

Proceedings of the 7th International Workshop on

CRITICAL CURRENTS IN SUPERCONDUCTORS

Alpbach, Austria 24 – 27 Jan 1994

Editor

Harald W. Weber

Atominstitut der Österreichischen Universitäten
Wien, Austria



World Scientific

Singapore • New Jersey • London • Hong Kong

APPARENT PARAMAGNETIC MOMENTS MEASURED BY VSM ON YBaCuO THIN FILMS

D. DLOUHÝ^{a,b}, L. PŮST^a, M. JIRSA^a, V. GREGOR^a

^a*Institute of Physics, Academy of Sciences of the Czech Republic,
Na Slovance 2, CZ-180 40 Praha 8, The Czech Republic*

^b*Faculty of Nuclear Physics and Physical Engineering, Czech Technical University,
V Holešovičkách 2, CZ-180 00 Praha 8, The Czech Republic*

ABSTRACT

Magnetic hysteresis loops (MHL) were studied on YBaCuO thin films with external field perpendicular to the film plane by a vibrating sample magnetometer. MHLs are symmetrical at high field sweep rates, but they exhibit a large paramagnetic (positive) moment offset at low sweep rates. Appearance of the paramagnetic moment offset is also illustrated by relaxation measurements. Origin of this effect is probably related to slight inhomogeneity of magnetic field in the position of the vibrating sample.

1. Introduction

Detailed study of magnetic hysteresis loops (MHL) recorded at various rates of field sweep (the dynamic relaxation - DR) gives important characterization of the vortex relaxation processes^{1,2}, complementary to the conventional relaxation (CR) at constant magnetic field. The value of magnetic moment m at external field B on MHL recorded with sweep rate dB/dt is the same as the value of m at such time of CR when the relaxation rate dm/dt is equal to $(\chi_0 \mu_0)(dB/dt)$ ¹. χ_0 is the low-frequency (differential) susceptibility. This straightforward mutual relation between DR and CR measurements enables to extend range of studied relaxation processes in vortex lattice to fast relaxations corresponding to DR. For majority of superconducting thin films the equilibrium magnetic moment m_e is negligibly small in comparison to the irreversible m induced by changing B .

In this paper we present results of MHL measurements using vibrating sample magnetometer (VSM) with conventional 11 inch magnet obtained on various superconducting thin films (TF) which significantly deviate from the "regular" behaviour. In certain temperature range these samples exhibit symmetrical MHLs (B perpendicular to the film plane) for higher sweep rates while at slow sweep rates MHLs are not only narrower but, in particular, considerably shifted to paramagnetic (positive) values (typically for $dB/dt < 1$ mT/s). By positive magnetic moment we understand moment parallel to the magnetic field.

2. Experimental

Epitaxial YBa₂Cu₃O_{7-x} thin films were grown by magnetron sputtering on Y:ZrO₂ substrate with (100) orientation. In this paper we present data obtained on two thin films A and B prepared by similar procedure with thickness between 200 and 300 nm and c-axis well oriented perpendicular to the film plane. Similar behaviour has been observed on several TF prepared on various substrates and by different methods. Samples were cut in

