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Propagation of a.c. magnetic field through high-T_c coatings

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Abstract. Studies on the propagation of AC magnetic field through plasma-sprayed superconducting $Y_1Ba_2Cu_3O_{7-x}$ coatings show that complete shielding is achieved up to a certain critical magnetic field strength H_0. Increase in the thickness or J_c of the specimen increases the H_0 value. Flux-trapping occurs in the specimen at high frequencies and the frequency at which it occurs increases with increase in specimen J_c.

Keywords. Magnetic field; shielding; high-T_c coatings.

1. Introduction

Ever since the discovery of high-T_c superconductors (HTSC) researchers around the world are studying the behaviour of these materials in applied magnetic fields. Many authors (Karthikeyan *et al* 1988a; Purpura and Clem 1989; Willis *et al* 1989; Yahara and Matsuba 1989; Macfarlane *et al* 1988; Hattori *et al* 1988; Fiory *et al* 1988) have studied the magnetic shielding properties of these materials in both parallel and perpendicular fields. Sintered pellets, tubes, cavities, epitaxial films as well as thick film coatings have been used as shielding specimens. The frequency and intensity of the applied field have been varied in the ranges of zero (DC field) to 100 kHz and 0 to 3.0 mT respectively. The results of these studies have shown that these HTSC materials are potential candidates for the construction of magnetically-shielded enclosures required for bio-magnetic and other applications.

We have prepared (Karthikeyan *et al* 1988b) large area plasma-sprayed superconducting $Y_1Ba_2Cu_3O_{7-x}$ coatings and studied (Karthikeyan *et al* 1988a) the shielding effectiveness of these coatings over a wide range of parameters. This study has established that the plasma-spray process can be used for preparing complex, large-area shielding surfaces required for any practical application. In order to gain insight into the shielding characteristics of these coatings, we have studied the penetration and propagation behaviour of incident AC magnetic field through the sprayed films and report the results here.

2. Experimental procedure

Plasma-sprayed superconducting $Y_1Ba_2Cu_3O_{7-x}$ shielding specimens were prepared as described in detail in Karthikeyan *et al* (1988b). Test specimens (thickness 150 to 180 μm) were prepared with J_c of 5 and 50 A/cm^2 for the study.

The experimental set-up and measurement procedure are detailed in Paithankar *et al* (1989). Two-coil mutual inductance method was used to study the field propagation through the specimen. The drive coil was energized by a sinewave

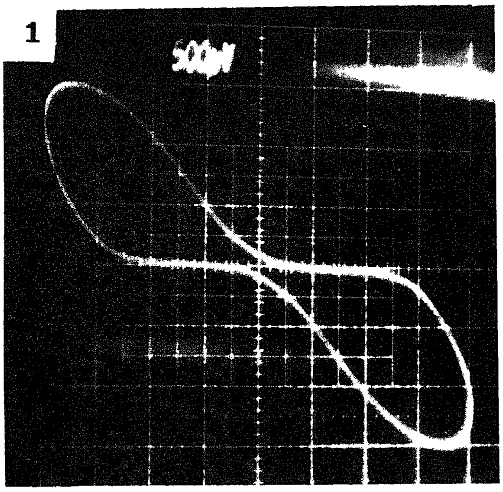

Figure 1. Variation of received field with applied field (thickness: 160 μm; J_c: 50 A/cm^2; frequency: 1 kHz) Axis X: H_a (2 G/div) Y: V_r (0.5 mV/div).

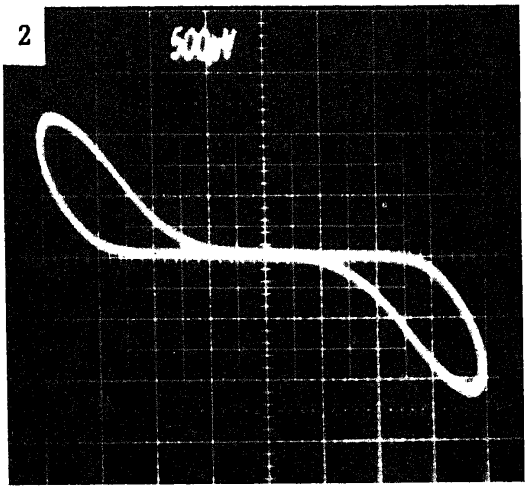

Figure 2. Variation of received field with applied field (thickness: 180 μm; J_c: 50 A/cm^2; frequency: 1 kHz) Axis X: H_a (2 G/div) Y: V_r (0.5 mV/div).

generator to produce AC (100 Hz–100 kHz) field ($H_a = H_{a\max} \sin \omega t$) of strength 0.01 to 3.0 mT at the specimen surface and the field propagating through the specimen (H_r) was detected by the receiving coil as voltage signal ($V_r = \partial H_r/\partial t$).

