AC Loss characteristics of HTS tapes subject to bending strains

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Dependence of AC loss characteristics of Bi2223/Ag-sheatled tapes on bending strains was experimentally investigated. AC transport current losses in the tapes subject to various bending strains were measured in the zero external magnetic field. These losses were compared with the losses of straight tapes. The measurement results show that values of the AC losses are affected by the degradations of the critical currents caused by the bending strain. Based on these results it can be concluded that the AC transport current loss characteristics of Bi2223/Ag-sheathed tapes subject to bending strain can be estimated by knowing values of critical currents of bended tapes and the loss characteristics of straight tapes.

INTRODUCTION

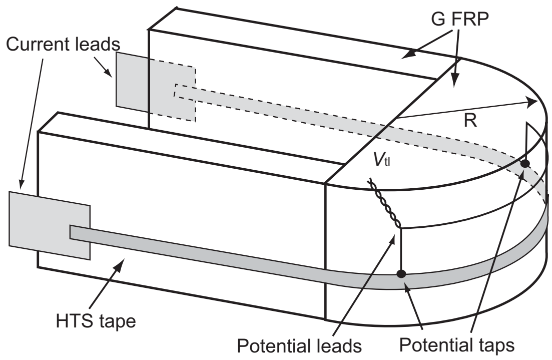
AC superconducting power apparatuses such as power cables and transformers are most promising applications of high temperature superconductor (HTS) because costs to cool the AC losses in the HTS conductors in those apparatuses are much lower than those in low temperature superconductor AC power apparatuses. However, AC losses even in HTS are the major losses in the apparatuses and dominate their efficiency and economic feasibility. Therefore, it is important to understand the AC loss characteristics correctly.

HTS conductors are used in forms of coils and cables in those apparatuses and subject to bending strains. The bending strains affect critical currents and may affect AC loss characteristics. We investigated the AC transport current losses in Bi2223/Ag-sheathed tapes subjected to the bending strains in the zero external field at the first step. We measured the AC losses in a straight Bi/Ag-sheathed tape also and compared with those in the bended tapes. That is because, if we find any relation between the loss data of straight and bended tapes, it is possible to estimate the AC loss characteristics of the tapes subject to the strains in the cables and windings form the loss data of a straight tape which are much easier to measure than those of bended ones.

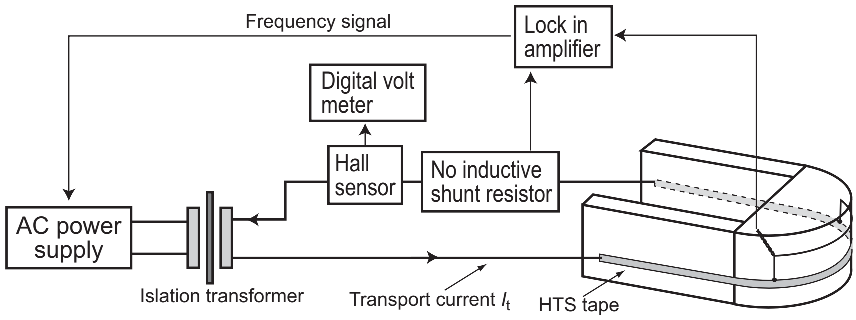
EXPERIMENT

<u>Measurement arrangement</u>

The transport current losses in Bi/Ag-sheathed tapes subject to bending strains were measured by a four-terminal electric method in the zero magnetic field. An arrangement for the measurement is illustrated in Figure 1 (a) and (b). Figure 1 (a) illustrates the sample arrangement and Figure 1 (b) the measurement circuit. Bi/Ag-sheathed tapes are placed on surfaces of half-cylinders made of GFRP of radii R = 15, 20, 25 and 30mm and leads from potential taps attached on the tape edge are arranged 1cm apart from the tape as shown in Figure 1 (a). As shown in Figure 1 (b), AC transport currents were supplied to the sample by a variable frequency power supply, and the transport current losses are measured by measuring the resistive voltage component of the voltage signal from the potential taps using a lock-in amplifier. The frequency of the transport current was controlled by the frequency signal generated in the lock-in amplifier.



