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

THE ANOMALOUS PEAK IN THE MAGNETIZATION CURVES OF HIGH-T_C SUPERCONDUCTORS: A STATIC OR A DYNAMIC EFFECT?

Y. YESHURUN, E. R. YACOBY, L. KLEIN, L. BURLACHKOV, R. PROZOROV
Department of Physics, Bar-Ilan University, 52900 Ramat-Gan, Israel

N. BONTEMPS
Laboratoire de Physique de la Matière Condensée, Ecole Normale Superieure, 24 rue Lhomond, 75231 Paris Cedex 05, France

H. WÜHL
Kernforschungszentrum Karlsruhe, Institut für Technische Physik, 76021 Karlsruhe, Germany

and

V. VINOKUR
Material Science Division, Argonne National Laboratory, Argonne, IL 60439, USA

ABSTRACT

We studied the dynamics of the anomalous second peak ('fishtail') in the magnetization curves of Y-Ba-Cu-O (YBCO) and Bi-Sr-Ca-Cu-O (BSCCO) crystals and attempted to extrapolate the data back to time t=0. Our analysis implies that the anomaly in YBCO is of static origin whereas in BSCCO the anomaly is absent at t=0. We discuss this apparent difference and propose that it may be a result of the difference in the effective time scales for relaxations in these materials.

Numerous recent reports[1-5] describe an anomalous increase in the width of the magnetization loops of high-temperature superconductors (HTS) with the increase of the external magnetic field H. The anomalous shape of the magnetization curves M(H) has been coined a 'fishtail'. The critical current $J_c(H)$, being proportional to the width ΔM of the magnetization curves, also shows an anomalous dependence on field: J_c decreases with the increase of the field up to $H=H_{min}$. It then curves upward, up to a field $H=H_{max}$, above which J_c decreases monotonously with the increase of the field.

The explanations for the fishtail may be divided into 'static' and 'dynamic' classes according to their (implicit) prediction of the behavior at the shortest time scale, $t \rightarrow 0$. The static approach attributes the anomaly to, e.g., oxygen-deficient superconducting areas, which become effective in higher fields due to suppression of the order parameter.[1] In this approach the anomaly should be present already at t = 0. In the dynamic approach the magnetization curves do not exhibit any anomaly in the short time scale. The anomaly is a result of slower decay of the magnetization in the field range where the peak is observed.[3] In this paper we summarize the results of our measurements of the anomalous magnetization curves in BSCCO[4] and in untwinned YBCO[5] crystals. In both studies we focused on the dynamic properties of the magnetization. We studied magnetization curves at various time windows and attempted to extrapolate the data to t=0.

The main results for BSCCO crystal: (i) The anomalous peak disappears gradually with time between 20 and 40 K. (ii) At lower temperatures (18 K) the peak is absent in the short time limit but it is gradually built up with time. (iii) A smooth 'universal' function relates the magnetization at H_{min} with that at H_{max} for all measured temperatures

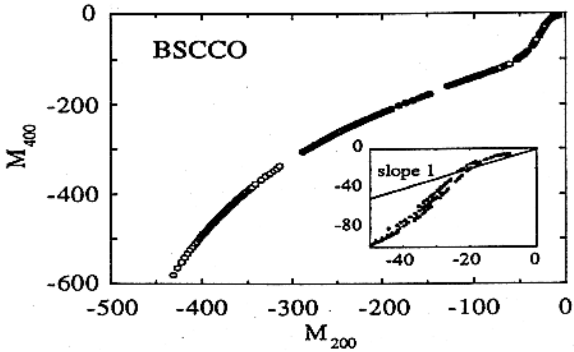

Figure 1. The magnetization at H_{max} (M_{400}) vs. the magnetization at H_{min} (M_{200}) for 15 isotherms starting at 15 K at the bottom left of the figure. Inset: Isotherms between 21 K and 43 K. The shortest possible time is at the bottom left of each isotherm. The anomaly is made apparent by the solid line ("slope 1") above which $M_{400} > M_{200}$.

and fields, and at any given time. This universal curve is described in Fig. 1 which includes data points for 15 isotherms (15-41 K) and time scales from 80 to 9000 s. Moving along the universal curve from points at the upper-right corner to points at the bottom-left, is equivalent to either reducing temperature or reducing time. Thus, the absence of the anomaly in the low-temperature limit is equivalent to the absence of such anomaly at t=0.

