ELSEVIER

Materials Science and Engineering B53 (1998) 174–176

MATERIALS SCIENCE & ENGINEERING B

The investigation of magnetic flux dynamics in the bulk HTS with the levitation techniques

Alexander A. Kordyuk [a,*], Vladimir V. Nemoshkalenko [a], Roman V. Viznichenko [a], Wolfgang Gawalek [b]

[a] *Institute of Metal Physics, Kiev, Ukraine*
[b] *Institut für Physikalische Hochtechnologie, Jena, Germany*

Abstract

We have developed an approach for the calculation of interactions in systems with bulk melt-textured high temperature superconductors (HTSC) and permanent magnets (PM). The non-contact resonance oscillations technique was modified to determine 'under surface' critical currents in these materials. Two parts of the ac energy losses in such HTSC, hysteretic and viscous ones, were separated from their amplitude dependencies. We have shown that the energy losses were largely determined by the magnetic properties of the HTS sample but the elastic properties of a PM–HTSC system are determined from the topology of the superconducting domains.

Keywords: Magnetic flux dynamics; Bulk HTS; Levitation techniques

1. Introduction

The opportunity to use liquid nitrogen as a coolant appeared after the discovery of high temperature superconductors (HTSC) initiated a number of investigations of different systems involving magnetic levitation. Many interesting results about the macroscopic magnetic properties of the HTSC have been obtained [1–3] although the interest in these systems for large scale applications depends on the development of the melt-textured HTSC technology [4,5]. Such large grain HTSC samples and levitation systems prepared by melt processing are actively studied now [6,7]. In previous papers [8–10] we had described the elastic properties of the system where a small permanent magnet (PM) levitated freely above a granular HTSC sample. We had shown that in such a system the granular HTSC at liquid nitrogen temperatures may be considered as a set of small isolated superconducting grains. This enabled the elastic properties of such a system and its damping determined by ac energy losses in the HTSC sample to be predicted. The melt-textured large grain HTSC samples are very different from granular ones with regards their levitation properties. Firstly, they have very strong pinning which results in the absence of PM levitation above the HTSC sample on cooling [8]. Secondly, the small isolated grains approximation cannot work for large grains.

The melt textured and single crystal HTSC with very high pinning approximate closely to ideal type-II hard superconductors. We have applied the image method for calculating of the static and dynamic parameters of the system where a permanent magnet levitates above such a superconductor. We have found the exact analytical solution of the levitation forces and elasticity for the point magnetic dipole over a flat superconductor [11].

In this paper we present the investigation of the ac energy losses in the bulk HTSC samples with a resonance oscillation technique. This technique was developed for the study of the granular HTSC and is described in detail in [8–10]. We used the modified experimental configuration shown in Fig. 1. We determined the amplitude dependencies of PM damping (or reversed Q-factor) to obtain information about energy losses and critical currents. The analytical solution described in [11] was used for checking our calculations at the limit of the point magnetic dipole in the field cooled case.

* Corresponding author.

0921-5107/98/$19.00
PII S0921-5107(97)00322-X

2. Resonance oscillation technique

The main idea is to use the advanced mirror image method [11] to describe in the first approximation, the elastic properties of the PM–HTSC system and magnetic field distribution. The distribution over the HTSC surface was then used to calculate the energy losses and to obtain the values of critical currents from comparison with the experimental data. The critical current value determines the penetration depth of the ac magnetic field component that arises with PM vibrations and makes a contribution to the non-linearity of the PM–HTSC system.

For the melt-textured HTSC where the energy losses have a predominantly hysteretic nature, the feasibility of such an approximation can be determined from the critical state model (the thickness of the layer carrying the critical current J_c must be less than the PM–HTSC distance z_0). For the above configuration:

$$z_0 \gg d = ch(\rho,s)/4\pi J_c, \tag{1}$$

where h is ac magnetic field amplitude at the HTSC surface, c is the velocity of light. This condition is much stronger than is necessary to validate the use of the approach described. Even for $J_c \approx 10^4$ A cm^{-2} and for $h \approx 100$ Oe, the penetration depth $d \approx 0.1$ mm.

