Peculiarities of magnetization of second generation high-temperature superconducting tapes in a wide temperature range

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Abstract. We present the results of study of magnetization and critical current of coated conductors with magnetic and nonmagnetic substrates. The measurements of magnetization curves were done in a wide temperature range from 4.2 to 100 K and magnetic field up to 14 T. To determine the dependence of transport critical current on the magnetic field we measured a set of current-voltage characteristics in the range of magnetic field from 0 to 8 T at T = 77 K with perpendicular to the tape field orientation. It was obtained that the substrates magnetism dramatically changes the form of magnetization curves but not influence the value of critical current. Comparison of field dependence of critical current, obtained by contact and contactless method at T = 77 K shows that for both samples is observed coincidence of the curves at low fields and a strong divergence at H> 1 Tesla.

1. Introduction

Recently, considerable attention is paid to the development of the second-generation current-carrying tapes based on high-temperature superconductor (HTSC) YBa2Cu3O7-x with critical temperature 92 K. Tapes are thin (less than 1 micron) layers of HTSC, deposited in various ways to the metal substrate alloy Hastelloy (Ni + W). Depending on the W concentration, which ranged from 0 to 5%, these substrates have different magnetic properties, which may influence the integral magnetization of HTS tapes. Since the substrates are weak ferromagnetic but high-temperature superconductors - diamagnetic, the total magnetization of the tape will depend on the relative contribution of the substrate and the HTSC magnetism. At the same time in different magnetic fields and at different temperatures, the contribution of various components of the magnetic tape can be different. In this report we present results of studies of the magnetization of HTSC tapes with different magnetic characteristics of metal substrates.

2. Materials and methods

Industrial tape manufactured by AMSC (magnetic substrate), and Super Power (non-magnetic substrate) were selected for study. Magnetization measurements were performed using vibration magnetometer [1] on samples of size 4x4x0, 1 mm. The temperature varied in the range 4.2-100 K, the
magnetic field was varied from 0 to 14 T, the orientation of the field was perpendicular to the plane of the tape.

Determination of the magnetization of the substrate was carried out in two ways. The first - the magnetization of the samples was measured at \( T = 95 \text{ K} \), i.e. when the superconductor is in normal state. However, it remained unknown temperature dependence of magnetic susceptibility of the substrate and it is not clear how the values of magnetization and susceptibility, obtained at \( T = 95 \text{ K} \) correspond to the values at lower temperatures. Therefore, for the sample with magnetic substrate we used a different procedure. After all measurements of the integral of the magnetization from 4.2 K to 77 K, the sample was split accurately on the HTS layer into two parts, a thin layer of HTSC was scraped carefully, and two half have been stuck together. The result was a new sample, which had a geometric dimensions and weight of almost the same as the original, but without the superconducting layer. It thus becomes possible to measure the magnetization of the substrate at temperatures ranging from 4.2 to 95 K. These measurements showed that the intrinsic magnetization of the substrate changes with temperature from 95 K to 4.2 K is not more than 3% (Figure 1).

3. Results and discussion

Measurements of superconducting samples both at \( T = 77 \text{ K} \) and at lower temperatures showed a significant difference in the form of curves \( M(H) \) due to influence of the magnetic properties of the substrates. Moreover, the influence of ferromagnetism of the substrate AMSC tape is so strong that the curve \( M(H) \) was absolutely no resemblance to the classical curve \( M(H) \) for type-II superconductors, such as, for SP tape (Figure 2, Figure 3). In fact, the diamagnetic HTS layer veiled completely the influence of the substrate. However, if the from total magnetization of tapes AMSC deduct the magnetization of the substrate, measured at the same temperature, the magnetization of the HTSC layer is obtained, analogous to the magnetization of SP tape. Obviously, small differences remain due to the difference in the properties of HTSC materials.

![Figure 1: Magnetization of 2G sample with magnetic substrate and nonmagnetic substrate (inset) at \( T=95 \text{ K} \)](image)

The significant difference between the curves of the magnetization of HTSC films on magnetic and nonmagnetic substrates is manifested in the whole temperature range from 4.2 to 77 K.
Thus, it is experimentally shown that the ferromagnetism of the metallic substrate significantly distorts the shape of magnetization curves of HTSC tape. However, after taking into account the magnetic susceptibility of the substrate, the magnetic characteristics of HTS layers are similar (Figure 4). Since the hysteresis of M(H) curves for 2G tape with magnetic substrate shown on Figure 2 is absent, we can expect that the magnetism of the substrate will not affect the magnitude of energy loss in alternating electromagnetic field. Analysis of the curves M(H) can give detailed information about the hysteresis losses in 2G HTS tapes AMSC and SP in wide temperature range from 4.2 to 77 K in magnetic fields up to 14 Tesla.

Figure 2: M(H) curves for 2G tape with magnetic substrate

Figure 3: M(H) curves for 2G tape with nonmagnetic substrate

Figure 4: M(H) curves for superconducting layers AMS (1) and SP (2) at T=77 K. Curve (2) is obtained by subtraction from magnetization of the entire tape magnetization of the substrate
High values of dissipationless flow of transport current in modern high-tapes of the second generation led to methodological difficulties in measuring the critical current, which are associated with the overheating of the current supply wires and electrical contacts. It is known that alternative transport measurements are various contactless techniques, in particular, the measurement of magnetization, from which, based on the critical-state model [2,3], we can determine the values of the critical current. The unquestionable advantages of the magnetization measurements should include the possibility of measurements in a wide range of temperatures and the possibility of using relatively small samples of superconducting tapes. The dependence of $I_c(H)$ can be relatively easily verified by direct transport measurements at the boiling point of liquid nitrogen and determine the range of magnetic fields, which applies non-contact method for measuring the critical current.

We compared the normalized dependences of the critical current, obtained by contact and contactless method. For both samples the coincidence of the curves at low fields and strong divergence at $H>1$ Tesla. The field at which the data obtained by different methods are roughly the same limited by the value 0.4-0.6 Tesla depends on sample types. Meanwhile, it should be noted that this range of fields is of practical importance, since the fall of the critical current below the level of 0.1 $I_{c0}$ makes bleak possibility of real devices.

4. Conclusion
In this report it is experimentally shown that the ferromagnetism of the metallic substrate significantly changes the shape of magnetization curves of HTSC second generation tape. The strong discrepancy between the results of transport and magnetic measurements of the critical current in fields above 1 T seems to indicate non-applicability of the critical state model for calculating the critical current of HTS tapes in high magnetic fields.

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