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THERMALLY ACTIVATED FLUX CREEP IN VIEW OF SOME RECENT EXPERIMENTS ON YBaCuO AND BiSrCaCuO SINGLE CRYSTALS

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ABSTRACT.

The Anderson - Kim's concept of thermally activated flux creep resulting in logarithmic decay of induced magnetic moment with time is compared with some recent experiments on different HTS single crystals. Relaxation experiments at constant magnetic field and hysteresis loop measurements are analyzed. The non-logarithmic decay of induced magnetic moment with time at sub-second region in YBaCuO and at wide range of times in BiSrCaCuO are examined. Fit of our experimental relaxation data by means of different recently proposed functions of time has not given a decision in favour of any particular model. Probably more relaxation mechanisms are active simultaneously.

1. Introduction

Extremely large time decay of the induced magnetic moment in HTS is usually investigated in the time range 10^{-5} - 10^5 s allowed by technical possibilities of commonly used measuring equipment¹⁻⁵. Many HTS samples, e.g. single crystals of YBaCuO, exhibit in this time interval logarithmic decrease of magnetic moment with time^{2,3}. Anderson's concept of thermally activated flux creep^{6,7} (TAFC) developed for conventional superconductors has been therefore accepted with slight modifications also for HTS⁸. Non-logarithmic magnetic moment decay has been observed in

single crystals of BiSrCaCuO and other materials even at longer times of relaxation⁹⁻¹¹.

Analysis of relaxation processes at short (sub second) times is important for good understanding of the relaxation mechanism. Direct static recording of relaxation is not reliable in this time range due to experimental limits represented by finite time constants of magnet, power supply and magnetometer, and not defined origin $t = 0$ of time scale. Relaxation processes can be, however, analyzed indirectly by reconstruction from set of magnetic hysteresis loops (HL) measured at different rates of sweep $\dot{H} = \delta H_{ext} / \delta t$. This method eliminates above mentioned difficulties of direct measurement: (i) smooth sweep with constant \dot{H} can be performed even on magnets with larger time constant, (ii) magnetic moment is not changing much on hysteresis loops and so the effect of finite magnetometer time constant is small and can be further simply minimized by proper data processing, and (iii) determination of corresponding t_{eff} from other parameters⁴ is possible even for very short t_{eff} .

In this paper we compare experiments of magnetic moment time relaxation at constant magnetic field H_{ext} (conventional relaxation) with analysis of hysteresis loops measured at different sweep rates \dot{H} (loop relaxation)^{4,5}.

2. Model

Size of HL in HTS depends on the value of sweep rate: the higher is \dot{H} the larger is the induced magnetic moment m . In sweeping magnetic field relaxation decay $\partial m / \partial t$ is just compensated by magnetic induction due to \dot{H} characterized by the differential susceptibility χ ¹² as $\partial m(t) / \partial t = \chi \dot{H}$, where $m(t)$ is a function describing the time relaxation of m at constant H_{ext} . Therefore HL measured at constant \dot{H} can be interpreted as a frozen state of relaxation. For each HL we can evaluate some value of effective time t_{eff} interpreted as the time of conventional relaxation $m(t)$ necessary to reach the same value of m . A set of HL recorded with

different \dot{H} enables indirect reconstruction of the process of relaxation down to very short times. In the case of pure logarithmic decay⁶

$$m(t) = m_1 + S \ln(t) \quad (1)$$

we can evaluate corresponding effective time simply as⁴ $t_{eff} = S / (\chi \dot{H})$. Similarly we can evaluate for each time t of conventional relaxation corresponding sweep rate $\dot{H} = S / (\chi t)$.

Besides Anderson's model⁶ also several alternative models has been reported with different analytical functions $m(t)$ for the time relaxation. Power function for logarithmic conical potential well^{10,13} yields

$$m(t) = a_1 + b_1 t^{-\beta} \quad (2)$$

The 'power' logarithm resulting from the glass model^{14,15} corresponds to

$$m(t) = a_2 / [1 + b_2 \ln(t)]^\mu \quad (3)$$

Magnetic relaxation can be also described by the phenomenological function¹¹

$$m(t) = a_3 + b_3 \ln[\ln(1+t/t_0)] \quad (4)$$

3. Results and discussion

Induced magnetic moment was measured by vibrating sample magnetometer on single crystals of YBaCuO and BiSrCaCuO ($T_c = 82.5$ K) in temperature range 7K - 44 K in fields between ± 2 T. Experimental results for $T = 16$ K are shown in Figures 1 and 2 as a function of \dot{H} . Magnetic moment measured by both methods well overlaps in the common range of \dot{H} or time t .

Decay of magnetic moment m at all analyzed temperatures in YBaCuO is well logarithmic at longer times ($t > 100$ s \leftrightarrow $\dot{H} < 2$ Oe/s), but relaxes more rapidly at short times (high sweep rates, Fig. 1). This effect was also recently observed in pulse and ac measurements^{16,17}.

Though any of the time functions Eq.2 - Eq.4 fits well experimental data at longer times, relaxation at short times

can be fitted only by power function Eq.2 and dependence Eq.4.

