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Intragrain magnetic relaxation in the HTSC under variant magnetic field

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We had observed and investigated the effect of viscous motion of the permanent magnet (PM) through the aperture of the granular high temperature superconducting sample (HTSC) by the action of a steady force. We had established a link between the PM velocity and the intragrain magnetic flux relaxation rate and determined the relaxation time.

1. INTRODUCTION

The opportunity to observe the superconductive state under nitrogen temperatures had given researches the chance to use non-contact mechanical methods for investigation of macroscopic magnetic dynamics in HTSC, which involve studying of dynamics of a superconducting sample in the magnetic field or a permanent magnet in the neighborhood of a superconductor. The unique possibilities for HTSC investigation here are accompanied by clear and simple experiment. A number of original results of the pinning and energy loss in the HTSC were obtained in experiments with levitated PM [1], and especially, with PM forced oscillations techniques [2, 3, 4]. Early, we had developed the method of PM resonance oscillations for investigation of inter- and intragrain magnetic flux motion in the granular HTSC [3] and for determine the superconducting volume fraction in these materials [4]. In this paper we describe the effect of viscous motion of the PM through the aperture of the granular HTSC under gravity.

2. EXPERIMENT AND RESULTS

We used the granular Bi-2223 superconductor with T_c = 120 K [3]. Typical dimensions of the component grains were 5–10 μm. This HTSC sample had a through vertical hole of 1.2 cm diameter. The thickness of the HTSC was much more than diameter of its hole. The PM of $SmCo_5$ had mass $m = 0.54$ g and magnetic moment $\mu = 34$ G cm^3. The work temperature was 77 K. In these conditions the PM can levitate above the hole in HTSC as long as is wished.

When we increase the PM mass more than m_0, the PM begins to move through the aperture of the HTSC sample with the constant velocity until it feels the underside of the sample. We had found that this velocity is dependent on the PM mass and is described by the equation

$$v = v_0 \left(\frac{m}{m_0} - 1 \right), \tag{1}$$

where $v_0 = (3.9 \pm 0.1) \times 10^{-2}$ cm/sec, $m_0 = 0.596 \pm 0.005$ g. The maximum magnetic field on HTSC surface was $B_{max} = 150$ G.

3. DISCUSSION

To account for this result we have considered the force between the PM and HTSC:

$$\vec{F} = \int_V (\vec{M}\nabla)\vec{H}\,dV. \tag{2}$$

Here V is the volume of the HTSC sample, $\vec{H}(\vec{r})$ is the field of the PM, $\vec{M}(\vec{r})$ is magnetization of the HTSC volume.

As suggested in our previous papers [3, 4], the granular HTSC at 77 K may be considered as a set of isolated superconducting grains with a density α. On this basis, we can integrate (2) over grains volume where M is the function of H. Taking into account that $\vec{F} = m\vec{g}$, the symmetry of experiment about vertical z-axis, and that elasticity of PM–HTSC system $k = m\omega_z{}^2 = \delta F_z/\delta z$ when intragrain magnetic field $\vec{B} = const$, we have found that

$$v = \frac{\alpha}{m\omega_z{}^2} \int_V \left(\frac{\partial M}{\partial t} \right)_{t=0} \frac{\partial H}{\partial z} dV. \tag{3}$$

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Here ω_z is the resonance frequency of vertical oscillations of the PM, and may be determined in experiment.

It is easily shown that Eq. (3) is similar to Eq. (1) for exponential magnetic relaxation of the type:

$$M(t) = M_0 + \Delta M \exp\left(\frac{-t}{\tau_0}\right), \qquad (4)$$

where $\Delta M = M(t) - M_0$, $M_0 = M(\infty)$ is equilibrium magnetization that is a thermodynamic function, and τ_0 is the character time of the short-time magnetic relaxation [5]. The relation for PM velocity like (1) can easily be obtained from (3) and (4) (the elasticity $m\omega_z{}^2$ do not depend on m):

$$v = \frac{g}{\tau_0 m\omega_z{}^2}(m - m_0), \qquad (5)$$

Comparing Eq. (5) with experimental data (1) and $\omega_z = 24.5$ Hz we have found that $\tau_0 = 1.0 \pm 0.1$ sec. Notice that in deriving of Eq. (5) we anticipated that $\tau_0(H) = const$. The truth of this assumption was proved by experiments with the different PM.

The value of τ_0 agrees with the same time obtained in Ref. [6] from measurements of the exponential magnetic relaxation in Bi-2212 single crystal and is three orders of magnitude more than time of transverse magnetic field penetration into HTSC grains [8]. The last time characterises the intragrain magnetic flux motion [3], and we may deduced that the effect of viscous motion of the PM is determined by very slow magnetic field diffusion through the grain boundaries (flux motion with a very high viscosity that is mach more than an intragrain viscosity) as a consequence of a strong surface pinning. It is in good agreement with the results of our previous paper [3] where we investigated the energy dissipation in HTSC grains in longitudinal and transverse varying magnetic fields [9], and with results of magneto-optical studies [10].

4. CONCLUSIONS

The effect described in this paper have presented with a unique possibility to investigate the magnetic flux motion in the HTSC while the magnetic field varies with time. It allows decreasing the lower limit of the time window of the relaxation measurements that is the well-known problem of the traditional techniques [5].

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