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Frequency Dependence of Susceptibility Higher Harmonics in YBCO Samples by Numerical Solutions of the non Linear Magnetic Flux Diffusion Equation

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Abstract

We present a numerical analysis of the diffusion equation of the magnetic flux in YBCO in presence of ac magnetic fields taking into account flux creep and flux flow. Despite critical state models, the results show the dependence of harmonic susceptibilities on the field frequency in agreement with the experimental behavior.

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Key words: susceptibility, higher harmonics, numerical analysis, pinning model, losses

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1. INTRODUCTION

The ac harmonic susceptibilities (χ_n) can be evaluated in the framework of critical state models [1,2], which predict an universal dependence of the χ_n on a parameter δ given by the ratio between the applied field and an effective full penetration field H^* [3]. However these models do not predict the experimental frequency dependence, since only hysteric losses are taken into account. On the contrary the frequency dependence of higher harmonic components ($\chi'_n + i\chi''_n$) of χ implies the presence of time dependent non-linear effects related to fluxons motion [4,5]. In order to consider these phenomena, the amplitude and the frequency dependence of χ_1 has been recently evaluated by numerical solutions of the diffusion equation for the magnetic field [6,7]. According to the same approach, in the present paper we calculate and discuss the behaviour of χ''_{3-5} .

2. NUMERICAL METHOD

We consider an infinite superconducting slab with thickness $2d$, in presence of magnetic fields parallel to the sample surface. The non linear diffusion equation of the field B into the sample is:

$$\partial B / \partial t = \partial / \partial x [(\rho(B, J) / \mu_0) \partial B / \partial x] \quad 1)$$

where $\rho(B, J)$ is the resistivity given by the parallel [8] between the creep (ρ_{cr}) and the flux flow (ρ_{ff}) resistivities:

$$\rho_{cr}(J) = 2\rho_c J_c / J \exp(-U_p / KT) \sinh[JU_p / (J_c KT)] \quad 2)$$

$$\rho_{ff} = \rho_n B / B_{c2}(t) \quad 3)$$

where U_p is the pinning potential, and $B_{c2}(t)$ is $B_{c2}(t) = B_{c2}(0) (1-t^2)/(1+t^2)$, with $t = T/T_c$.

Equation (1) is numerically solved by the FORTRAN NAG routines. The boundary conditions are $B(d, t) = B(-d, t) = B_0 \sin(2\pi ft)$, where $B_0 = 20 \text{mT}$. Then the steady magnetization loops are computed and the harmonics of the susceptibility are calculated

The parameters for an YBCO sample are $d = 1 \text{cm}$, $T_c = 92.28 \text{K}$, $B_{c2}(0) = 112 \text{T}$, $U_p(0)/K_B = 2 * 10^4 \text{K}$, $J_c(0) = 10^{10} \text{A/m}^2$. We assume $\rho_c = \rho_{ff}$.

3. RESULTS AND DISCUSSION

The temperature dependence of χ is a function of the pinning model. For a collective pinning [9] we have:

$$U_p(B, t) = U(B, 0) (1-t^4) \quad 4a)$$

$$J_c(B, t) = J(B, 0) (1-t^2)^{5/2} (1+t^2)^{-1} \quad 4b)$$

We neglect the field dependence of the critical current. In a previous work [6], we have shown the temperature dependence of χ''_1 at different frequencies. As shown in Fig. 1, at higher frequencies the progressive departure from the Bean prediction is due to the contemporary

presence of hysteretic and flux motion losses, which increase the area of magnetization loops. The frequency induced distortions of the magnetization loop affect higher harmonics of the susceptibility, as reported in Figs. 2 and 3, where the imaginary part of the 3rd and 5th harmonics are shown as a function of the temperature at different frequencies. In the same plots the Bean model predictions [3] are reported.

