by optical and scanning electron microscopy (SEM) on both the polished and fractured surfaces. The degree of texturing, twist pitches, and crack were observed after etching the Ag sheath with an etchant (H_2O_2 : NH_3 = 1:1) The measured samples are 37-core Bi-2223 tapes with Ag matrix, untwist and twist pitch, respectively. The heat

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Table 1 Specific characteristics of heat treatment

	Condition
Annealing rate	5℃/min
Annealing time	850℃ /150h
Heat treatment condition	O_2 gas
Sintering rate	3.33℃/min

Table 2 Constant characteristics of samples

	Sample Multi-filamentary (37)	
	No twist	Twist(8mm)
Width	4.15mm	2.29mm
Thickness	0.29mm	0.15mm
Length	7.48mm	6.23mm
Weight	72.49mg	34.05mg
Twist Pitch	70.00mm	8.00mm
Matrix	Ag-Au	Ag
Density	8.05200mg/mm^3	15.91117mg/mm^3
Filling factor	2.2	2.2

Fig. 1 is schematic diagram of apparatus for twisting Bi-2223 tapes. The speed of drawing for twisting Bi-2223 multi-filament is RPM 32~2000. And samples was two times annealing when it is twisting. Flux loss measurements of pinning effect in super conductors. The sample is prepared for this measurement by cooling in a measurement by cooling in a measurement field, and then removing the field. The measurements are made on warming. It. is flux creep equipment as follows. This is changing of magnetization with time while applying a magnetic field to a zero-field-cooling sample. This phenomenon can be explained by thermo activated movements of vortices though the pinning centers.

Quantitative evaluation of the AC loss of HTS s one of the key issues in the research and development of HTS and its applications. The objective of this paper is to examine experimental techniques for the magnetization loss measurement. The magnetization loss was measured with several types of pick-up coil sample tape configurations. The finite element analysis of AC losses was made to compare its results with the experimental results to study the nature of the measured AC losses.

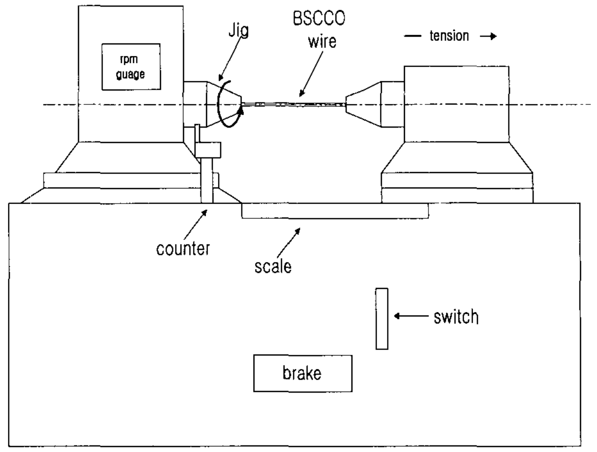


Fig. 1 Schematic diagramming of the main part of experimental apparatus used to prepared the PIT tapes.

In the first experiment, critical currents of each sample were measured at 77K under the environment with the external field of 60Hz applied. The magnitude AC susceptibility measurement, superconducting transition temperatures around 50k and 118k were reported for the old sample and new sample as-prepared samples, respectively. A phase with a higher Tc(119k) was also reported to exist in some sample. But it was not identified, owing to its very small supercoducting volume[6] of external field and its incident angles to the c-axis of the sample were used as measurement variables.

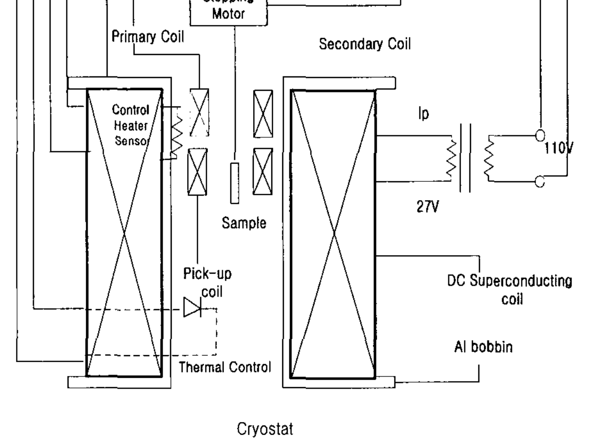


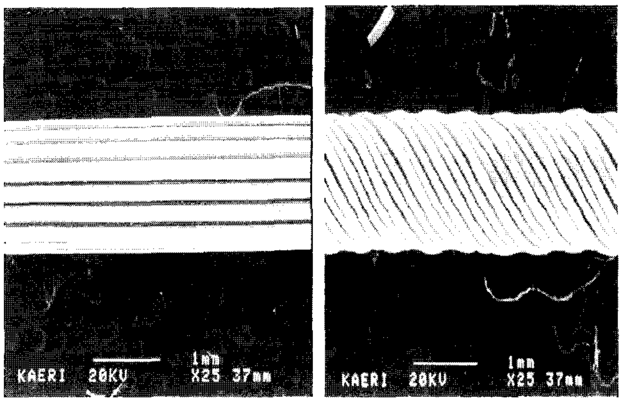
Fig. 2 Schematic drawing of experimental apparatus of main part of AC loss measurement