In the case of ideal hard superconductors, the ac field component at the superconducting surface $h(\rho)$ is twice that without the superconductor $(\mathrm{d}H/\mathrm{d}z)A$ due to a local shielding current. So, using this approach we can obtain the exact analytical expression for the spatial distribution of the ac magnetic field component $h(\rho)$ [11] in the dipole case and can calculate it numerically in any cases. The surface density of energy loss per period is then $w(\rho) = (c/24\pi^2)h^3(\rho)/J_c$. For a dipole, the full energy loss is:

$$W = k\frac{c}{J_c}\frac{\mu^3}{z_0^{10}}A^3, \tag{2}$$

where z_0 is the distance from the HTSC surface to the PM, $k \approx 0.83$.

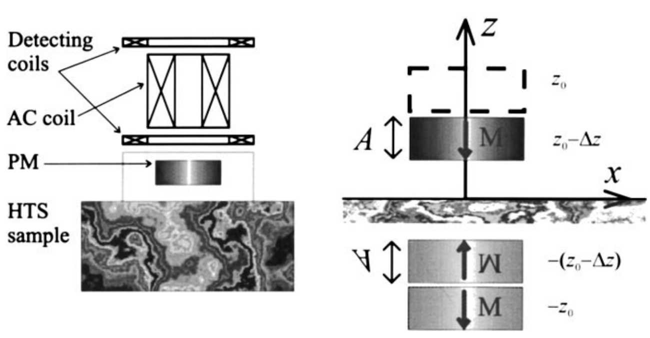

Fig. 1. The experimental configuration.

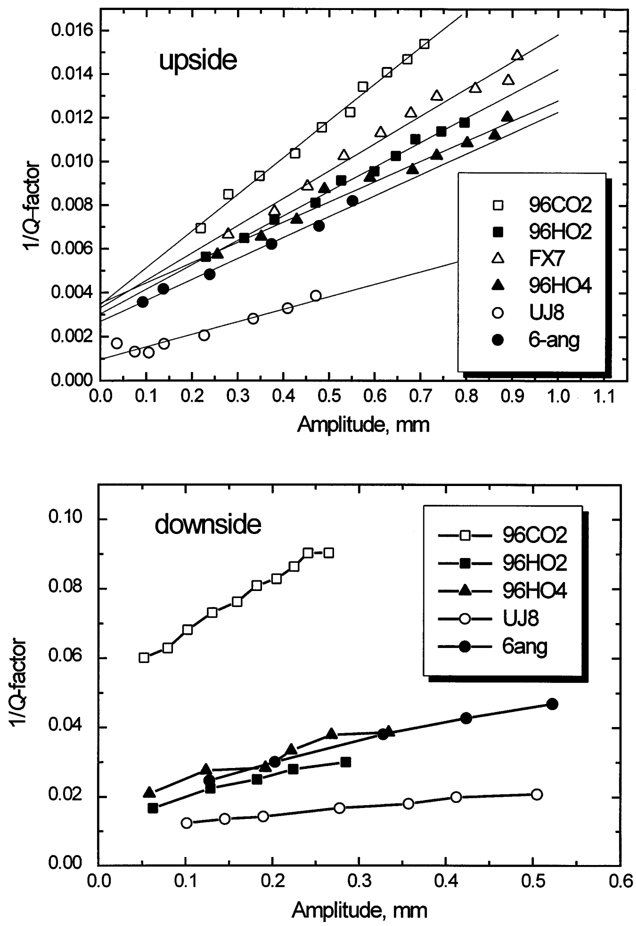

Fig. 2. The experimental values of the reversed Q-factors vs. PM amplitude.

3. Experimental results and discussion

The experimental results are presented in Fig. 2. The linear dependencies for the reversed Q-factor ($Q^{-1} \approx \alpha + \beta A$) mean that energy losses have two conponents: 'viscous' and hysteretic:

$$W = \alpha A^2 + \beta A^3. \tag{3}$$

The first part ('viscous' losses) needs further investigation regarding its frequency dependece. The second component is the well known hysteric loss described by tht critical state model. So, from a comparison of the experimental and theoretical relations, Eq. (2), the value of the critical current can be obtained. For the experimental configuration we used the critical current:

$$J_c = \frac{cI(z_0)}{3\pi^2\beta}, \qquad I(z_0) = \int_S h^3(\rho)\,\mathrm{d}S, \tag{4}$$

where $I(z_0)$ is the integral over the HTSC surface and β is the coefficient in Eq. (3).

