Loss in QMG Processed Y-123 Superconductor due to Ac Current

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ABSTRACT

Ac transport current loss is measured for a QMG (Quench and Melt Growth) processed Y-123 bulk superconductor up to 300 A at 77.3 K. For this purpose a simple current transformer is used. The frequency of ac current is 400 and 550 Hz. The hysteresis loss extrapolated to zero Hz is compared with the prediction of the Irie-Yamafuji model where the critical current density is estimated from the hysteresis of dc magnetization. The obtained hysteresis loss is slightly smaller than the theoretical prediction. This is considered to be caused by the reduction in the critical current density due to the flux creep in the dc magnetization measurement.

KEYWORDS: Melt processed Y-123, ac loss, Irie-Yamafuji model, flux creep

INTRODUCTION

Y-123 superconductor can carry currents of high density up to high magnetic fields even at 77.3 K because of the strong pinning, if it is not influenced by weak links due to grain boundaries. This is one of the outstanding features of this superconductor in comparison with Bi-based superconductors which are significantly affected by the flux creep. Hence, QMG processed Y-123 superconductors which do not contain grain boundaries are promising material and the application of this material to various fields is expected.

One of them is the application to current leads for ac use. The important characteristic for this application is the ac loss. The ac transport current loss was measured for current leads made of bulk Bi-based superconductors [1, 2]. Thus, it is necessary to estimate the loss energy density when ac transport current is applied to the QMG processed Y-123 superconductor. In this study, a current transformer is made to apply the ac current up to 300 A in peak value to the superconductor because of high critical current. The ac transport loss in a bulk QMG specimen is measured at 77.3 K using the transformer. The observed loss energy density is compared with the prediction of the Irie-Yamafuji model with the critical current density estimated from dc magnetization measurement.

EXPERIMENTS

The specimen was a QMG processed Y-123 bulk superconductor prepared by Drs. K. Kimura and M. Morita of Nippon Steel Corp. and the cross-section was 3.0×2.0 mm^2 and the length was 30 mm. The direction of the length was parallel to the a-b plane. The critical temperature, T_c, estimated from a dc magnetic susceptibility measurement was 90.6 K. A dc magnetization was measured at 77.3 K in a magnetic field parallel to the c-axis using a SQUID magnetometer. The critical current density, J_c, estimated from the hysteresis of dc magnetization at zero external field was 2.6×10^8 A/m^2.

The ac transport current was applied to the specimen using a current transformer. A copper wire of 0.5 mm in diameter was used for a primary winding of the transformer and the number of turn was 200. A copper wire of 0.8 mm in diameter was used for a secondary winding and 24 wires were connected in parallel to reduce the resistance of the secondary winding. The number of turn is 2. Thus, the secondary current is expected to be enhanced 100 times as high as the primary current in the case of ideal coupling. An iron core of the cross-section of 20×20 mm^2 was used to improve the coupling between the primary and secondary windings. The specimen was connected to the secondary winding by soldering. The resistance at 77 K and the inductance of the primary winding were 10.5 Ω and 4.34×10^{-2} H, respectively and those values of the secondary winding were 2.71×10^{-3} Ω and 4.12×10^{-6} H, respectively. The mutual inductance was 4.17×10^{-4} H and the coupling coefficient was 0.986. Since the resistance in the secondary winding is relatively large, the coupling is bad at low frequencies. For example, the frequency at which the reactance due to the inductance is equal to the resistance is about 100 Hz. In fact, the wave form of the secondary current was deformed at such a low frequency. Thus, the measurement was done at frequencies higher than 400 Hz. It is necessary to reduce the resistance in the secondary winding to apply the

