ELSEVIER

Physica C 341–348 (2000) 2045–2046

PHYSICA C

www.elsevier.nl/locate/physc

Magnetic behavior of thin superconducting disks with B-dependent J_c

D. V. Shantsev[a,b], Y. M. Galperin[a,b], and T. H. Johansen[a]

[a]Department of Physics, University of Oslo, P. O. Box 1048 Blindern, 0316 Oslo, Norway
[b]A. F. Ioffe Physico-Technical Institute, Polytekhnicheskaya 26, St.Petersburg 194021, Russia

The ac susceptibility, $\chi = \chi' + i\chi''$, of a superconducting thin disk in a perpendicular magnetic field is calculated in the critical-state model assuming a field-dependent critical current, $J_c(B)$. We find both analytically and numerically that the asymptotic behavior at large ac-field amplitudes B_{am} changes from $\chi' \propto B_{am}^{-3/2}$ and $\chi'' \propto B_{am}^{-1}$ for the Bean model, to $\chi' \propto B_{am}^{-3}$ and $\chi'' \propto B_{am}^{-2}$ for J_c decreasing with $|B|$ as $|B|^{-1}$ or faster. In the parametric $\chi''(\chi')$ plot the peak of χ'' increases in magnitude and shifts toward $\chi' = 0$. This allows an easy experimental discrimination between a Bean model behavior, one with $J_c(B)$, and one where flux creep is an ingredient. Account of the B-dependence of J_c improves substantially agreement with available experimental $\chi''(\chi')$ data.

During the last years much attention has been paid to the critical state model (CSM) analysis of thin samples in perpendicular magnetic fields. Within the Bean model, the magnetic behaviour of a long thin strip [1] and a thin circular disk [2] has already been thoroughly investigated. However, an analysis of thin samples with a field-dependent critical current, $J_c(B)$, has so far been restricted to calculation of flux distributions and magnetization loops [3,4]. In this work we calculate complex ac susceptibility for a thin disk with B-dependent J_c. The results are compared with similar results for long samples in a parallel field [5], with results of flux creep simulations [6] and with experimental data [7].

We consider a thin superconducting disk of radius R and thickness d, where $d \ll R$. A set of integral equations derived in [4] is solved numerically to obtain the field and current density distributions for a given applied field B_a. Repeating this procedure for different B_a we calculate the magnetization hysteresis loops $M(B_a)$. The ac susceptibility $\chi = \chi' + i\chi''$ is then determined by the first coefficient of the Fourier series of $M(t) = M[B_a(t)]$ for oscillating applied field $B_a(t) = B_{am} \cos \omega t$.

The most dramatic change of the $\chi(B_{am})$ behavior due to a B-dependence of J_c is found at large B_{am}. For the real part, χ', we find a power-law behavior with different exponents for different $J_c(B)$-dependences ranging from -3/2 (for the Bean model) to -3, see Fig. 1. This asymptotic power-law behavior can also be obtained analytically. We find that if $J_c \propto |B|^{-s}$ at large $|B|$, then

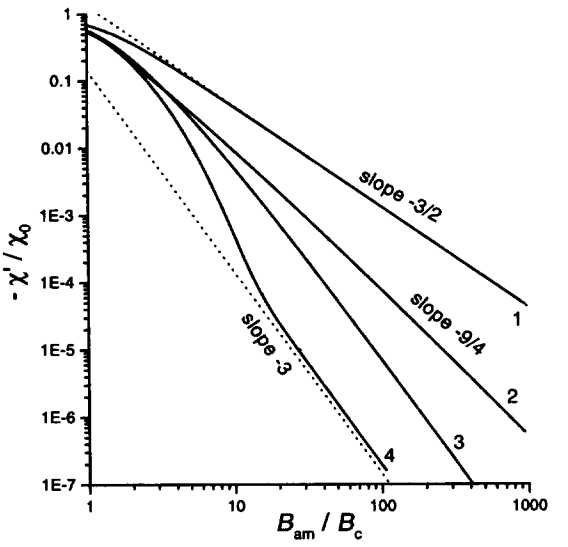


Figure 1. High-field behavior of the real part of the susceptibility normalized to the Meissner state value $\chi_0 = 8R/3\pi d$: (1) the Bean model; (2) $J_c = J_{c0}/(1 + b^{1/2})$; (3) $J_c = J_{c0}/(1 + b)$; (4) $J_c = J_{c0}\, e^{-b}$, where $b = 2|B|/3\mu_0 J_{c0}$.

