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Magnetic Characteristics Measurements In Htc Superconductors

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I. Introduction

High temperature oxide superconductors are characterised by peculiar magnetic properties, allowing treat them as unique magnetic materials. They are diamagnetic materials for small applied increasing magnetic field but indicate too, from other side giant trapped magnetic flux in reverse direction. It allows consider these superconductors as very efficient permanent magnets.

Magnetic characteristics of superconductors are related to very peculiar form of the penetration of magnetic flux into these materials in the form of vortices - flux lines or pancake shape, each of them transports lowest known value of quantized magnetic flux $\Phi_0 = 2{,}067 \cdot 10^{-15}$ Wb. Such small quantity of magnetic flux allows use superconducting materials for construction of ultra sensitive devices for detecting lowest magnetic fields. In the paper two methods of detecting magnetic quantities in HTc superconductors are discussed: first one follows from the magnetization hysteresis curves measurements and second for which only first results were received until now, is based on the dynamic anomalies of the current-voltage characteristics measurements.

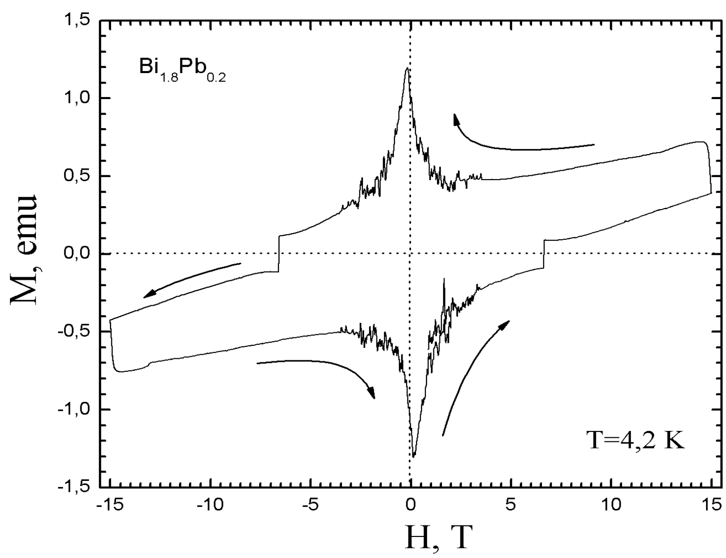

Fig. 1 : Full hysteresis loop of the magnetization curve in high magnetic field, of sintered HTc superconductor $Bi_{1.8}Pb_{0.2}Sr_2Ca_2Cu_3O_{10}$ composition as a function of applied magnetic induction. Arrows indicate the direction of variation of applied magnetic field. Measurement performed by dr. D. Gajda from MLSPMiNT.

II. Experimental Results

Example of the magnetic hysteresis curve measured on sintered HTc superconductor of the $Bi_{1.8}Pb_{0.2}Sr_2Ca_2Cu_3O_{10}$ composition is shown in Fig. 1. Large irreversibility of hysteresis loop is observed here as well as numerous instabilities of magnetic induction distribution, which in uncontrolled way can lead to rapid transition of superconductor into the normal state. Partial flux jumps in superconductors are therefore in some sense analogous phenomenon to Barkhausen noises appearing in magnetic materials. Magnetization measurements allow to determine most of the magnetic quantities of HTc superconducting materials, including magnetic critical fields but also critical currents, magnitude of trapped magnetic induction, magnetic hysteresis losses and other parameters. Experimentally magnetization curves are measured frequently by using vibrating sample magnetometer, which method is now

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the subject of the standardization procedure, according to the standard IEC EN 61788-13. In this method sample is vibrating in longitudinal magnetic field generated by superconducting electromagnet. Induced in the pick-up coils signal, directly proportional to the magnetic moment of the superconductor is given onto the power amplifier and registered in the computer unit in the function of an applied magnetic field. Area of the magnetization curve hysteresis loop, shown in Fig. 1 determines the losses generated in bulk superconductor during closed cycle of magnetic field. Irreversibility of the magnetization curve observed in measurements, determines the critical current density of the superconductor j_c, according to the relation joining the hysteretic magnetization of the superconducting pellet of the diameter D, with its critical current density: $M = j_c \cdot D$, received in the Bean's critical state model [1]. Magnetization M is important magnetic quantity allowing to determine also the levitation force F between two magnetic materials characterized by the magnetization values M_1 and M_2 respectively, which is essential parameter of the superconducting bearings: $F = M_1 M_2 /(2\mu_0)$, where μ_0 is magnetic permeability. According to above considerations it is clear too that most attractive for using in the superconducting bearings and levitating devices are superconducting macromolecules, which can reach the dimension even up to 10 cm.