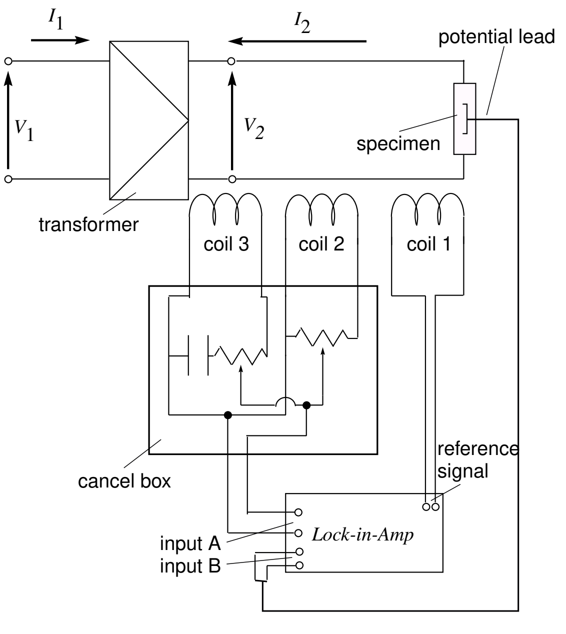

Fig. 1. Electric circuit for measurement of ac loss.

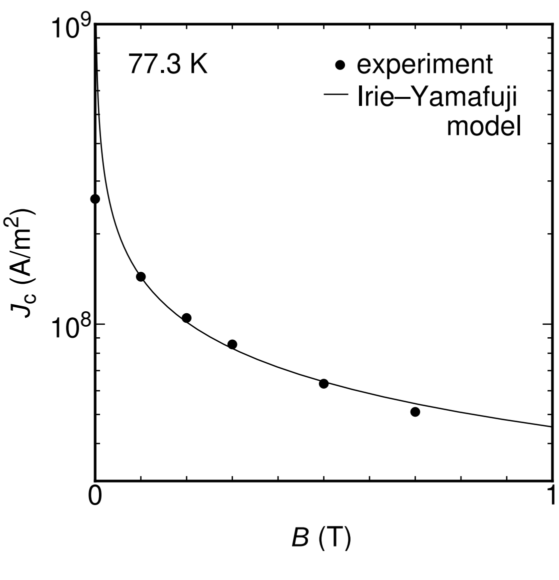

Fig. 2. Magnetic field dependence of critical current density estimated from dc magnetization at 77.3 K. Solid line shows the theoretical result of Irie-Yamafuji model.

current of low frequencies. The use of silver-sheathed Bi-based superconducting tapes seems to be promising for the purpose.

The ac transport current was applied to the specimen using an ac power amplifier through this current transformer. The frequency of the ac current was 400 and 550 Hz. The circuit for the measurement is shown in Fig. 1. The induced voltage was measured using potential leads separated by 6 mm. The ac loss was estimated from the in-phase component of the measured voltage. Three toroidal coils around the secondary wires were used to detect the secondary current and to compensate the out-phase signal. The experiment was carried out in liquid nitrogen.

RESULTS AND DISCUSSION

The result of the magnetic field dependence of the critical current density, J_c, obtained from the dc magnetization hysteresis is shown in Fig. 2. Here the Irie-Yamafuji model [3] is assumed to express the magnetic field dependence of J_c. According to this model, J_c is expressed as $J_c(B) = \alpha B^{\gamma-1}$, where α and γ are the pinning parameters. These parameters are determined so as to get a good agreement between above equation and experimental results. The obtained parameters are $\alpha = 4.5 \times 10^7$, $\gamma = 0.5$.

The ac loss energy density is estimated from $W = IV/2fS$, where I is the ac peak current, V is the in-phase component of the peak voltage across the potential leads, f is the frequency and S is the cross-sectional area of the specimen. The obtained results are shown in Fig. 3. The ac loss energy density at 550 Hz is larger than that at 400 Hz. This seems to be caused by the additional viscous loss energy density due to the flux motion. Then, the hysteresis loss energy density is estimated by extrapolating the data linearly to $f = 0$. The obtained hysteresis loss energy density is shown in Fig. 4 and compared with the theoretical prediction of the Irie-Yamafuji model with J_c in Fig. 2. It is seen that the experimental results are smaller than the theoretical prediction. This seems to be ascribed to the effect of the flux creep. That is, it is speculated that the effective

