Relaxation study of RE-123 materials with different types of pinning defects.

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Abstract

The well known fact that the shape of magnetic hysteresis loop (MHL) is closely related with relaxation phenomena, is documented on a wide range of different pinning structures. It is shown that the normalized relaxation rate can be directly calculated from characteristics of the MHL. In the case of known additive contributions to the global moment, the relaxation behaviour is accessible for these individual pinning mechanisms. Thus relaxation studies have exactly the same information value as magnetic hysteresis curves.

Key words: relaxation; high-Tc superconductors; magnetic hysteresis loop;

Shape of magnetic hysteresis loop (MHL) of a type II superconductor is a result of equilibrium among magnetic induction, pinning, and relaxation [1,2]. Quantitatively, the relationship between relaxation behaviour and the size of the hysteresis loop was expressed by Perkins et al. [3]: The normalized relaxation rate, $Q = \partial \ln J/\partial \ln \dot{B}$, is a linear function of the logarithmic susceptibility, $\chi_{\ln} = \partial \ln J/\partial \ln B$,

$$Q = \gamma_{\rm E}(k_{\rm E} - \chi_{\ln}) \tag{1}$$

where $\gamma_{\rm E} = |\partial \ln B_{\max}/\partial \ln E|_{\rm T} = \left|\partial \ln B_{\max}/\partial \ln \dot{B}\right|_{\rm T}$ and $k_{\rm E} = |\partial \ln J_{\max}/\partial \ln B_{\max}|_{\rm T}$ are field independent parameters.

Analysis of a broad range of experimental data on $\mathrm{REBa_2Cu_3O_{7-\delta}}$ (RE-rare earth, RE-123) single crystals and melt-textured samples [3–5] showed that $k_{\rm E} \simeq 1$. Because $\chi_{\ln}(B_{\max}) = 0$, this setting means that $\gamma_{\rm E} = Q(B_{\max})$. Thus the relaxation rate value at $B_{\max}$, together with a single MHL suffice for determination of relaxation properties in the whole field range up to irreversibility field. Moreover, according to Eq. (1), the extremes of $Q(B)$ should coincide with inflection points of the corresponding $J(B)$ dependence. From the Perkins' model it follows that the secondary peak can follow the modified exponential function [6]

$$J(B) = J_{\max} b \exp[(1 - b^{\rm n})/{\rm n}] \tag{2}$$

where $b = B/B_{\max}$ and $J_{\max} = J(B_{\max})$. This function has the logarithmic derivative $\chi_{\ln}(B) = 1 - b^{\rm n}$ and one inflexion point at $b_{\rm inf} = \sqrt[\rm n]{\rm n+1}$. This has the following consequences: $\frac{J(B_{\rm inf})}{J_{\max}} = \frac{B_{\rm inf}}{B_{\max}}{\rm e}^{-1}$; $-\chi_{\ln}(B_{\rm inf}) = {\rm n}$; $Q(B_{\rm inf}) = \gamma_{\rm E}(1+{\rm n}) = Q(B_{\max})(1+{\rm n})$. From Eq. (1) it follows that

$$Q(B) = \gamma_{\rm E} b^{\rm n} = Q(B_{\max}) b^{\rm n}\ . \tag{3}$$

This means that as long as $J(B)$ exhibits a scaling property, i.e. n is independent of temperature, $Q(B)$ scales with temperature, too.

None of equations (2) and (3) describes correctly the experimentally observed behaviour at low fields. This is due to ommitting in the above considerations the central peak contribution. Taking this peak into account [6], $J(B)$ acquires its typical form,

$$J(B) = J_{01}\exp(-\alpha B) + J_{\max} b \exp[(1 - b^{\rm n})/{\rm n}] \tag{4}$$

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and $Q(B)$ exhibits the typical flat wavy character observed experimentally at low fields (see Figs. 1 and 2). It is easy to show that the normalized relaxation rates of the individual terms in Eq. (4) constitute the total $Q(B)$ dependence as

$$Q(B) = Q_1 J_1/J + Q_2 J_2/J \quad (5)$$

where Q_i, $i = 1, 2$, are the relaxation rates of the two terms on the right-hand side of Eq. (4).

