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Longitudinal magnetization loss in twisted multifilamentary Bi2223 tape

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Abstract

Multifilamentary Bi2223 tapes are exposed to the longitudinal magnetic field as well as the transverse one in some electrical power apparatuses such as multilayer power transmission cables. Here, we define the longitudinal and transverse magnetic fields as the field components parallel and perpendicular to the tape axis, respectively. If the filament-bundle is twisted, it can couple to the AC longitudinal magnetic field to generate the longitudinal magnetization loss. Furthermore, the AC transport current flowing spirally in the twisted filament-bundle possibly influences the longitudinal magnetization. The longitudinal magnetization loss was measured in a twisted multifilamentary Bi2223 tape exposed to longitudinal magnetic field and carrying the transport current. The measured longitudinal magnetization loss in the twisted tape exposed to the longitudinal magnetic field is larger than that in another untwisted tape. Supplying the AC transport current changes the longitudinal magnetization loss in the twisted tape exposed to the AC longitudinal magnetic field. The influence of the transport current depends on the phase relation between the longitudinal magnetic field and the transport current. If their phase difference is 0°, the longitudinal magnetization loss decreases remarkably with increasing amplitude of the transport current. It means that the change in the current distribution due to the transport current results in the decrease in the power flow from the magnet power supply. But, a preliminary measurement of the transport loss shows that the total loss increases with increasing transport current.

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Keywords: Bi2223; Twist; Magnetization loss; Longitudinal magnetic field

1. Introduction

The external magnetic field to superconducting tapes can be classified by its direction; transverse and longitudinal magnetic fields that are perpendicular and parallel to the tape axis, respectively. In some electrical power apparatuses such

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as multilayer power transmission cables, high T_c superconducting tapes are exposed to the longitudinal magnetic field as well as the transverse one. Though the influence of the longitudinal magnetic field on AC loss characteristics in low T_c superconductors have been studied for a long time [1], there are only a few reports about its influence in high T_c superconductors [2,3].

The purpose of this work is to study the longitudinal magnetization in twisted multifilamentary high T_c superconducting tapes experimentally. The longitudinal magnetic field is applied to a twisted multifilamentary Bi2223 superconducting tape with or without transport current to measure the longitudinal magnetization loss with a pick-up coil. In the following, first, a brief theory about the influence of the longitudinal magnetic field and the transport current on the longitudinal magnetization is described. The experimental method is explained also in the same section. Then, results of the longitudinal magnetization loss measurements are presented.

2. Brief theory and experimental method

When the longitudinal magnetic field is applied to a twisted multifilamentary high T_c superconducting tape, the magnetization current flows to shield the applied longitudinal magnetic field. It flows spirally along twisted filaments in the peripheral region to produce the anti-parallel longitudinal magnetic field, that is to produce longitudinal magnetization, and returns through almost straight filaments in the central region. If the transport current is supplied to a twisted tape, the current flowing spirally along the filaments produce the self longitudinal magnetic field. The combination of this self-longitudinal magnetic field and the applied longitudinal magnetic field possibly influences the longitudinal magnetization loss.

In a series of experiments, the longitudinal magnetic field is applied by a solenoid magnet, and the longitudinal magnetization loss is measured with a pick-up coil. The power dissipated in the sample superconducting tape comes from the magnet power supply and the transport-current power supply. It is to be noted that only the power flow from the magnet power supply can be measured by the pick-up coil, and that the power flow from the transport-current power supply can be measured by the voltage taps attached optionally. The preliminary measurement of transverse magnetization loss is made with another set-up reported in Ref. [4].

3. Experimental results

Specifications of the sample twisted tape and the reference untwisted tape are listed in Table 1. Although only the critical currents at self-field are listed, the influence of the longitudinal magnetic field on them was rather small. All experiments were made in liquid nitrogen.

