WASTAGE OF ENERGY DURING JOSEPHSON VORTEX MOVING IN HTSC

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It deals with the mechanism of energy dissipation in high-T_c superconductors, connected with the interaction of magnetic flows with the subsystem of electronic spins of paramagnetic ions. The contribution into the dissipation function of high-T_c superconductors has been found, caused by the interaction of isolated Josephson vortex with paramagnetic ions system. The dependence received is substantially non-analytical in the speed of the magnetic flow movement.

Recently a number of papers dealing with penetration of weak magnetic fields into HTSC ceramic was published [1,2]. The available experimental data show that HTSC can be considered as a weekly-connected medium, that is to say, in the medium, consist of accidental Josephson junctions (JJ). In such medium penetration of the weak magnetic field occurs by means of formation of the local magnetic flux in weak links — Josephson vortex (JV) [4]. According to the appreciations [3] the lower critical field (the field of penetration of JV into HTSC) is 0.1–0.01 Oe.

Under the influence of different external factors (magnetic, electric fields etc.) redistribution of the magnetic flux takes place resulting in dissipation of energy, which deals with interaction of a moved magnetic flux with the other subsystems of a superconductor. In the process of HTSC-preparation of HTSC, for improvement of their physical properties different dopants are added (Zr, Fe, Al etc.). The availability of such admixtures results in formation of the subsystem of paramagnetic ions (PI) in HTSC . In some cases the mechanism of energy dissipation, which deals with availability of such subsystem, becomes the determining factor [5,6]. Let's consider this mechanism (JV-case) in detail.

Let us suppose that in a long Josephson transfer (JT) an isolated JV along OX-axis moves at a speed v (v = const). The distribution of field in the uniformly moving JV is written as (see [4]):

$$H_j = \frac{\Phi_0}{\pi d \lambda_j \alpha \,\mathrm{ch}\left(\frac{x - vt}{\lambda_j \alpha}\right)}, \tag{1}$$

where $\alpha = \sqrt{1-\beta^2}$; $\beta = v/c_0$; Φ_0 — quantum of the magnetic flux; λ_j — the Josephson depth of penetration of the magnetic field into transfer; d — thickness of JT; c_0 — Swihart speed.

Let's write the Hamiltonian of interaction of isolated PI with the magnetic flux and the magnetic subsystem of a superconductor

$$\hat{H} = -2\mu_0 H_\Sigma \hat{S}, \tag{2}$$

where $H_\Sigma = H_f + H_j$; μ_0 is the Bohr's magneton; $\hat{S}$ is the operator of spin; H_f is the effective field, stipulated by a change of PI interaction with magnetic subsystem of the superconductor [6].

We shall consider the effect of H_j, as dependent on coordinates and time addition to the main Hamiltonian, due to which in spin subsystem the transfers between energy levels PI can occur resulting in dissipative processes.

Using the perturbation theory [7] , we get from (1),(2) the formula for the probability of PI transfer from level l to m level:

$$\omega_{m,l} = \frac{\mu_0^2 \sin^2\varphi\, \Phi_0^2 \left[\theta(y+d/2) - \theta(y-d/2)\right]}{d^2 \hbar^2 v^2 \operatorname{ch}^2\left(\frac{V\alpha}{2\beta}\right)} (S+m)(S-m+1)\, \delta_{m-1,l}, \tag{3}$$

here $V = \frac{2\mu_0 H_f \lambda_j}{\hbar c_0}$; $\hbar$ — Dirac constant, $\theta(x)$ — the Heaviside function, S — full ion's spin.

Power of losses, which falls on a unit of length JV in approximation of slow relaxation PI is :

$$Q = nv\left(\sum_{m=-s}^{s} f_m^+ E_m^+ - f_m^- E_m^-\right), \tag{4}$$

where $E_m^{+,-} = \pm\mu_0 H_f m$ — the true values of asymptotes the unperturbed part of Hamiltonian (2); n — PI strength; f_m^+, f_m^- — the relative occupancy of energy levels, according to $t \to \pm\infty$. Here it is assumed, that at the moment $t \to -\infty$ the Boltzmann distribution PI on energy levels takes place and at the moment $t \to +\infty$:

$$f_m^+ = f_m^- + \sum_{l=-s}^{s} f_l^- \omega_{m,l} - f_m^- \omega_{l,m}. \tag{5}$$

Substituting (4),(5) to (3), we get for capacity of losses on a unit of length JV :

$$Q = A_j \frac{V}{\beta \operatorname{ch}^2\left(\frac{V\alpha}{2\beta}\right)},$$

$$A_j = \frac{2n\mu_0^2 \Phi_0^2 \sin^2\varphi}{\hbar d \lambda_j}\left[N \operatorname{cth} N\eta - \operatorname{cth}\eta\right], \tag{6}$$

$$\eta = \frac{\mu_0 H_f}{kT}, \quad N = 2S + 1,$$

here k — Boltzmann constant, T — temperature.

Let's evaluate the contribution of electromagnetic and paramagnetic losses to the dissipative function of superconductor with JV. In [8] the formula for dissipation of energy at the expense of Ohm losses is of the form:

$$Q_R = A_R \frac{\beta^2}{\alpha},$$

$$A_R = \frac{2\Phi_0^2 c_0^2}{\pi^2 \lambda_j d c^2 \rho}, \tag{7}$$

here ρ — specific Ohm resistance JT.

Let's introduce for comparison (6) and (7)

$$\gamma = \frac{A_j}{A_R}.$$

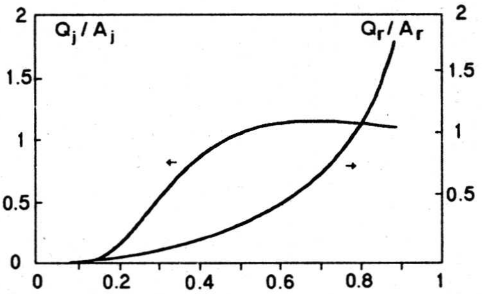

Fig. 1. The dependence of paramagnetic and ohmical losses on the speed β

In dependence on PI strength and condition of HTSC preparation [9], the value of γ can change in the range 0.1– 10 .

In Fig. 1 the dependencies of paramagnetic and ohmical losses on speed β are given. It can be seen that even at $\gamma = 1$ paramagnetic losses can be compared with electromagnetic ones over a wide interval of speeds JV. Consequently, it is nessary to take into account the contribution of both mechanisms in the dissipative function of SC. The dependence of total losses (electromagnetic and paramagnetic) on the speed can be unmonotonous.

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