In the second experiment, AC loss measurement was carried out under the environment of constant transport current and applied time-varying field of 60Hz. Fig..2 Schematic drawing of experimental apparatus of main part of AC loss measurement. The magnetization within the sample can be detected by integrating the generated e.m.f. in the pickup coil. Unnecessary part of the voltages in the pickup coil, the voltage generated by external time-varying results with the experimental results to study the. nature of the measured AC losses. In the first experiment, critical currents of each sample were measured at 4.2k, 60k and 77K under the environment with the external field of 60Hz applied The magnitude of external field and its incident angles to the c-axis of the sample were used as measurement variables. All signals through lock-in amp and data acquisition device were stored in the analog recorder.

3. Results and Discussion

Micro-structural observations have been made to evaluate the uniformity of superconductor filaments deformed during the twisting process. Fig. 3 shows the SEM photomicrographs of sheath has been completely etched away. It can be observed that exposed filaments of un-twisted wire were uniformly deformed and their interfaces were uniform and straight. Similarly, the exposed filaments of. twisted wire, which were rotated 55 turns, still retained uniformity throughout the whole length of the interface was not degraded. Fig. 3 shows the SEM photo micro-graphy of (a) non-twisted wire and (b) twisted wire after Ag-sheath etching (25 times).

The AC loss of each sample versus the frequency density were plotted in Fig. 4 As expected, the AC losses at an angle of 0 degree were lower than those at an angle of 90 degrees. Also, the critical current of the sample with Ag matrix was slightly lower than that of the sample with Ag-Au matrix. The difference is too small to be on the plot scale. This is because the eddy current loss at Ag matrix is slightly larger than that at Ag-Au matrix. Fig. 4 shows the measured AC losses of each sample according to the transport current and the incident angle to the c-axis of the tape. These data include the self-hysteresis loss due to transport current. When the parallel field to the c-axis of the tape was applied, the measured loss was too larger than that due to the perpendicular field. Also, AC loss of conductor with Ag matrix and twisted was almost 2 times larger than that of conductor with Ag-Au matrix and untwisted . It is considered that this phenomenon is due to the lower critical current of the conductor with Ag matrix and twisted current of the conductor with Ag matrix and twisted included on the plot scale. This is because the eddy current loss at Ag matrix is slightly larger than that at Ag-Au matrix.



(a) Non-twisted wire (b) Twisted wire

Fig. 3 SEM photomicrography of (a) non-twisted wire and (b) twisted wire after Ag-sheath etching (25 times)

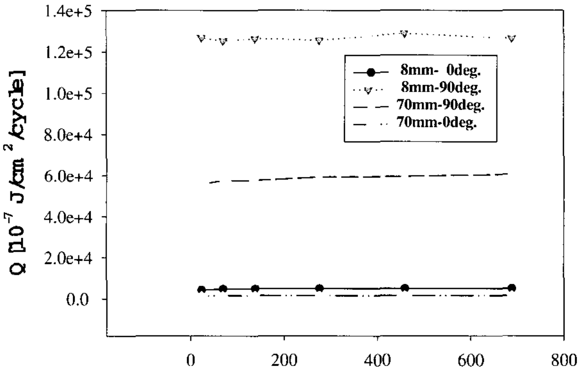


Fig. 4 Losses by magnetic field direction and ramping rate in the twisted multi-filamentary tape wire [External Magnetic Field : 1 T]

It was suggested that the AC losses of filament BSCCO tape, in general, were effectively reduced when the filament size, the electrical resistivity of the matrix, and the twist pitch of the filaments were properly modified. The relation between AC losses and twist pitch can be expressed by the following equations [10]

$$Qc = \frac{n \pi B^2_a \omega\tau}{\mu_o (1 + \omega^2 \tau^2)} \tag{1}$$

and

$$\tau = \mu_o \sigma_c L^2_P \frac{d^2_c}{16 \omega^2_c} \tag{2}$$

Where, Qc is the coupling current loss, n is the sharp factor, B_a is the external field amplitude, ω is the angular frequency of the field, τ is a time constant, μ is initial permeability, σ_c is the conductivity of the matrix, L_P is the twist pitch, and d_c and ω_c are the thickness and width of the core, respectively. It is expected that the AC loess will decrease as the twist pitch , according to the equation. However , the increase in twist pitch in the ac loss of the tape as a result of the micro-structural damages.

