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Surface influence on flux penetration into HTS bulks

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Abstract

The influence of surface treatment on AC loss in melt-processed quasi-single crystal HTS was investigated with resonance oscillations technique. We have found that amplitude dependencies of AC loss on magnetic field amplitude become rather complicated after surface polishing. The experimental data show well-distinguished dynamic crossover from absence of barrier at low rates of field variation to its appearence at higher rates. An explanation of such a dynamic surface barrier appearance based on consideration of along surface vortex propagation was suggested. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: AC losses; Melt processed HTS; Resonance oscillation technique; Surface barrier

1. Introduction

In paper [1] the approach to calculate mechanical properties of levitation systems with melt-processed high-temperature superconductors (MP HTS) was introduced. It starts from an 'ideally hard superconductor' approximation which assumes that the penetration depth δ of alternating magnetic field is zero. Within this 'zero' approximation the stiffness or resonance frequencies in the permanent magnet (PM)–MP HTS system can be calculated analytically and appeared to be in a good agreement with the experiment [2], but to calculate energy loss due to PM motion [3] or hysteresis of levitation force [4] the next ('first') approximation has to be used and finite values of δ have to be considered.

We have shown in Ref. [3] that the energy loss W in the PM–HTS system during PM oscillations is mostly determined by AC loss in the HTS undersurface layer $\delta = (c/4\pi)h_r/J_c$, where h_r is the tangential component of AC field at the HTS surface S and J_c is the critical current density in ab-plane for field parallel to this plane, and for initial MP samples can be subdivided into two parts: $W = \int_S \mathrm{d}S(\alpha h_r^3 + \beta h_r^2)$. The first part is well-known bulk hysteretic loss within critical state model from which J_c [3] and even its profiles [5] can be determined. In this paper, we consider the second part of W and investigate the effect of surface treatment (polishing) on $W(h)$ dependence. We discuss a possibility for thermal activation through surface barrier and introduce an idea of dynamic surface barrier appearance.

2. Experiment and discussion

Fig. 1 represents the experimental dependence of inverse Q-factor of PM forced oscillations at resonance frequency ω on PM amplitude $A \propto h$. $Q^{-1} = 2\pi W/W_0 \propto W/h^2$, where $W_0 \propto A^2$ is storage energy. Symbols represent the data for the MP HTS sample with polished top surface; dotted line shows $Q^{-1}(A)$ dependence for depolished sample.

To explain the presence of the part of W which is $\propto A^2$, a motion of perpendicular to the surface vortices with an amplitude $s(A)$ was considered. In axially symmetrical configuration $\mathbf{r} = (r, z)$, due to small value of δ, we can say that normal to the surface AC magnetic field component b_z is determined by $h_r(r)$ distribution: $b_z = (1/2\pi r)(\mathrm{d}\Delta\Phi_r/\mathrm{d}r)$, where $\Delta\Phi_r = (cr/4J_c)h_r^2$ is the parallel to surface magnetic flux variation. This is true for $b_z \ll b_r$ which in our case is reinforced by anisotropy:

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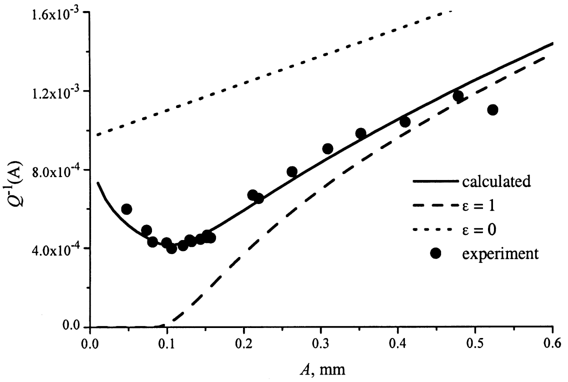

Fig. 1. Inverse Q-factor versus PM amplitude: experimental and calculated data.

$J_c(\mathbf{B}||c) \ll J_c(\mathbf{B}||ab)$. The function $s(r, A)$ can be obtained from the equation

$$rB_z(r) - (r - s)B_z(r - s) = -rb_z(r, A), \quad (1)$$

where $B_z(r)$ is distribution of normal component of "frozen" magnetic field. In such a way we have shown that for HTS with uniform bulk properties both parts of AC loss are related to vortex motion in HTS volume.

By polishing the surface of sample we introduce a surface barrier for flux entry which causes a field jump $\Delta h(B_r)$ in undersurface 'vortex free region' [6]. The influence of Δh on W can be taken into account by substitution $h_r - \Delta h$ instead of h_r and adding the surface loss as it was made by Clem [7]. The function $Q^{-1}(A)$ obtained in such a way is shown in Fig. 1 by the dashed line. So, we can deduce that experimental data show transition from absence of barrier at $A = 0$ to distinguish barrier at $A > 0$, and the first reason which comes to mind here is thermally activated flux penetration over the barrier [8], but it seems to be impossible to describe the experimentally observed barrier disappearence at small A using the relations from [8].

This points to another possible mechanism of suppressing the surface effect at low amplitudes. It is quite natural to expect that the barrier leads to Δh not at whole surface but at its part ε only. The reason for this is nonuniform flux penetration: after a part of vortex or vortex bundle has penetrated into HTS, the further penetration can take place without surmounting the barrier but with vortex propagation along the surface. Fixing vortex velocity the part of vortices that penetrates through barrier can be calculated by energy loss minimizing. We have found: $\varepsilon = (1 + \zeta/h)^{\mu}$, where $\mu = -\frac{1}{2}$ and $\zeta \approx 25$ Oe. Then AC loss

$$W(h) = \varepsilon W(h, \Delta h) + (1 - \varepsilon)W(h, 0). \quad (2)$$

The dependence (2) is represented in Fig. 1 by solid line. Dashed line and dotted line represents the dependencies $W(h)$ for $\varepsilon = 0$ and 1, respectively.

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