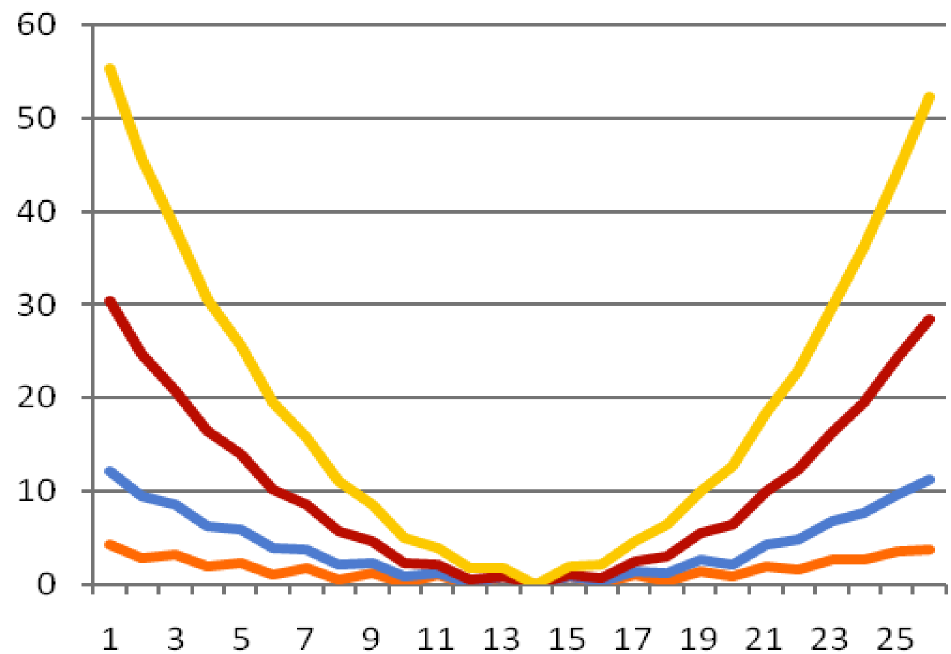


Fig. 2 : Profiles of the measured deflection along an axis of superconducting coil with inserted inside HTc shield, of magnetic induction distribution from the maximal value, in relative units. Subsequent curves from bottom are given for increasing magnetic induction: 0.1T, 0.2T, 0.5T, 1T

Diamagnetic features of superconductors, observed especially in low magnetic field, are useful for construction of the magnetic shields, allowing to homogenize the magnetic induction distribution of the superconducting electro-magnets. An example of measurements the profiles of magnetic induction inside the superconducting coil with inserted inside superconducting HTc shield is shown in Fig. 2. Observed here small steps in magnetic induction profile, especially well seen at low applied magnetic field, reflect the structure and shielding properties of this superconducting thin coil, formed from wound spirally single layer of HTc superconducting tape of the first generation. The length of this tape L, of the width b and thickness a, necessary for construction of HTc superconducting shield of the inner radius R, thickness $T = \dfrac{\Delta Bab}{\mu_0 I_C}$ and length C screening magnetic induction ΔB, is connected with critical current IC of this tape according to the relation:

$$L = \frac{2\pi Cb\Delta B}{\mu_0 I_C}\left(R + \frac{a}{2}\left(\frac{b\Delta B}{\mu_0 I_C} - 1\right)\right) \quad (1)$$

III. Modeling of Dynamic Current-Voltage Characteristics of HTc Superconductors in Varying Magnetic Field

Measurements of magnetization curves allow in inductive way determine essential electro-magnetic quantities characterizing HTc superconductors, including critical current. This essential parameter of superconductors is determined directly in resistive way from current-voltage curves, assuming appropriate voltage or resistivity criterion. In this clause we consider the I-V characteristics in slowly varying magnetic induction. Then dynamic current-voltage characteristics anomalies we have observed previously: normal and inverse one [2], as is shown in Fig. 3. These anomalies should be useful as a new tool for detecting magnetic quantities in superconductors – especially describing the magnetic flux penetration and concerning therefore the stability behavior of magnetic induction in HTc superconductors.