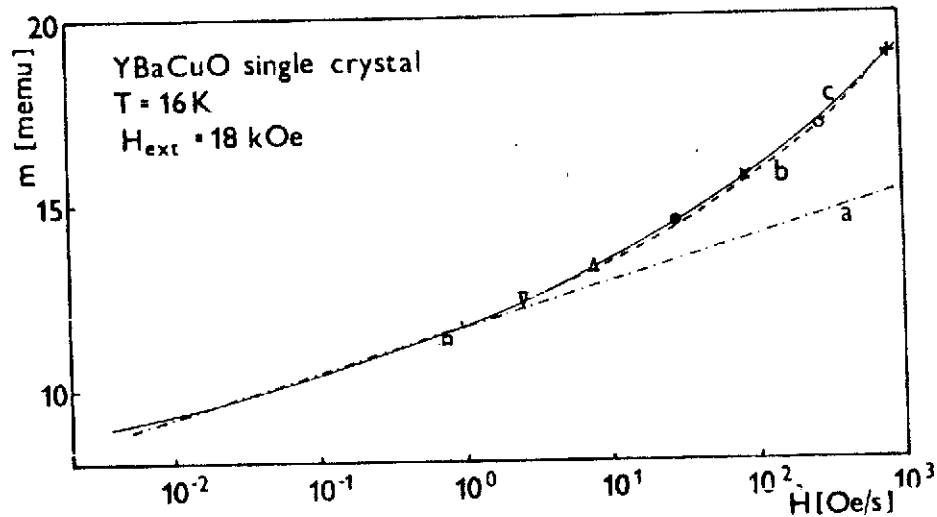


Figure 1: Plot of $m(H)$ representing magnetic moment relaxation measured: (i) at $H_{ext} = \text{const.}$ (left side) and (ii) at $\dot{H} = \text{const}$ (hysteresis loops) - marks +, o, x, e, Δ , ∇ and \square corresponding to $\dot{H} = 816, 290, 89, 29, 8.7, 2.3$ and 0.8 Oe/s, respectively. Sample area 2.12 mm^2 , a-b plane, thickness $30 \text{ }\mu\text{m}$, $\chi = -0.036 \text{ memu/Oe}$, penetration field for high H is $H^* = 3.2 \text{ kOe}$. Curves a to c are the best fits of Eqs. 1, 2, 4, respectively.

Our experiments on BiSrCaCuO single crystals exhibited a pronounced nonlogarithmic time dependence, Fig. 2, even in the region of conventional relaxation and only Eqs. 2 and 4 fit the experiment well.

Fitting parameters of all used functions are in Table 1. Detailed study of the dependence of fitting parameters on temperature and magnetic field is underway.

Table 1. Parameters of fitting functions, Eqs. 1, 2 and 4.

	m_1	S	a_1	b_1	β	a_3	b_3	t_0
123	13.04	-0.52	6.60	7.99	0.152	21.30	-4.99	0.02
2212	---	---	-21.6	77.90	0.130	129.8	-49.00	0.0105

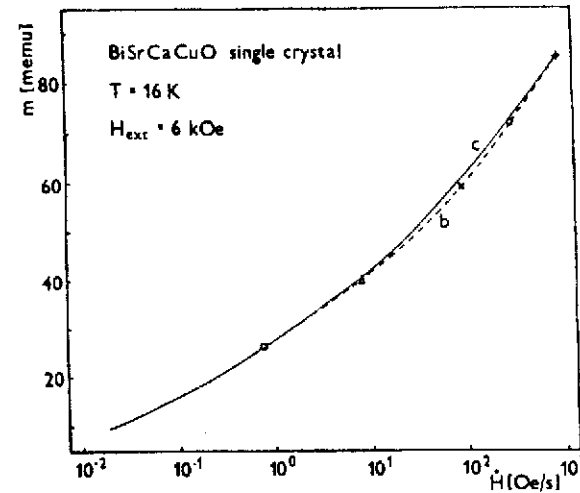


Figure 2: The same as in Fig.1 for BiSrCaCuO single crystal ($T_c = 82\text{K}$), $\chi = -0.183 \text{ memu/Oe}$. Marks +, o, x, Δ and \square correspond to $\dot{H} = 870, 290, 89, 8.7$ and 0.08 Oe/s, respectively. Curves b and c correspond to fitting functions Eq.2 and 4.

The presented experiments indicate that the Anderson's model of TAFC describes the relaxation processes only under certain conditions and even then only at longer relaxation times. At the beginning of relaxation the decay rate of magnetic moment is faster than extrapolated logarithmic dependence from long time range. It may be due to a different mechanism of relaxation (collective flux pinning¹⁸, flux motion under viscous forces¹⁹, gradual activation of pinning sites with different pinning strengths with time²⁰). Their identification is difficult as experimental data can be well fitted by different expressions.

Flux line dynamics at very short times corresponds more likely to flux flow than to flux creep.

In such samples as Bi-based single crystals the situation is further complicated by a strong dependence of irreversible magnetization on magnetic field. This leads in connection with low effective pinning energy to the rapid melting of flux lattice, namely at higher fields and temperatures.

5. References

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