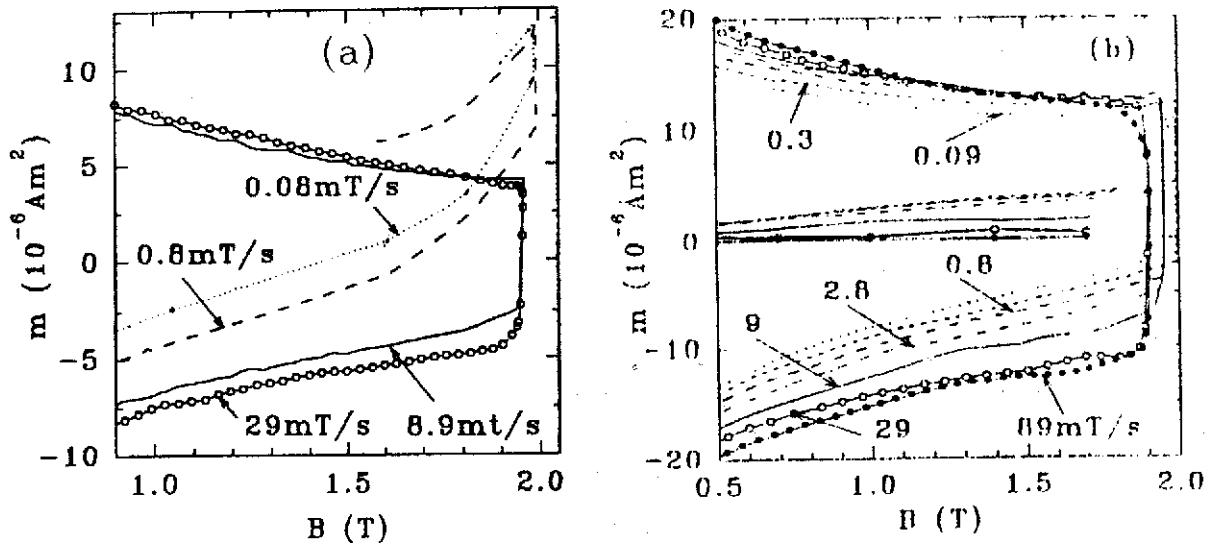


Figure 1: Magnetic hysteresis loops measured (a) on sample A at 65 K and (b) on sample B at 50 K at various rates of field sweep. The mean value of magnetic moment $m_p = (m^+ + m^-)/2$ at various rates of sweep are also plotted in figure b.

the shape of squares 5x5 mm. Differential susceptibility of these samples with magnetic field perpendicular to the film plane is very high, $\chi_0/\mu_0 = \Delta m/\Delta B \approx 60 \text{ mm}^3$. Measurements were performed on the vibrating sample magnetometer PAR-155 with Newport Instruments 11 inch electromagnet type F with fields up to ± 2 T.

In Figure 1a we see MHLs recorded on sample A at various dB/dt between 89 and 0.1 mT/s at $T = 65$ K. At very low dB/dt MHL were recorded only in short field intervals because of long time of such measurements. Set of MHLs recorded at $T = 50$ K on sample