The values of the critical currents were obtained for some melt-textured HTSC for the upper and lower surfaces. These are presented in Table 1 with the values of resonance frequencies.

Table 1
Experimental results for upper and lower surfaces of the bulk melt-textured HTSC samples

Sample	$\omega(0)$ (Hz)	Δz (mm)	$Q^{-1}(0)$ (10^{-3})	dQ^{-1}/dA (10^{-3} mm^{-1})	J_c (10^4 A cm^{-2})
96CO2	37.1/32.3	0.19/0.11	3.5/52	16.8/151	1.27/0.15
96HO2	36.9/26.8	0.24/0.37	3.0/14	11.2/59.5	2.08/0.92
96HO4	37.7/29.1	0.31/0.55	3.3/18	9.3/66	2.68/0.94
FX7	34.8/—	0.23/—	3.5/—	12.5/—	2.10/—
UJ8	36.6/27.0	0.13/0.27	1.0/10.4	5.7/21.7	3.49/2.11
6ang	31.2/32.3	0.11/0.48	2.7/18	9.6/56	2.75/0.81

$\omega(0)$, PM resonance frequency; Δz, PM displacement from the initial FC position; $Q^{-1}(0)$ and dQ^{-1}/dA, reverse Q-factor vs. PM amplitude A; J_c, critical current under HTSC surface.

The theoretical value of the resonance frequency for the above configuration is 38 Hz which is in good agreement with the experimental values for the upper surface of the samples. It shows the appropriateness of our calculation technique and indicates that these samples are very close to an ideal hard superconductor. The 'granularity' of the HTSC samples can slightly reduce the PM resonance frequency. Since the energy losses depend on such 'granularity' even less critically than the resonance frequency, the critical current density in the thin layer under the HTSC surface can be determined with a high acuracy.

4. Conclusions

Two components of the ac energy losses in the bulk melt-textured HTSC were found: viscous and hysteretic. The simple non-contact technique we developed gives us the opportunity to determine the 'under surface' critical currents in the bulk large grain samples. It provides high accuracy results for the samples with $J_c > 10^4$ A cm^{-2}. This technique also allows information about the 'granularity' of HTSC samples to be obtained from the resonance frequencies.

References

[1] F.C. Moon, M.M. Yanoviak, R. Ware, Appl. Phys. Lett. 52 (1988) 1534.
[2] E.H. Brandt, Appl. Phys. Lett. 53 (1988) 1554.
[3] R. Grosser, J. Jäger, J. Betz, W. Schoepe, Appl. Phys. Lett. 67 (1995) 2400.
[4] K. Salama, V. Selvamanickam, L. Gao, K. Sun, Appl. Phys. Lett. 54 (1989) 2352.
[5] M. Murakami, T. Oyama, H. Fujimoto, T. Taguchi, S. Gotoh, Y. Shiohara, N. Koshizuka, S. Tanaka, Jpn. J. Appl. Phys. 29 (1990) L1991.
[6] Z.J. Yang, J.R. Hull, T.M. Mulcahy, T.D. Rossing, J. Appl. Phys. 78 (1995) 2097.
[7] T. Sugiura, H. Fujimori, IEEE Trans. Magn. 32 (1996) 1066.
[8] A.A. Kordyuk, V.V. Nemoshkalenko, Appl. Phys. Lett. 68 (1996) 126.
[9] V.V. Nemoshkalenko, A.A. Kordyuk, Low Temp. Phys. 21 (1995) 791.
[10] A.A. Kordyuk, V.V. Nemoshkalenko, J. Supercond. 9 (1996) 77.
[11] A.A. Kordyuk, J. Appl. Phys. 83 (1998) 610.