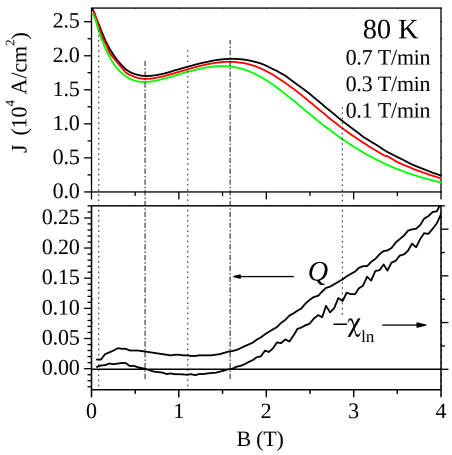

Fig. 1. *J(B) dependence of sample A (upper figure) versus dynamic normalized relaxation rate and logarithmic derivative of J(B),$-\chi_{\ln}(B)$ (lower figure).*

Two melt-textured samples were chosen for illustration, sample A of $(Nd_{0.33}Eu_{0.33}Gd_{0.33})Ba_2Cu_3O_{7-\delta}$ with 30 mol% Gd-211 and sample B, a (Nd,Eu,Gd)-123 compound, with Nd:Eu:Gd=33:38:28 and 5 mol% NEG-211 particles. Both samples of an approximate size 1.5 x 1.5 x 0.5 mm^3 were optimally oxygenated in order to reach T_C over 93 K. Magnetic hysteresis loops were measured by means of a vibrating sample magnetometer with magnetic field aligned along c-axis, at the field sweep rates 0.1; 0.3; 0.7 T/min. Critical current densities were calculated using the extended Bean model for a rectangular sample [8].

In Fig. 1 $\chi_{\ln}(B)$ was calculated from the $J(B)$ curve measured with sweep rate 0.3 T/min and $Q(B) = \Delta \ln J(B)/\Delta \ln \dot{B}$ was obtained from the data measured with 0.7 and 0.1 T/min. The dot-dash vertical lines indicate correlation between extremes of $J(B)$ and the points $\chi_{\ln}(B) = 0$ where, according to Eq. (1), $Q(B) = \gamma_E$. While at the intermediate inflexion point $Q(B)$ reaches its minimum, at the high-field one $-\chi_{\ln}(B_{\inf 3}) =$ n and thus $Q(B_{\inf 3}) = \gamma_E(1+ \mathrm{n})$. We see that at this inflexion point the relaxation rate is (n+1)-times higher than at the top of the secondary peak.

Fig.2 shows that the analysis does not apply only to the combination of a pure central and a pure secondary peak. In sample B, due to twin structure (as proved by an angularly dependent experiment [7]) a plateau appeared on $J(B)$ dependence instead of the dip between central and secondary peak. Though the MHL shape significantly changed, all the above-described features stood well reproduced, only shifted to higher fields. In the region of the plateau Q was constant as indicated by Eq. (1).

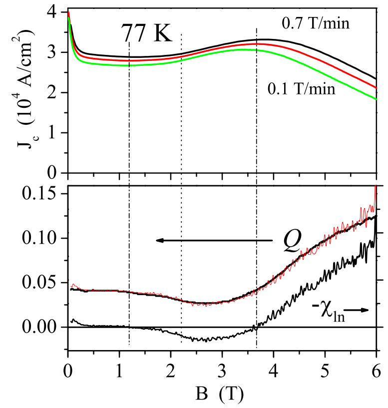

Fig. 2. Correlation of $J(B)$ dependence (upper figure) with $Q(B)$ and $-\chi_{\ln}(B)$ (lower figure) in a twinned sample B.

In summary, we demonstrated that MHL is a dynamic object carrying a full information on relaxation behaviour of the sample. Field-dependent logarithmic relaxation rate, $Q(B)$, and the related information on pinning energy, $U(B)$, thus directly follow from analysis of the MHL shape in the full investigated range and no time-consuming relaxation experiments are needed. This correlation generally works in samples with different pinning structures reflected in different shapes of MHL.

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