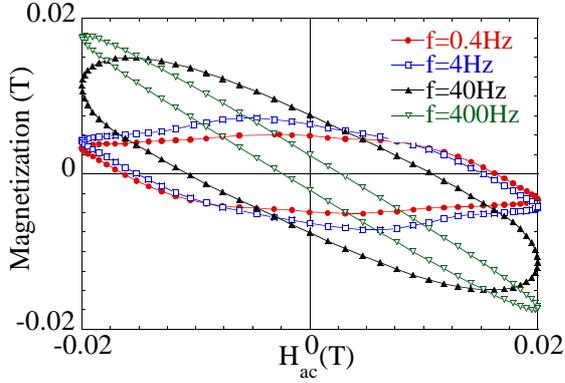


Fig. 1 – Magnetization curves at $T=91\text{K}$ for different frequencies in the collective pinning model.

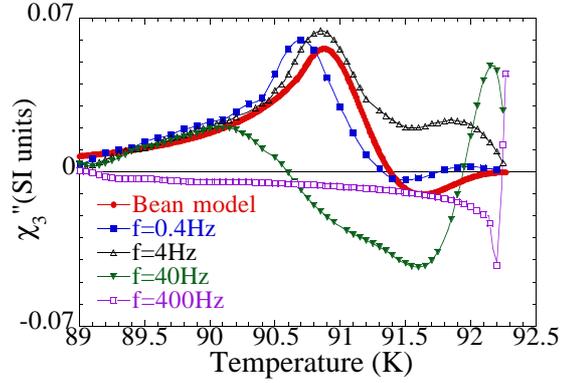


Fig. 2 – Numerically computed χ_3'' vs temperature for four frequencies; full line is the Bean result.

As the frequency increases, the activation processes, together with strong non-linearity of ρ_{ff} , are more important near T_c . In fact in Fig. 2, the negative values of χ_3'' for T around 92K, predicted by the Bean model, move up, and a positive peak appears, whose peak temperature increases with the frequency. Moreover, the frequency increase changes the oscillations of the χ_3'' at lower temperatures. In fact at low frequency (0.4–4Hz) the Bean minimum at about 91.65K shifts up, and the temperature and the amplitude of the peak between 90.5–91K increase with a Bean like behavior. However, the first becomes again negative and the seconds significantly decrease at higher frequencies with large deviations from the critical state description. In an analogous way the temperature dependence of χ_5'' at different frequencies, is show in Fig. 3. Large changes of the temperature and amplitude of the peaks are evident near T_c and at higher frequencies, so that deviations from the critical state description (full line) cannot be neglected. In particular the χ_5'' maximum, present in the Bean model near T_c is much higher in the diffusion approach, and it increases with the frequency. At low frequency the corresponding peak temperature is lower than the Bean one, and it becomes higher at higher frequencies. Moreover only at low frequency the general shape of χ_5'' is similar to the Bean one.

In conclusion the large variations of the shape and of the peak amplitudes of the susceptibilities with the frequency show that, in presence of time dependent relaxation effects, the universal behavior [3] predicted by critical state models is not found. Moreover, experimental temperature dependences of χ_3'' [10–12] can be explained by our model taking

into account the diffusion effects, without considering a local magnetic field dependence of J_c .

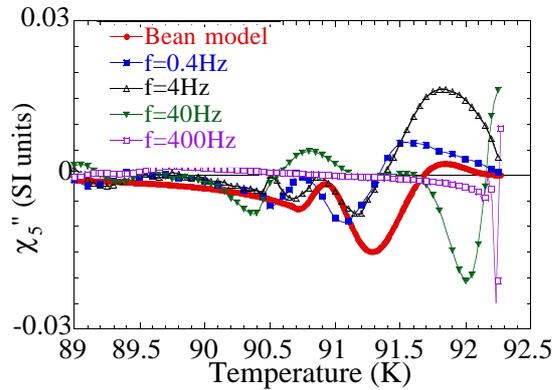


Fig. 3 – Numerically computed χ''_5 vs temperature for four frequencies; full line is the Bean result.

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