Comment on "Collapse of the vortex-lattice inductance and shear modulus at the melting transition in untwinned $YBa_2Cu_3O_7$"

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Matl *et al.* [Phys. Rev. B **65**, 214514 (2002)] have measured the linear complex resistivity due to the vortex lattice in an untwinned YBaCuO crystal. They observe a discontinuity in the frequency-dependent inductance at the first-order transition which is analyzed in terms of a collapse of the vortex lattice shear modulus. In this Comment, we stress that the observed anomaly is standard for superconducting transitions and not specific to vortex-melting. In addition, we suggest that the analysis should take into account three-dimensional effects such as described by the two-mode theory in previous measurements of the vortex linear response in both low- and high-T_c materials.

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In a recent paper, Matl, Ong, Gagnon, and Taillefer (MOGT) present a high-frequency study of the complex resistivity of a pinned vortex lattice in YBaCuO.[1] They focus on the inductive-to-resistive transition which is investigated as a function of temperature at a constant field $B_0 = 2$ T, so that the transition is associated with the vanishing of vortex pinning strength. The case of high-temperature materials is of particular interest since the transition temperature T_m is smaller by a few degrees than the diamagnetic transition T_c. The nature of the inductive transition is still debated, with, however, strong indications from thermodynamics in favor of a first-order scenario. In this context, the linear response is a very rich and useful probe that allows to characterize both the resistive and inductive responses of the vortex state. As discussed in the literature,[2] the high-frequency domain, including the pinning frequency $\omega_p \lesssim 1$ MHz in soft materials such as YBaCuO crystals, is especially relevant for elucidating the nature of the pinning mechanism. However, as a drawback, it requires to handle experimental complications due to skin effects.

The most salient feature of the MOGT data is a strong divergence, followed by a sharp discontinuity, of the low-frequency inductivity $L_s(T)$ at T_m which is identified as the temperature of the first-order transition. As is clear from the title of their paper, Matl *et al.* attribute this discontinuity to the collapse of the vortex-lattice (VL) shear modulus C_{66}. We stress here that the observed, λ-shaped, temperature dependence $L_s(T)$ is quite standard for a superconducting transition and rather indicative of a second-order transition; it can therefore not be regarded as a proof of a collapse of C_{66}, even though this collapse is very much reclaimed if the transition is a genuine melting.

As a main point, we recall that the relevant parameter for a superconducting transition is not $L_s(T)$ but the effective superconducting-electron density $\tilde{n}_s(T)$ which is inversely proportional to L_s. In the vortex state the apparent superconducting density $\tilde{n}_s$ is determined by the elastic pinning properties of the VL. Although $\tilde{n}_s$ can be deduced from the critical-current density, it is best and most directly related to the kinetic inductivity since in the expression $L_s = m/(\tilde{n}_s e^2)$ only the elementary mass m and charge e intervene. Now, according to the experimental low-frequency data of Matl *et al.* (see the 1 MHz data in Fig. 7 of Ref. 1), $1/L_s(T) \sim (T_m - T)$ is linearly vanishing at T_m which is the prescription for a second-order transition. In order to understand to which part of the experimental data, the shear discontinuity reported in Fig. 7 of Ref. 1 can be traced back, we need to look into the details of the MOGT data analysis.

If not related to the quasistatic response, the discontinuity must come from the finite-frequency deviations in the complex resistivity (dispersion). We agree with the authors that the conventional Gittleman-Rosemblum (GR) model, based on a purely local force-balance model with a single spring constant κ and a viscous drag coefficient η,[2,3] cannot explain the pinning frequency spectrum. In this respect, the proper account of nonlocal effects is certainly the key ingredient for tackling this long-standing disagreement. But this concern is very general and not specific to the MOGT data. As a matter of fact, MOGT data are quite representative of clean-YBaCuO spectra and very similar to what was previously published[4] using a slightly different technics; the YBaCuO spectra themselves are not different from those of standard pinned vortex states in low-T_c materials.[2] In these materials, the question of the depinning spectrum has been successfully solved by relying on a simple model: the two-mode electrodynamics.[2] This model is very well suited for pinning of vortices by surface irregularities, a mechanism which is always present and prevails in clean materials, like untwinned YBaCuO.[4] In this model, the shear modulus is not relevant at all for dispersion but may intervene indirectly in the phenomelogical parameter for the quasistatic response.

The situation with the MOGT analysis is quite opposite. Matl *et al.* use a different model which relies on the existence of a dilute concentration of very strong pinning centers with a matching field B_ϕ typically 100 times smaller than their working field $B_0 = 2$ T. A further strong assumption is that VL dynamics is purely two dimensional. These hypotheses would need to be controlled experimentally. This model is quite complicated; it contains, beside the onset frequency for the skin effect, three characteristic frequencies: the pinning frequency $\omega_p = \kappa/\eta$ for the strongly pinned vortex fraction (in the GHz range), the effective pinning frequency $\tilde{\omega}_p = \omega_p B_\phi / B_0$ (in the 10 MHz range) associated with the averaged pinning force $\tilde{\kappa} = \kappa B_\phi / B_0$, and finally the shear frequency $\omega_{66} = 4\pi C_{66}/\eta$ (in the sub-MHz range). Importantly for the analysis is the hierarchy $\omega_p \gg \tilde{\omega}_p \gg \omega_{66}$, so that the low-frequency dispersion is dominated by shear interactions. Note also that the quasistatic inductance is given, up to a small logarithmic correction, by the classical GR formula, taking $\tilde{\kappa}$ as an effective spring constant and, therefore from principle, insensitive to C_{66}. Finally the reality of the three-decade jump in C_{66} which in their analysis precedes the true depinning transition ($\kappa = 0$) is very much dependent on the details of the fitting procedure for the few frequency spectra taken in a the tiny temperature range below T_m. In our view, the MOGT conclusions rely on a rather brittle experimental body and the collapse of C_{66} results from an involved analysis of the finite-frequency corrections to $\rho(\omega)$. These corrections are not necessary since the complex frequency spectrum has been previously interpreted by the two modes model, first proposed for low-T_c materials.[2] We think that it is more adequate to interpret the present data and should be at least considered.

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