3. Results and discussion

Figure 1 gives the variation of 1 kHz field penetrating through a typical specimen (thickness: 160 μm; J_c: 50 A/cm^2) with the incident field strength. As can be seen, up to a critical incident field strength H_0, the field is completely shielded, above which partial

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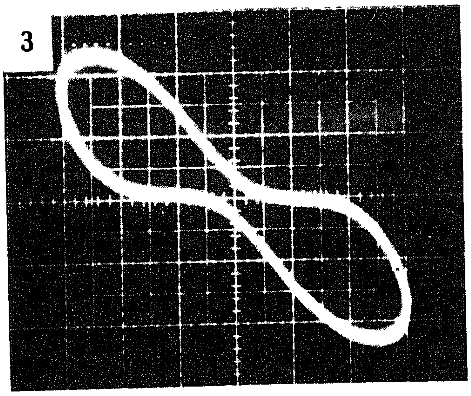

Figure 3. Variation of received field with applied field (thickness: 160 μm; J_c: 5 A/cm^2; frequency: 1 kHz) Axis X: H_a (2 G/div) Y: V_r (0.5 mV/div).

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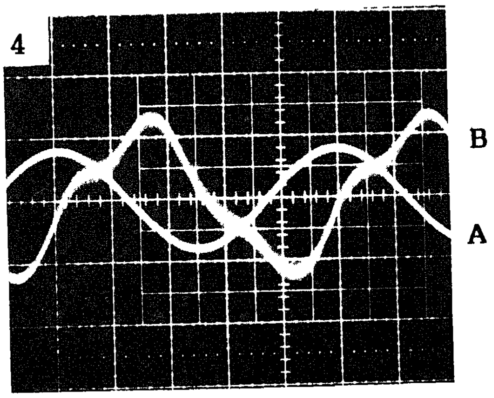

Figure 4. High-frequency response of a typical specimen (thickness: 180 μm; J_c: 50 A/cm^2; frequency: 100 kHz) Axis X: time (2 μs/div); Y: Curve A: H_a (4 G/div); curve B: V_r (1 mV/div).

flux penetration occurs. Perfect shielding of the incident field up to H_0 can be explained on the basis of Bean's critical state model (Bean 1962), which shows that a superconducting slab of thickness a and critical current density J_c will completely shield the applied field up to a certain parametric magnetic field strength H^* given by

$$H^* = KJ_ca, \tag{1}$$

where K is a geometrical constant. The H^* value was found to be 4 G for the 160 μm specimen yielding a shielding factor of 25 G/mm, which can be compared with 16 G/mm reported by Yahara and Matsuba (1989) for sintered plates.

The 1 kHz field propagating through a 50 A/cm^2 specimen of 180 μm thickness is presented in figure 2. The response of a 5 A/cm^2 specimen of thickness 160 μm is given in figure 3. As can be seen, the increase in either thickness (figures 1, 2) or J_c (figures 3 and 1) results in increase in the H_0 value, in accordance with equation (1). However, it was observed that increase in thickness from 160 to 180 μ resulted in a large increase in H_0 value from 4 G to 7 G and a decrease in specimen J_c by an order of magnitude reduces the H_0 value by only half (from 4 G to 2 G); while linear dependence of H_0 on both thickness and J_c is required by equation (1). The observed nonlinear dependence of H_0 on thickness and J_c agrees well with earlier findings (Macfarlane *et al* 1988; Purpura and Clem 1989) and the deviation from (1) is believed to arise due to the dependence of the constant K on the demagnetization coefficient and the magnetic field dependence of J_c (Campbell 1988; Bhagwat and Chaddah 1989).

High-frequency (100 kHz) response of a 50 A/cm^2 specimen of 180 μm thickness is presented in figure 4. When the field strength reduces from $H_{a\max}$ to zero, non-zero voltage output ($V_r \neq 0$) is seen for fields $H_a < H_0$, showing trapping effects in the specimen. It was observed that: (i) the magnitude of the trapped flux (H_{tr}) is the same on either half cycles; (ii) H_{tr} increases with increase in the $H_{a\max}$ value; (iii) variation in the thickness of the specimen of the same J_c does not affect either the frequency (f_{tr}) at which trapping effect appeared or the H_{tr} value; (iv) Reducing the J_c from 50 A/cm^2 to 5 A/cm^2 reduces f_{tr} from 100 kHz to 10 kHz.

Similar flux-trapping effects have been observed by others as well (Srinivasan 1989; Purpura and Clem 1989). The exact mechanism and the nature of the flux-trapping effect is not yet understood and is presently under study.

4. Conclusions

Study of the propagation of AC magnetic field through plasma-sprayed superconducting $Y_1Ba_2Cu_3O_{7-x}$ coatings show that absolute shielding is achieved for applied fields less than a critical field strength.

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