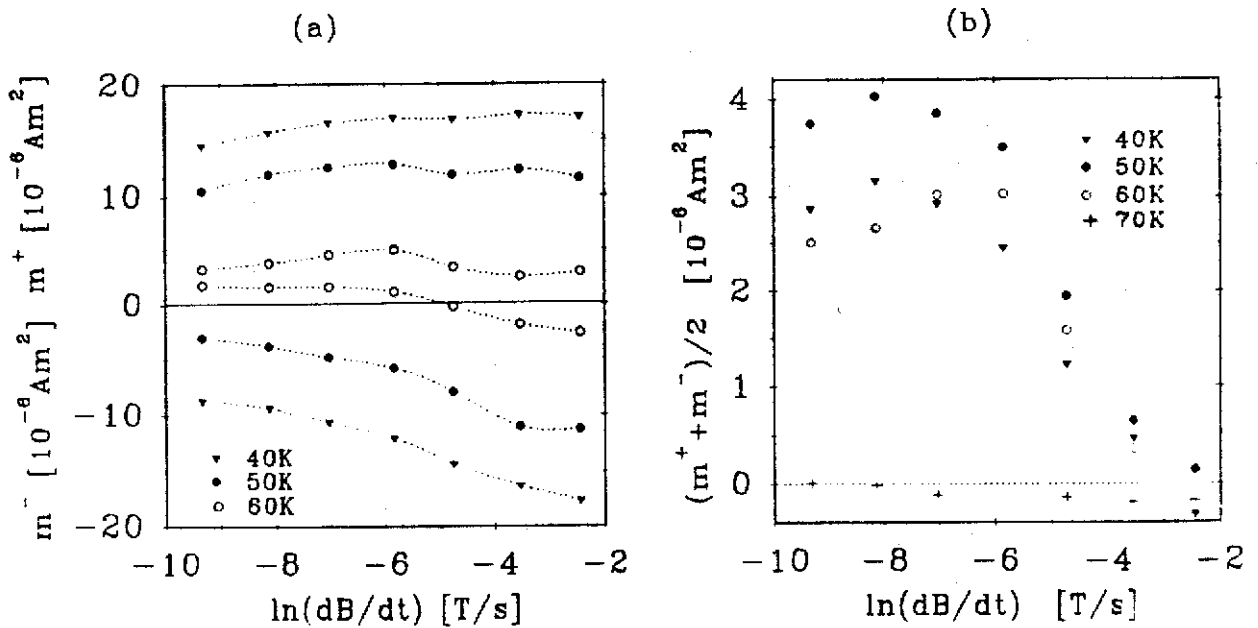


Figure 2: (a) The dependence of the magnetic moment values m^+ and m^- at $B = 1.8$ T on lower and upper branches of MHL plotted as function of the field sweep rate dB/dt on sample B at $T = 60$ K. (b) The mean magnetic moment value $m_p = (m^+ + m^-)/2$ plotted in the same way.

B is plotted in Figure 1b. On both samples we see that at slow sweep rates both branches of MHL are considerably shifted to positive values of m at higher magnetic fields B , while MHLs are symmetrical with respect to the field axis for high sweep rates.

The moment values m^+ and m^- on upper and lower branches of MHL, respectively, are in Figure 2a. They are measured at several temperatures on sample B at various dB/dt and evaluated at $B = 1.8$ T. At medium sweep rates the paramagnetic offset (PO) just appears and at even slower sweep rates PO "saturates".

To characterize PO we use the mean value $m_r = (m^+ + m^-)/2$. The dependence of m_r on $|dB/dt|$ is plotted in Figure 2b. We see that m_r is close to zero at higher rates of field sweep

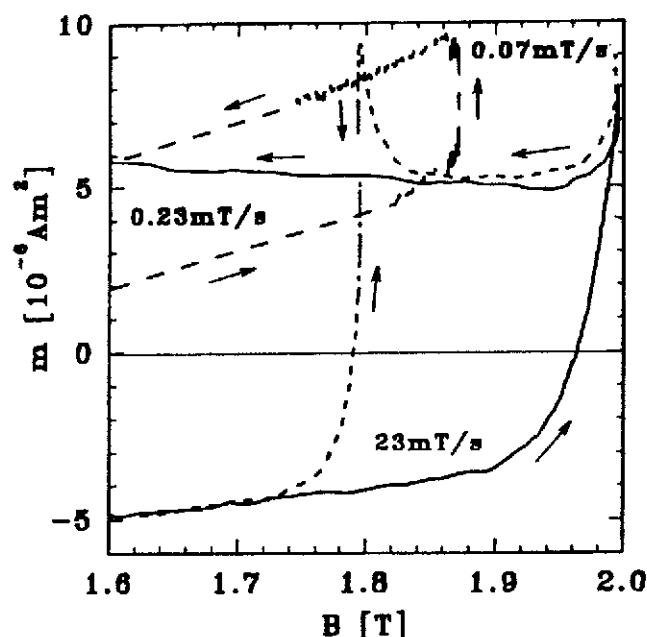


Figure 3: Relaxation of the magnetic moment after stop of field sweep at $B = 1.8$ K from both low and high fields. For comparison MHLs at low and high sweep rates are plotted along with both relaxation curves.

(typically for $dB/dt > 30$ mT/s), while m_r is considerably high and positive at slow sweep rates. The dependence of $m_r(dB/dt)$ saturates at low sweep rates $dB/dt < 1$ mT/s.