At first, the magnetization loss in the transverse magnetic field parallel to the tape wide face was measured for the twisted and untwisted tapes. In Fig. 1, loss factors are plotted against the amplitude of the magnetic field. The measured value of the twisted tape is larger than the analytical value for decoupled filaments and does not decrease even if the frequency is decreased. This suggests

Table 1
Specifications of sample multifilamentary Bi2223 tapes

	Twisted tape	Untwisted tape for reference
Width and thickness of tape	3.76 mm × 0.236 mm	3.91 mm × 0.240 mm
Approximate thickness of filamentary region (mm)	0.2	0.2
Approximate thickness of filament (mm)	0.03	0.03
Fraction of superconductor in whole cross-section (%)	28	29
Number of filaments	61	61
Twist pitch	15 mm, Z-twisted	NA
Critical current (A) at 0 T	55.9	69.6

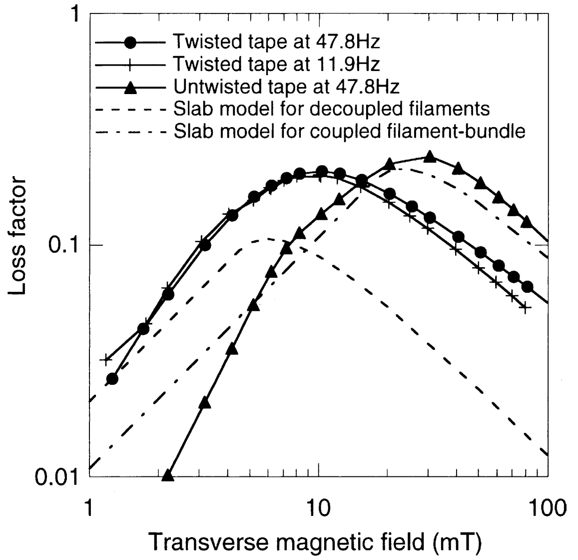

Fig. 1. Loss factor, that is normalized magnetization loss, measured in transverse magnetic field parallel to tape wide-face together with analytical values. Analytical values by slab model are based on Bean's critical state model.

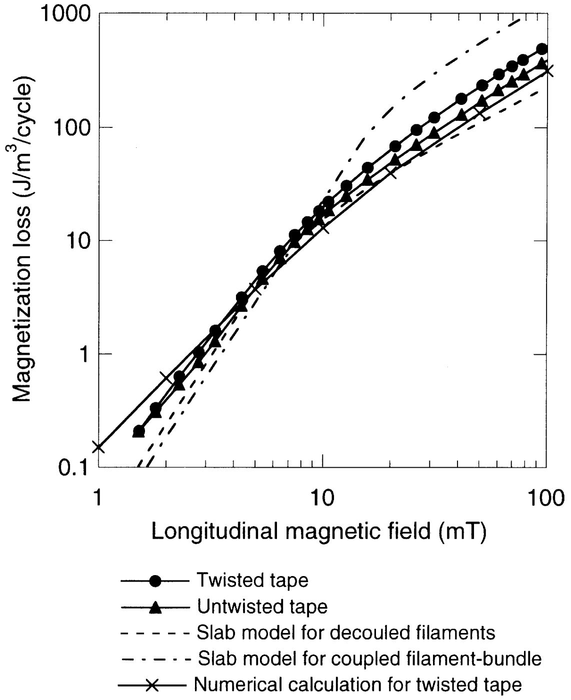

Fig. 2. Measured magnetization loss in longitudinal magnetic field at 47.8 Hz together with several theoretical values. Analytical values by slab model are based on Bean's critical state model.

that filaments should be inter-connected with each other by superconducting bridgings.

Fig. 2 shows the longitudinal magnetization loss in the twisted and untwisted tapes without transport current. Several theoretical plots are also shown; an analytical value for decoupled filaments based on the critical state slab model, an analytical value for coupled filament-bundle, and a result of numerical calculation whose model is described in Ref. [2]. The measured loss in the twisted tape is larger than that in the untwisted tape. It may be an effect of the coupling of the twisted filament-bundle to the longitudinal magnetic field, but both measured losses deviate from theoretical values presented, and it is difficult to deduce a definitive conclusion from the results.

In Fig. 3, the longitudinal magnetization loss in the twisted tape with its transport current is plotted against the longitudinal magnetic field, together with the loss in the tape without transport current, where the phase difference between the longitudinal magnetic field and the transport current is 0° or 180°. When the phase difference is 180°, the loss is almost same as the loss without transport current. When the phase difference is 0°, the loss is remarkably lower than the others. The superposition of the transport current to the magnetization current against the longitudinal magnetic field results in the change in the current distribution. The direction of the superposed transport current depends on the phase difference, and hence, the resulting current distribution as well depends on the phase difference. This change in the current distribution influences the power flow from the magnet power supply that is measured as the magnetization loss by the pick-up coil.