0921-4534/00/$ – see front matter © 2000 Elsevier Science B.V. All rights reserved.
PII S0921-4534(00)00993-X

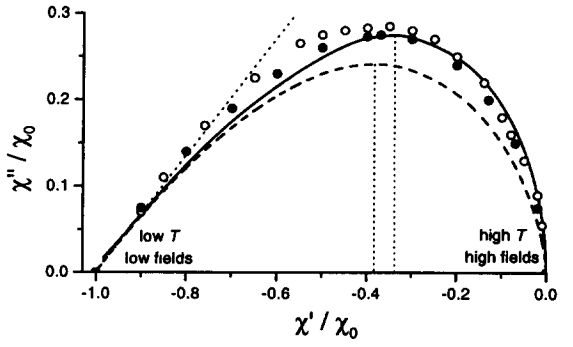


Figure 2. Parametric $\chi''(\chi')$ plot for the Kim model, $J_c = J_{c0}/(1+2|B|/3\mu_0 J_{c0})$ (full line) and for the Bean model (dashed line). Symbols show experimental susceptibility data from [7].

$$\chi'' \propto \chi'^{2/3} \propto \begin{cases} B_{am}^{-1-s}, & s < 1 \\ B_{am}^{-2}, & s > 1 \end{cases} \quad (1)$$

It should be emphasized that this result holds true not only for a thin disk but also for *any geometry* of the superconductor.

A very convenient way to analyze ac susceptibility data is to consider a $\chi'(\chi'')$ parametric plot, see Fig. 2. For the Bean model the χ'' has a maximum value of 0.24 at $\chi' = -0.38$, while for a B-dependent J_c the χ'' peak increases in magnitude and shifts towards $\chi' = 0$. Also, the high-field part of the plot is strongly modified. Meanwhile, the asymptotic behavior at low fields, $\chi''/\chi_0 = 32/15\pi(1+\chi'/\chi_0)$ (dotted line) remains unchanged for *any* $J_c(B)$. These results are qualitatively similar to those for long samples in parallel field [5]. It can also be seen from Fig. 2 that the curve calculated for a B-dependent J_c provides a much better agreement with available experimental data [7].

It is interesting to compare our $\chi''(\chi')$ plots to the ones obtained by calculations based on a nonlinear current-voltage curve, $J \propto E^{1/n}$, $n < \infty$. Shown in Fig. 3 together with the CSM results is a $\chi''(\chi')$-curve (dotted line) drawn in accordance to typical graphs presented in [6]. In contrast to the effect of having a B-dependent J_c,

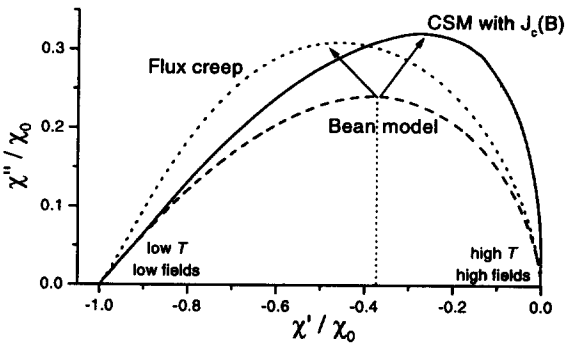


Figure 3. The behavior of $\chi''(\chi')$ for various models. The Bean model predicts a peak located at $\chi' = -0.38$. A B-dependence of J_c shifts the peak to the right and changes the behavior at $\chi' \to 0$ (our results), while flux creep shifts it to the left and changes the behavior at $\chi' \to -1$ (Ref. [6]).

the χ'' peak shifts here towards $\chi' = -1$ and the slope at $\chi' \to -1$ becomes significantly steeper. Thus, an analysis of the $\chi''(\chi')$ plot allows one to discriminate between a Bean model behavior, one with $J_c(B)$, and one where flux creep is an ingredient.

The financial support from the Research Council of Norway (NFR), and from NATO via NFR is gratefully acknowledged.

REFERENCES

1. E. H. Brandt, and M. Indenbom, Phys. Rev. B **48**, 12893 (1993); E. Zeldov et al., Phys. Rev. B **49**, 9802 (1994).
2. J. R. Clem and A. Sanchez, Phys. Rev. B **50**, 9355 (1994).
3. J. McDonald and J. R. Clem, Phys. Rev. B **53**, 8643 (1996).
4. D. V. Shantsev, Y. M. Galperin, T. H. Johansen, Phys. Rev. B **60**, 13112 (1999).
5. D. X. Chen and A. Sanchez, J. Appl. Phys. **70**, 5463 (1991).
6. E. H. Brandt, Phys. Rev. **B58**, 6523 (1998).
7. O. Stoppard and D. Gugan, Physica C **241**, 375 (1995); Th. Herzog et al., Phys. Rev. B **56**, 2871 (1997).