THE INVESTIGATIONS THE LOW-FIELD CRITICAL STATE IN THE CERAMIC Y—Ba—Cu—O

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The study of field dependences of the first and higher harmonics dynamic susceptibility in ultra-low fields has been performed. The results show the satisfactory fit with the conclusions of the critical state theory of low field electrodynamics of high-T_c superconductors.

The present paper is devoted to the experimental check of employing the concept of the critical state to describe the penetration of the ultra-low fields in the granular HTCS.

The critical state of a superconductor is strong nonequilibrium state, described by equation: $|\frac{dh}{dx}| = 4\pi j_c(h)$, j_c has the sense of critical current and is the function of h. This function is the very important characteristic of the system investigated since it may be employed for a calibration certificate of ceramic HTCS.

Let field $h(t)=H+h_0 \cos \omega t$ be applied to the sample. In this case the induction B(t) can be expanded in Fourier series: $B(t)=\Sigma [a_n \cos n\omega t + b_n \sin n\omega t]$. We obtain in adiabatic approximation at $h_0 << H$, the following expressions for coefficients a_n and b_n (namely these values are obtained in our experiments):

for odd

$$a_1=\frac{\mu_{eff}h_0^2}{4\pi j_c(H)d} \qquad b_{2k+1}=\frac{\mu_{eff}h_0^2}{8\pi^2 j_c(H)} \frac{1}{(k^2-1/4)(k+3/2)}$$

harmonics

$$a_{2k+1}=0 \ (k>1)$$

for even

$$a_2=\frac{\mu_{eff}h_0^3}{32\pi d} \frac{d}{dH}\left\{\frac{1}{j_c(H)}\right\}; \qquad a_{2k}=0 \ (k>1)$$

harmonics

$$b_{2k}=-\frac{\mu_{eff}h_0^3}{16\pi^2 d} \frac{d}{dH}\left\{\frac{1}{j_c(H)}\right\} \frac{k}{(k^2-1/4)(k^2-9/4)} \cdot$$

(Here μ_{eff} — the effective magnetic permeability of the ceramic, d — thickness of the slab.).

Let us proceed to the experiments. We studied the dependence of imaginary and real parts of the first harmonic of induction a_1 and b_1 as well as the moduli of higher harmonic amplitudes $c_n=(a_n^2+b_n^2)^{1/2}$ on the intensity of the ac and dc fields. The experiments were performed with ceramic Y—Ba—Cu—O sample with density 4.8 g/cm^3 at 78K within the frequency range 10^2—10^5 Hz and $10^{-2} \leqslant h_0, H \leqslant 1$ Oe. In order to avoid the demagnetization effects the sample has toroidal shape. The background field did not exceed 10 mOe.

Figure 1 shows the dependencies of a_1, b_1, c_3, c_5 on h_0 obtained for H=0. One can see that the values studied show the h_0^2 dependence, h_0 amplitude being changed by two orders of magnitude.

The studies in dc fields have shown the h_0^3 and h_0^2 dependencies for even and odd harmonics respectively at $h_0 << H=\text{const}$. The study of harmonic behaviour in dc magnetic field at $h_0=\text{const}$ enables us to obtain the form of $j_c(H)$ function. The dependence $(c_3^H-c_3^0)/c_3^0$ on H (at $h_0{}^3\text{const}$) is given in

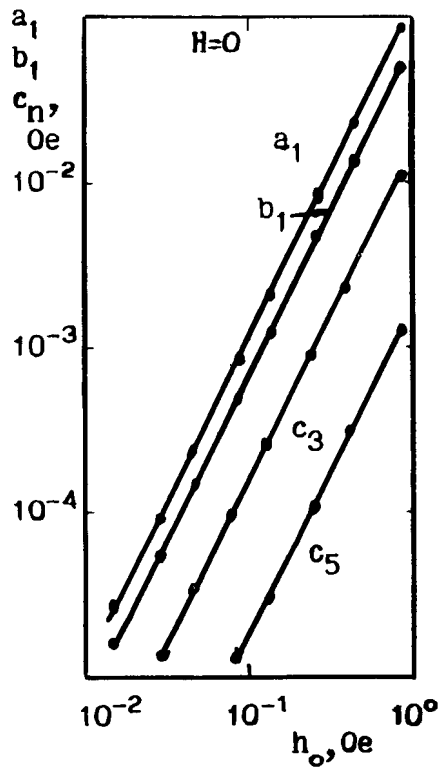

Fig. 1. Dependences of a_1, b_1, c_5 on h_0 at H=0; a_1 and b_1 were measured at f=100 kHz; c_3 and c_5 were measured at frequency of ac field 20 kHz

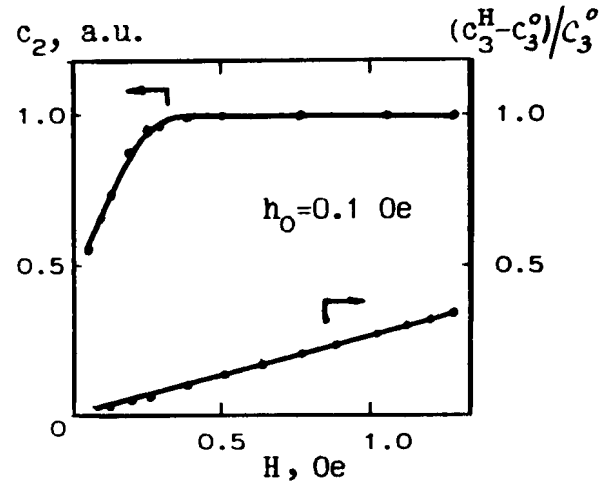

Fig. 2. Dependences of c_2 and $(c_3^H - c_3^0)/c_3^0$ on H at h_0=0.1 Oe. The quantity of c_2 is normalized to its value at H=1.25 Oe; c_3^H and c_3^0 are the third harmonic amplitudes at $H \neq 0$ and H=0, respectively; f=20 kHz

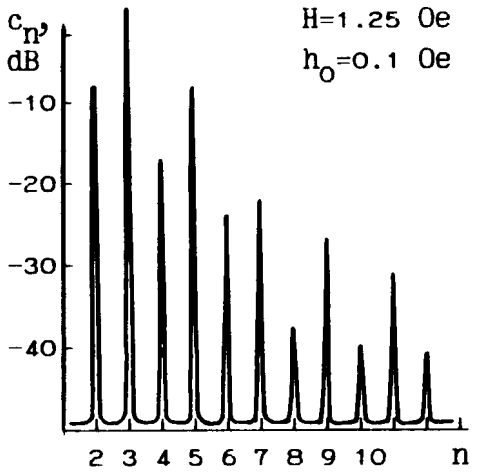

Fig. 3. The spectrum of higher harmonics: f= =10 kHz; H=1.25 Oe, h_0=0.1 Oe

fig. 2 as an example, where c_3^H and c_3^0 are the third harmonic amplitudes at $H \neq 0$ and H=0, respectively. Here the second harmonic amplitude is independent of H. According to the theory even harmonics should be proportional to $\frac{d}{dH}(1/j_c(H))$. The comparison of these facts regarding to thebehaviour of c_2 and c_3 in dc field results in the self-consistent determination of the evident aspect of $j_c(H) = j_0 H_0/(|h| + H_0)$. The strongly pronounced nonlinear properties of granular superconductor in low fields show the spectrum of harmonics having slightly decreasing amplitudes (see fig. 3). This is also the confirmation of the critical state picture.

The results of the study performed enable us to assert that the idea of critical state theory may be used for low field electrodynamics of HTCS.

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