In Fig. 4, the longitudinal magnetization loss in the twisted tape is plotted against the transport current where the amplitudes of the longitudinal magnetic field are 48, 23.5 and 51 mT, and the phase differences are 0° and 180°. When the amplitude of the field and the phase difference are 4.8 mT and 180°, respectively, the longitudinal magnetization loss increases with increasing transport current. In the other cases, it decreases with

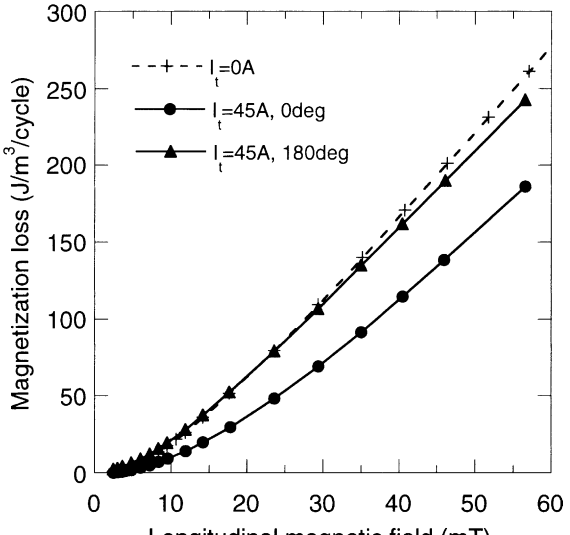

Fig. 3. Longitudinal magnetization loss in twisted tape vs. longitudinal magnetic field, with and without transport current of 45 A. Frequency of current and magnetic field is 47.8 Hz. Phase difference between current and magnetic field is 0° or 180°.

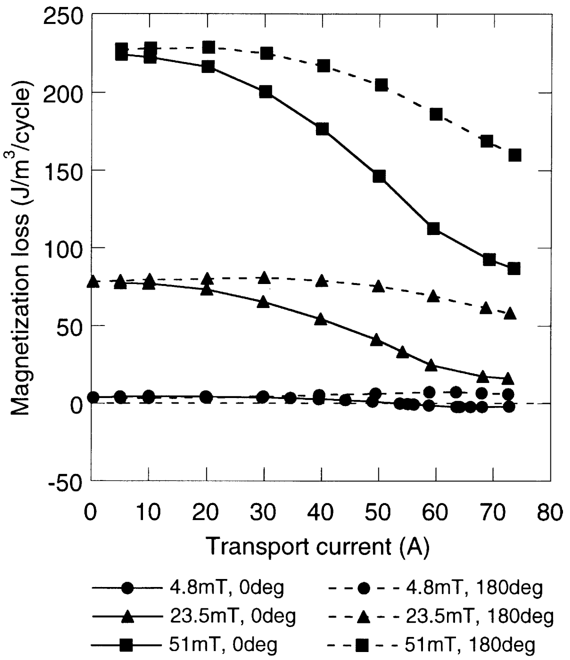

Fig. 4. Longitudinal magnetization loss in twisted tape with transport current vs. magnitude of transport current. Frequency of current and magnetic field is 47.8 Hz. Phase difference between current and magnetic field is 0° or 180°.

increasing transport current. In this figure too, the effect of the transport current depends on the phase difference. Decrease in the magnetization loss is more remarkable when the amplitudes of the longitudinal magnetic field and/or the transport current are larger, and when the phase difference between the longitudinal magnetic field and the transport current is 0°. Though the magnetization loss is reduced by supplying the transport current, a preliminary transport-loss measurement shows that the total loss including the power flow from the transport-current power supply increases with increasing transport current.

4. Concluding remarks

The externally applied longitudinal magnetic field and the transport current flowing spirally along filaments in the twisted multifilamentary Bi2223 tape lead to the longitudinal magnetization and influence the AC loss characteristics. When the longitudinal magnetic field and the transport current are applied simultaneously to the twisted multifilamentary Bi2223 tape, in some cases, the longitudinal magnetization loss decreases with increasing transport current. This means that the change in the current distribution in twisted filament-bundle by the transport current results in the decrease in the power flow from the magnet power supply. But it does not straightforwardly mean the decrease in the total loss in the tape including the power flow from the transport-current power supply.

Acknowledgements

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