Influence of point-like disorder on the guiding of vortices in a rotating current scheme

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Abstract

Explicit current-dependent expressions for anisotropic longitudinal and transverse (with respect to the current direction) nonlinear magnetoresistivities are represented and analyzed on the basis of a Fokker-Planck approach for two-dimensional single-vortex dynamics in a washboard pinning potential in the presence of point-like disorder. Graphical analysis of the nonlinear resistive responses is presented in the rotating current scheme.

Key words: vortex, guiding, correlated and uncorrelated disorder
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One of the open issues in the field of vortex pinning is the influence of *isotropic* point-like disorder on the vortex dynamics in the *anisotropic* washboard planar pinning potential (PPP) in those high- and low-T_c superconductors which were used so far for resistive measurements of the *guided vortex motion* for different temperatures, magnetic fields $\mathbf{H}$, and angles α between the channels of the PPP and the current density $\mathbf{j}$-direction [1-7]. The objective of this paper is to present a few new results of a theory for the calculation of the nonlinear anisotropic magnetoresistivities at arbitrary value of competition between point-like and anisotropic planar disorder for the case of in-plane geometry of experiment. Our approach [10] generalize the results obtained for limiting cases of purely anisotropic [8] and isotropic pinning [9] and gives us the experimentally important theoretical model which, in contradistinction with Ref. [8], demonstrates the j_c-anisotropy for all α.

The initial Langevin equation for a vortex moving with velocity $\mathbf{v}$ in a magnetic field $\mathbf{B} = \mathbf{n}B$ ($B \equiv |\mathbf{B}|$, $\mathbf{n} = n\mathbf{z}$, $\mathbf{z}$ is the unit vector in the z-direction and $n = \pm 1$) has the form

$$\eta_0 \mathbf{v} + n\alpha_H \mathbf{v} \times \mathbf{z} = \mathbf{F}_L + \mathbf{F}_p^a + \mathbf{F}_p^i + \mathbf{F}_{th}, \qquad (1)$$

where $\mathbf{F}_L = n(\Phi_0/c)\mathbf{j} \times \mathbf{z}$ is the Lorentz force (Φ_0 is the magnetic flux quantum, c is the speed of light), $\mathbf{F}_p^a = -\nabla U_p(x)$ is the anisotropic pinning force ($U_p(x)$ is the washboard planar pinning potential), $\mathbf{F}_p^i$ is the isotropic pinning force, induced by uncorrelated point-like disorder, $\mathbf{F}_{th}$ is the thermal fluctuation force, represented by a Gaussian white noise, η_0 is the vortex viscosity, α_H is the Hall constant.

After some calculations [10] in the limit for a small dimensionless Hall constant $\epsilon \ll 1$ the experimentally observable longitudinal $\rho_\parallel$ and transverse $\rho_\perp$ magnetoresistivities have the form:

$$\begin{aligned} \rho_\parallel &= \rho_f[\sin^2\alpha + \nu_a(f_a)\cos^2\alpha]\nu_i(f_i), \\ \rho_\perp &= -\rho_f \nu_i(f_i)[1 - \nu_a(f_a)]\sin\alpha\cos\alpha, \end{aligned} \qquad (2)$$

where the flux-flow resistivity $\rho_f \equiv \Phi_0 B/\eta_0 c^2$, $\nu_a(f_a)$ and $\nu_i(f_i)$ are the probability of overcoming the potential barriers of the PPP and i-pins under the influence of dimensionless moving forces f_a and f_i, respectively [10]. These ν- functions are step-like functions of the di-

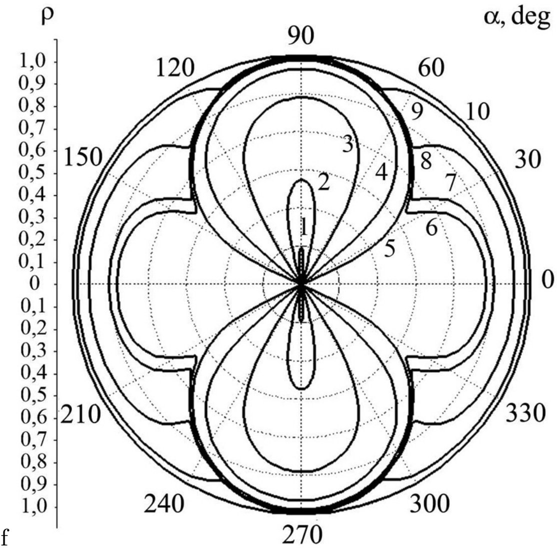

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Fig. 1. Series of graphs of the function $\rho(\alpha)$ for a sequence of the parameter j: 0.63 (1), 0.65 (2), 0.75 (3), 1.00 (4), 1.50 (5), 1.92 (6), 2.00 (7), 2.50 (8), 4.00 (9), 20.0 (10) for $T = 8K$.