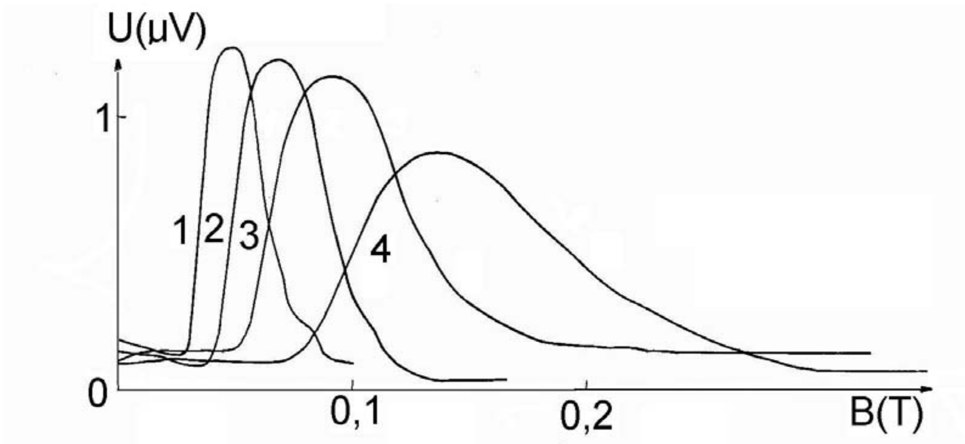


Fig. 3 : Measured dynamical anomalies of I-V curves on YBaCuO bulk superconductor for various values of the linearly time-varying magnetic field: (1) 1 mT/s, (2) 5 mT/s, (3) 10 mT/s, (4) 15 mT/s

Theoretical analysis of this phenomenon has been performed in two ways, basing on generalized critical state model received, while taking into account in details the nano-sized pinning centre-vortex interaction [1] and by considering the diffusion equation. In the critical state model the critical current magnetic field dependence has been then assumed as:

$$\mu_0 j_c = \pm \frac{\alpha}{\left(B(x)+B^0\right)^{\gamma}} \tag{2}$$

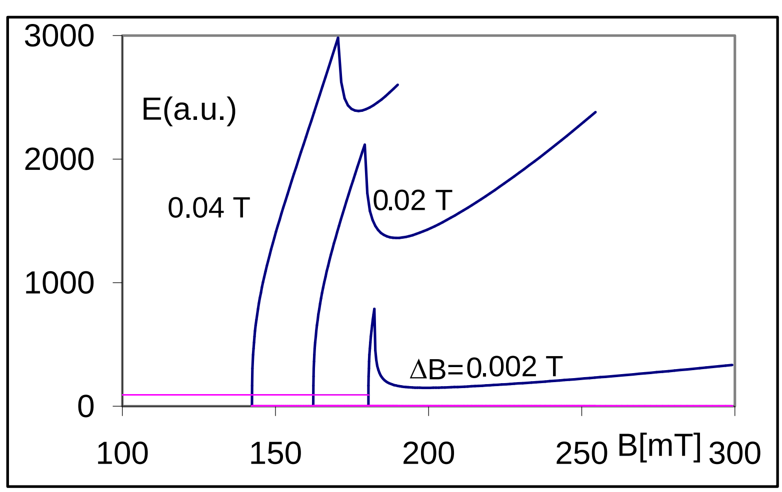
where $\mu_0$is magnetic permeability α and B^o material parameters, while γ varies between 0 and 1. Generated electric field has been calculated separately for non-saturated case, it is when magnetic induction does not penetrate into the centre of the superconducting slab, while both branches of the magnetic induction do not meet together and saturated case of total flux penetration. For non-saturated case in generalized pinning force model and saturated one, induced electric fields are described by relations 3 and 4 respectively:

$$E = \frac{\dot{B}}{\alpha}\left(B+\Delta B+B^0\right)^{\gamma}\cdot\left\langle\left[\left(B+\Delta B+B^0\right)^{1+\gamma}-\alpha(1+\gamma)x_m\right]^{\frac{1}{1+\gamma}}-B^0\right\rangle \tag{3}$$

$$E = \frac{\dot{B}}{\alpha}\left\langle\left(B+\Delta B+B^0\right)^{\gamma}\cdot\left(\left[\left(B+\Delta B+B^0\right)^{1+\gamma}-\alpha(1+\gamma)x_m\right]^{\frac{1}{1+\gamma}}-B_{av}(x_m)\right)+B^1\left(B_{av}(x_m)-B^0\right)\right\rangle \tag{4}$$

In Eqs. 3-4 symbol B denotes time dependent applied magnetic induction, while $\dot{B} = \partial B/\partial t$ its time derivative, while x_m sample half-thickness. ΔB is magnetic induction shift on the surface of superconductor connected with the transport current flow, while functions B_{av} and B^1 are related to the shift of magnetic induction in the middle of the superconductor and on its surface in dependence on the amplitude of the transport current.

Fig. 4 : Calculated influence of transport current expressed here by ΔB on dynamic I-V curves anomalies in slowly varying magnetic field.



Results of calculations according to relations 3-4, dynamical current-voltage characteristics anomalies in this model, in the function of transport current amplitude flowing through the HTc superconductor, expressed by parameter ΔB, are shown in Fig. 4. Above anomalies as shows Fig. 3 are also sensitive to magnetic field sweep rate, as well as magnetic field dependence of critical current. Similar results are received after solving the magnetic diffusion equation, mentioned previously, which indicates on general form of observed phenomenon, which can be useful therefore as new tool for detecting such dynamic magnetic quantities as magnetic field sweep rate, current amplitude and its frequency, flux diffusion velocity, sample quality.

Acknowledgment

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