Fig. 5 shows the measured AC losses of each sample according to the frequency and the incident angle to the c-axis of the tape. These data include the self-hysteresis loss due to transport current. When the parallel field to the c-axis of the tape was applied and at 77K, the measured loss was too larger than that due to the perpendicular field. Also, when the parallel field to the c-axis of the tape was applied at 60K and 4.2K the measured loss was a few larger than that due to the perpendicular field. We didn't find out the reason why the sample have a same loss different when the parallel field and perpendicular field to the c-axis of the tape was applied and at 60K and 4.2K. Based on Fig. 4 , Fig. 5 and equation (3),(4),(5)and (6), AC loss is magnetization due to applied field vary temperature, vary field and applied field two direction.

$$dH \ / \ dT = \frac{5 * [1.7, 0.5, 0.1,] * 10^{4}}{time \ (\mathrm{min}) \ * 60} \qquad (3)$$

and

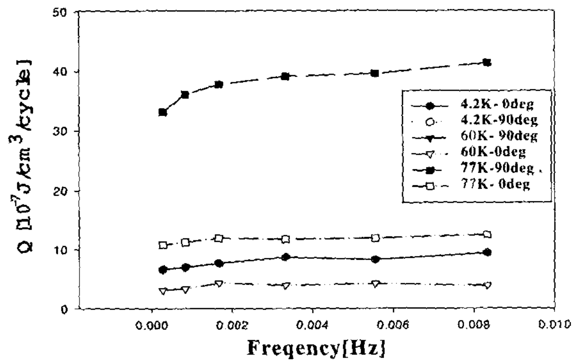


Fig. 5 AC losses according to the temperature and the incident angle to the c-axis of the tapes[70mm].

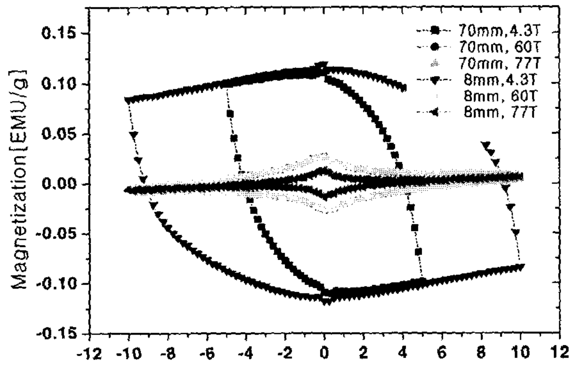


Fig. 6 Hysteresis loop depend on temperature in sheathed $Bi_{1.8}Pb_{0.4}Sr_{2.0}\ Ca_{2.2}\ Cu_{3.0}O_{10+}\delta$ (Bi-2223/Ag) with virgin curve at 1.2Koe

$$Qv = \frac{Q}{V} = \frac{Q}{dT \ * \ dD \ * \ dl} \qquad (4)$$

and

$$Q = \frac{1}{8} * \left(\frac{a}{b}\right)^{2} \left(\frac{Lp^{\ 2}}{2 * 10^{\ 9}}\right) Hm \ * \ \frac{dH}{dt} \qquad (5)$$

and

$$Q = \frac{1}{8} * \left(\frac{a}{b}\right)^{2} \left(\frac{Lp^{\ 2}}{2 * 10^{\ 9}}\right) \frac{\dfrac{Hm}{\Delta Q}}{\Delta \dfrac{dH}{dT}} \qquad (6)$$

Where, dH / dT is the magnetic field due to time varying, Q is the total loss , Qv is the loss to volume of sample, Lp is the twist pitch of core, V, a and b are the volume, width and length of the core, respectively.

Fig. 6 shows a hysteresis loop at 4.3K, 60K and 77K for the two materials used for the measurements Fig. 5. For one of the materials that possessed the ability to be levitated easily by a magnet from vary temperature, sheathed $Bi_{1.8}Pb_{0.4}Sr_{2.0}Ca_{2.2}Cu_{3.0}O_{10+}\delta$ (Bi-2223/Ag), the field dependence of its magnetization at 77k, 60k, 4.2k after being cooled to this temperature in zero field cycles. This temperature is well above the onset temperature of the supeconducting 80K phase and 15K below the onset temperature of 110k phase. The loop obtained would not be expected for a material simply undergoing a phase transition to a diamagnetic material but is typical for loops obtained from oxide superconductors near their onset temperatures. For this sample (density ≅ 8.05200mg/mm^{3,} untwist) the initial small field (-20Oe $\leq H \leq$ +20 Oe) loop (not show) indicated no magnetic flux penetration into the sample and had an initial sloop of -0.078emu/cm^3 Oe (1.3 times to the theoretical $-1/4\ \pi$ value for diamagnetism. Flux penetration (deviation from M vs. H linearity) in twisted 8mm, 4.3k, began to occur in this sample at fields near 68Oe(=Hc1); from the measurable width of the (-200Oe $\leq H \leq$ +200 Oe) loop shown in Fig. 6,flux pinning may be deduced to occur at slightly higher fields

5. Conclusion

We have compared the loss factors of tapes with different matrix and different angles to the c-axis of the tape. From experiment, losses for fields applied parallel to the c-axis of the textured Bi-2223 grains are larger by over an order of magnitude than those applied perpendicular. For the tape, which had a twist pitch of 70 mm, approximately 64% of the loss was maintained compared to that of the untwisted tape. The reduced may be related to interface irregularity, smaller grain size, poorer texture, and the presence of cracks caused by induced by induced strain during the twisting process. And it is confirmed that losses self-hysteresis loss due to the transport current, is currently in progress.

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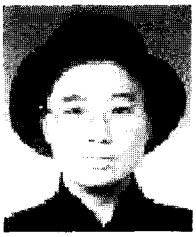

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