mensionless current density j and demonstrate at $j = j_c(\alpha)$ a crossover from the TAFF to the FF regime [8]; they can be found independently from the experiment (ν_i - from the $\rho_{\parallel}^{+}(\alpha = \pi/2)$, see Eq. (2), ν_a - from the $\Theta_E(\alpha)$, see below Eq. (4)).

Recently the $\rho_{\parallel,\perp}(T)$ dependences of Nb films deposited on facetted sapphire substrates [5] were measured at small current densities and different angles α between **j**-direction and facet ridges for relatively small magnetic field **H** [6]. The pinning parameters of the a- and i-pins were estimated from the experimental data [6, 7] (which are in good agreement with the theoretical model described here) and will be used below for the graphical presentation (see Figs. 1, 2) of nonlinear anisotropic (j, α)- dependent magnetoresistivity responses in the current-rotating scheme. This scheme was used earlier in the experimental study of the vortex dynamics in YBaCuO crystals with unidirectional twin planes in [3, 4] in order to measure the polar diagrams of the total magnetoresistivity $\rho(\alpha)$, where

$$\rho(\alpha) = \rho_f \nu_i(f_i)(\sin^2\alpha + \nu_a^2(f_a)\cos^2\alpha)^{1/2}. \tag{3}$$

The characteristic form of the $\rho(\alpha)$ dependences presented in Fig. 1 will obviously be determined by the sequence of dynamical regimes through which the vortex system passes as the current density vector is rotated. For the curves 1-4 the condition $j < j_{ca}(0)$ is satisfied and practically zero resistance in corresponding region follows. As the $j_{ci}(\alpha)$ and $j_{ca}(\alpha)$ behavior is qualitatively opposite, the $\rho(\alpha)$ has a minimum at fixed magnitude of the current density for curves 6-9, which magnitude decreases with the j-increasing and the minimum shifts from the $\alpha \simeq \pi/4$ to the $\alpha \simeq \pi/2$ for the curve 10.

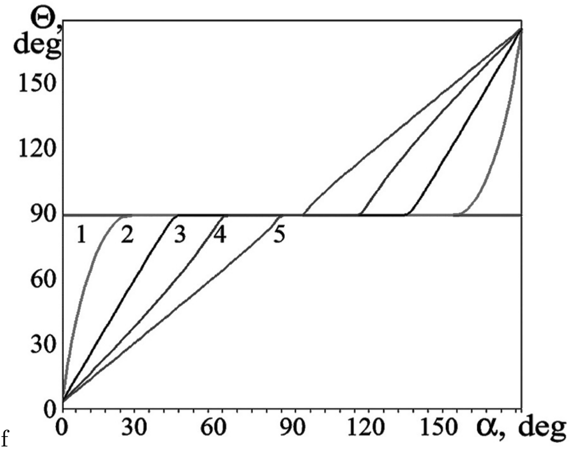

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Fig. 2. Series of graphs of the function $\Theta_E(\alpha)$ for a sequence of the parameter j: 1 (1), 1.7 (2), 2.2 (3), 3.5 (4), 20 (5) for $T = 8K$.

Another type of the experimental dependence has been recently studied [3] for the angle Θ_E between **j**-vector and the electric field vector **E** measured at fixed values of the current density and temperature, where

$$\Theta_E(\alpha) = \arctan(\tan\alpha/\nu_a(f_a)). \tag{4}$$

Note, that the ν_i term, describing the i-pinning, is absent in Eq. (4). Consequently, the $\nu_a(\alpha)$ can be found from the experimental dependence $\Theta_E(\alpha)$, which was found so far only for the FF-regime (see Fig. 2 in Ref. [3]) and theoretically calculated also for the TAFF-regime (see Fig. 17 in Ref. [10]).

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