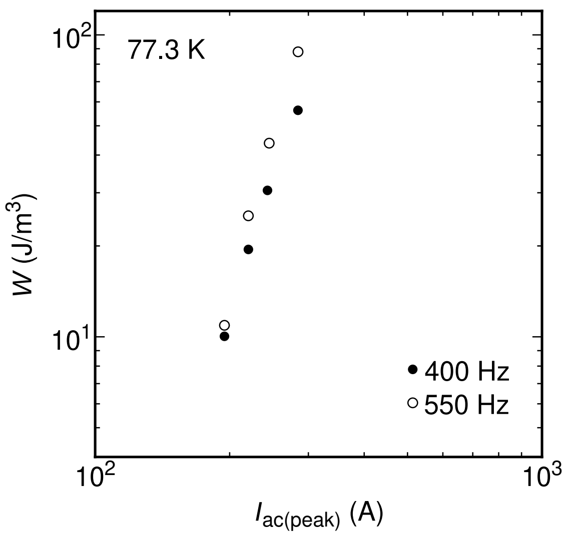

Fig. 3. Ac loss energy density vs peak ac current at 77.3 K.

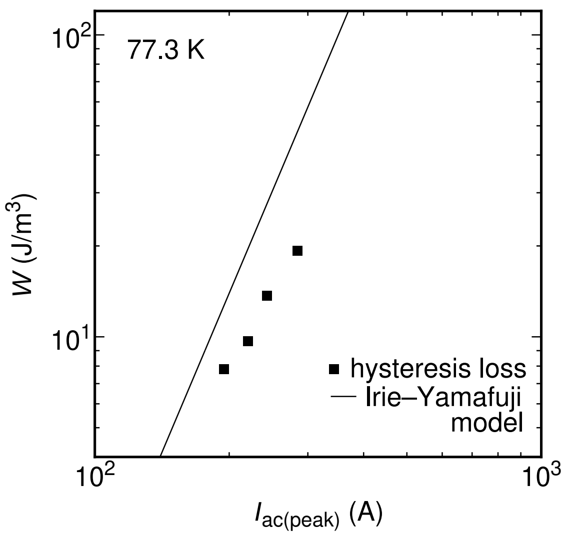

Fig. 4. Comparison of measured hysteresis loss energy density and theoretical prediction of the Irie-Yamafuji model.

J_c value is reduced due to the flux creep at the dc magnetization measurement, resulting in the larger ac loss.

The depth of penetration of ac flux is of the order of $B_m/\mu_0 J_c$, where B_m is the amplitude of the ac self field. Thus, the induced electric field at the surface is roughly estimated as $2\pi f B_m^2/\mu_0 J_c$. This amounts to $E = 3.55 \times 10^{-2}$ V/m at $I = 200$ A and $f = 400$ Hz. On the other hand, at the dc magnetization measurement, the induced electric field is estimated as $\dot{B}d/2$, where $\dot{B}$ is the sweep rate of the external magnetic field and conductor. This amounts to $E = 1.61 \times 10^{-7}$ V/m. Hence, the two values of the electric field is approximately different by a factor of 2×10^5. Here it is assumed that the current-voltage characteristic is expressed as $E \propto J^n$ in this region with the n-value. If n is 20, the critical current density measured by the dc magnetization is reduced by a factor of 1.85 because of the measurement at the low electric field region. This means that the ac loss is enhanced by the same factor. Thus, such a deviation in Fig. 4 seems to be possible. From this argument the agreement between the observed ac loss and the theoretical estimation is rather satisfactory.

SUMMARY

The ac transport current loss in a QMG processed Y-123 sample was measured at 77.3 K at 400 and 550 Hz. The hysteresis loss estimated from the observed results is compared with the Irie-Yamafuji model with the value of the critical current density obtained from the dc magnetization. It is found that the theoretical prediction is slightly larger than the experimental results. This seems to be ascribed to the reduction in J_c due to the flux creep during the dc magnetization measurement.

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