(a) Sample arrangement



(b) Measurement circuit

Figure 1 Schematic illustration of arrangement for electric measurement of AC transport current losses

A sample piece of Bi/Ag-sheathed tape was changed when the radius of the sample holder was changed to avoid any deterioration of performance of the tape caused by heat cycles. The sample pieces were taken from the same long tape. The specifications of the tape used in the experiment are listed in Table 1.

Table 1 Specifications of Bi2223/Ag-sheathed tape used in experiment

Width × Thickness	4.0×0.22 mm^2
Number of filaments	70
Ag / SC	1.5

Measurement results

Critical currents I_c of the samples (defined at 1μV/cm) of different bending radii are plotted against bending strain σ together with I_c of a straight sample in Figure 2. Degradation of I_c is remarkable for

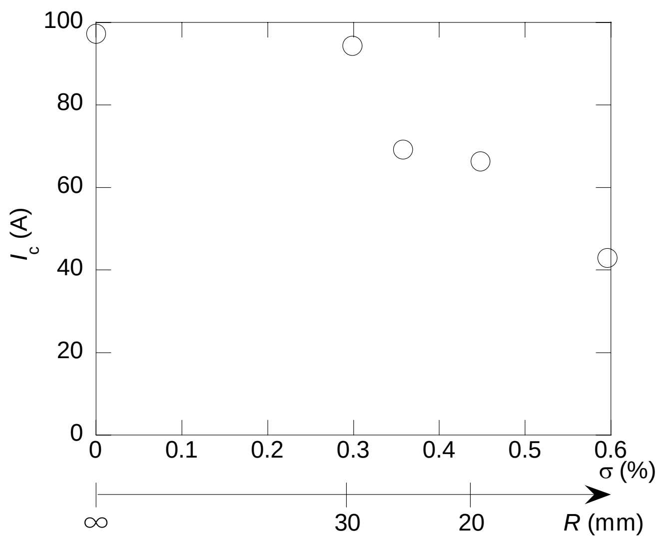


Figure 2 Critical current vs. bending strain σand radius R

R=15mm (bending strain 0.6%). AC transport current losses per cycle per unit length of the tape Q_t are shown in Figures 3~5. Figure 3 shows dependence of Q_t vs. the amplitude of the transport current I_t curves on R at 60Hz. Figure 4 shows normalized losses $q_t = Q_t/I_c^2$ vs. normalize transport current $i= I_t /I_c$ for various R at f = 60Hz. As seen in Figure 4, curves of q_t vs. i for the samples of different values of R including the straight sample almost fall to one curve which is close to the Norris curve of the elliptical model [1]. Figure 5 shows frequency dependence of q_t for various i and R. As seen in Figure 5, dependence of Q_t on frequency is not remarkable in the range of f = 30~720Hz and $I_t < 0.7I_c$, which means that the losses were hysteretic in this range. Also as seen in Figure 5 q_t is dependent on f for $I_t \sim I_c$, which is because the tapes become resistive and dissipate joule heats.

Obviously from these results, the AC transport current losses in Bi/Ag-sheathed tapes subject to bending strain can be estimated by knowing the AC transport current loss characteristics of a straight tape and I_c of a bended tape.