Our study of the dynamics in YBCO yields the opposite conclusion. In this study we failed to find a reasonable scaling behavior for $M(H_{min})$ vs. $M(H_{max})$. This failure is probably related to the fact that the H_{min} and H_{max} (unlike the situation in BSCCO) depend on temperature and time. We therefore tried a different approach: We plot the effective pinning force $F_p = J_c x H$ vs. H for various isotherms and time scales. These curves present a well defined peak at H_{peak}. We then scale the pinning force by $F_p(H_{peak})$ and the field by H_{peak}. As a result of this procedure all the data (6 isotherms between 79 and 86 K, fields up to 1.6 T and time scales ranging from 4 to 1500 s) collapse into a single curve. Typical scaled data is described in Fig. 2. The change in the slope of this function (larger or smaller than 1) reflects the observed peak effect. The fact that the functional form of the pinning force does not depend upon the time scale seems to imply that dynamics is not essential. To further support this conclusion we show in Fig. 3 the ascending branch of the magnetization together with the measured normalized relaxation rates. For the dynamic interpretation[3] one would naively expect the field dependence of relaxation rate to be a "mirror image" of the anomaly in ΔM namely, that a maximum relaxation rate corresponds to H_{min}. This is not borne out in the experiment.

In view of the different experimental field-temperature characteristics of the anomaly in BSCCO and YBCO, it is quite plausible that their origin is indeed different. However, we propose here a preliminary alternative approach which relates the fishtail in both HTS systems to the dynamics. In this approach, J_c and ΔM do not show an anomaly at time t=0. The anomaly, which is observed during the experimental time window, is a result of slower relaxations in the field regime where the creep is controlled by thermal activation of pinning bundles. This activation energy grows with the increase of the field and thus relaxation is suppressed. Therefore, larger ΔM is expected in higher fields, giving rise to

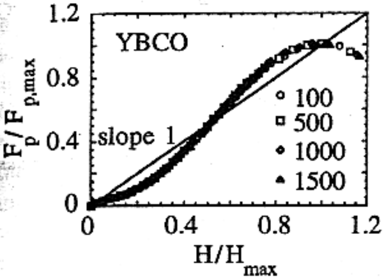

Figure 2. The rescaled density of the pinning force as a function of the reduced field, for the indicated time scales.

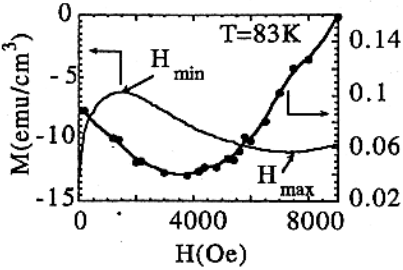

Figure 3. The ascending branch of the magnetization (light line) and the normalized relaxation rates (bold) as a function of field at 83 K.

the apparent anomaly. We stress that the anomaly appears when the measured $\Delta M = J$ is much smaller than the critical current J_c expected at t=0. The relaxation is a function of t/τ where τ is a time scale for pronounced activated relaxations. As noted by Blatter et al.,[6] τ is a macroscopic rather than a microscopic time scale and it is inversely proportional to the collective pinning activation energy U_c. The energy U_c is determined by $T_c\{(J_c/J_o)/Gi\}^{1/2}$ where Gi is the Ginzburg parameter and J_o is the depairing current. Recalling that for YBCO J_c/J_o is larger whereas Gi is smaller, we conclude that τ(YBCO) < τ(BSCCO). The **experimental** time scale t is similar for YBCO and BSCCO but the **effective time scale** t/τ is much smaller for BSCCO. Thus, for BSCCO the experiment takes place on time scales which are effectively closer to $t/\tau = 0$. This explains our ability to observe the growth of an anomaly for BSCCO at T = 18 K. It also explains the success of the extrapolation of the scaled data (Fig. 1) to reflect the t=0 behavior. For YBCO, on the other hand, because of the small τ, t/τ is large, the data is concentrated in a regime which is far away from t=0, and thus, the extrapolation to this time cannot reflect the true behavior. Pursuing this approach to explain Fig. 3 we propose that the maximum relaxation rate corresponds to H_{min} at effective earlier times. On the other hand, at later times the anomaly (at H_{max}) should gradually disappear and therefore the normalized relaxation rate, measured in this 'late' time window, cannot be the mirror image of the anomalous fishtail.

This work is supported by Grant No. I-0210-206.07 from G.I.F., the German-Israeli Foundation for Scientific Research and Development.

References

1. M. Daeumling, J. M. Seuntjens, and D. C. Larbalestier, Nature **346** (1990) 332.
2. V. N. Kopylov et al., Physica **C170** (1990) 291; N. Chikumoto et al., Physica **C185-189** (1991) 2201; N. Chikumoto et al., Phys. Rev. Lett. **69** (1992) 1260; T. Kobayashi et al., Appl. Phys. Lett., **62** (1993)1830.
3. L. Krusin-Elbaum et al., Phys. Rev. Lett. **69** (1992) 2280.
4. Y. Yeshurun et al., Phys. Rev. **B49** (1994) 1548.
5. L. Klein et al., Phys. Rev. **B49** (1994) 4403.
6. M. Feigelman et al., Phys. Rev. **B43** (1991) 6263; V. Vinokur et al., Phys. Rev. Lett. **67** (1991) 915; For a review see G. Blatter et al., Rev. Mod. Phys., in press.