Unusual dependence of m_r with dB/dt is also well illustrated by relaxation measurements in Fig. 3. During stopping of fast decreasing field sweep m^+ first increases as PO appears and later m relaxes towards lower values while relaxation of m^- generated by preceding increasing field is large monotonous and even changing sign.

Signal pickup coils of the VSM were geometrically centred between magnet pole faces and

before each measurement the sample was placed in the saddle point of the signal pickup coils with accuracy about ± 1 mm. To check the effect of homogeneity of the external magnetic field we also measured PO at slow field sweep rates with sample at various positions slightly out of the saddle point of signal pickup coils by only a few mm where the magnitude of measured moment changes only very little. We have observed strong dependence of PO on the sample position, while the minimum PO with nearly symmetrical MHL was found with sample about 3 mm from the saddle point.

3. Discussion and Conclusions

We have observed in limited range of temperatures and fields apparent paramagnetic positive magnetic moments on various thin YBaCuO films. PO of MHL depends strongly on the field sweep rate. In high dB/dt ($> \approx 30$ mT/s) we have symmetrical MHLs and $m_r = (m^+ + m^-)/2 \approx 0$. In lower dB/dt PO appears and consequently we have large positive

m_r . Magnitude of PO characterized by $m_r(dB/dt)$ saturates at slow sweep rates ($dB/dt < 1$ mT/s). This transition (i.e. appearance of PO) can be also illustrated by relaxation measurements. PO can be observed independently on preceding field history (i.e. after both increasing or decreasing magnetic field), see Fig. 3.

Our results are partly similar to the Paramagnetic Meissner Effect (PME)³⁻⁴, i.e. the spontaneous superconducting currents yielding paramagnetic moment. All measurements published so far report observation of the PME only at low magnetic fields.

Origin of PO of MHL measured by VSM on YBaCuO TF is clearly indicated by the strong dependence of PO on position of sample in the magnet, when also homogeneity of magnetic field changes. Close relation of PO to homogeneity of the bias magnetic field in which sample vibrates is also supported by increasing PO at higher magnetic fields (see Fig. 1) where conventional electromagnet is close to saturation and homogeneity of magnetic field decreases. Similar interpretation of apparent positive magnetic moments was published by Blunt⁵. They explained positive magnetic moments measured on sintered HTS samples in QD SQUID magnetometer as a consequence of moving sample in inhomogeneous superconducting magnet.

Our measurements indicate, that the most homogeneous magnetic field in our magnet is probably about 3 mm from the geometrical centre of the magnet poles and this difference is mainly responsible for measured apparent positive offset of MHL.

Strong dependence of the apparent positive moment on field sweep rate $dB(t)/dt$ can be explained qualitatively by time dependent magnetic field $B_{vs}(t)$ experienced by the vibrating sample. In constant or slow sweeping external field $dB_{vs}(t)/dt$ changes sign while at high sweep rates of external magnetic field sample experiences monotonously changing magnetic field $B_{vs}(t)$. However, detailed explanation of processes in vibrating thin film is not clear yet. Is it necessary to take into account the nonlinear field inhomogeneity? Further detailed study of induced currents in thin films in small oscillating fields is necessary.

Acknowledgement

We are grateful to P. Svedlinh, P. Nordblad and L. Kraus for valuable discussions and to J. Smoliková for technical assistance. This work was partly supported by grants no. 19060 of GA ASCR and no. 202/93/0669 of GACR.

References

1. L. Püst: Superc. Sci. Technol. 5 (1990) 497.
2. M. Jirsa, L. Püst, H. G. Schnack, R. Griessen: Physica C 207 (1993) 85.
3. W. Braunisch et al., Phys. Rev. B 48 (1993) 4030.
4. D. Khomskii, J. Low Temp. Phys., in print.
5. F. J. Blunt, A. R. Perry, A. M. Campbell, R. S. Liu, Physica C 175 (1991) 539.