CONCLUDING REMARKS

Dependence of the AC transport current losses on the bending strain was experimentally investigated. The experimental results show that the AC transport current losses in Bi2223/Ag-sheated tapes are hysteretic and that their dependence on the bending strain can be explained by the dependence of the critical currents on the bending strain. This result suggests that the AC losses of Bi2223/ Ag-sheathed subject to bending strains can be estimated by knowing the dependence of the critical currents of tapes on

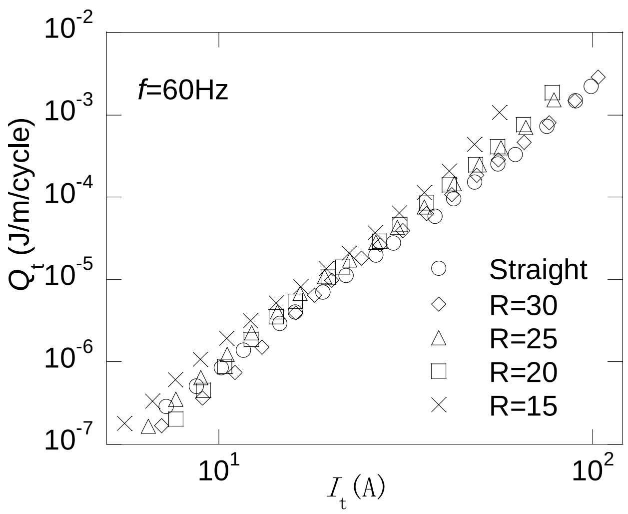


Figure 3 Transport current loss Q_t vs. transport current I_t for various R at 60Hz

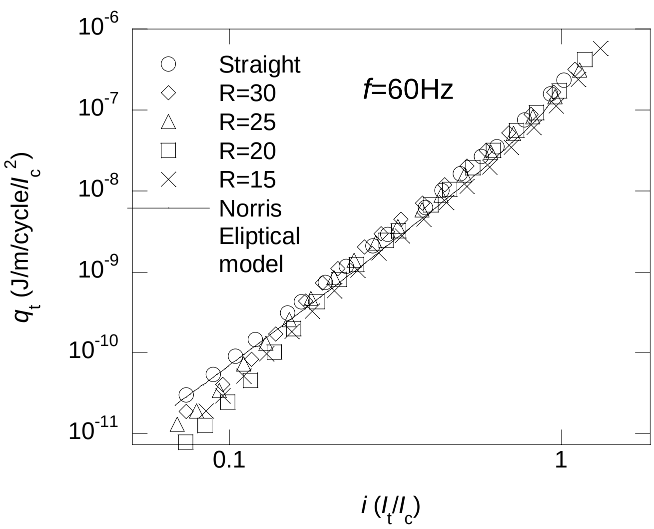


Figure 4 Normalized transport current loss q_t vs. normalized transport current i at 60Hz for various R

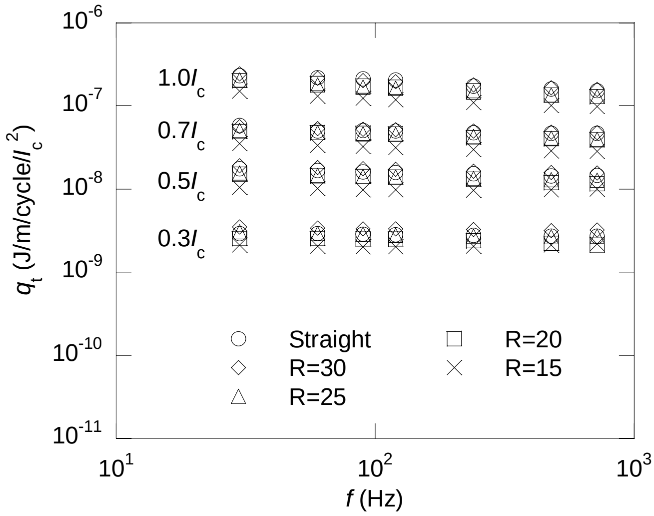


Figure 5 Frequency dependence of q_t for various values of i and R

the bending strain and the AC loss characteristics of straight tapes.

Generally, the HTS conductors in the AC apparatuses are carrying AC transport currents in AC external magnetic fields. Therefore, as the next step, we are investigating AC loss characteristics of HTS tapes subject to bending strains and carrying transport currents in AC external magnetic fields. In the case, it is difficult to measure the AC losses by an electric method but possible by a calorimetric method [2].

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