SHEET CURRENTS RETRIEVAL IN HIGH-T_C SUPERCONDUCTOR FILMS[1]

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ABSTRACT

Investigations of 2-D sheet current distributions based on measurements of magnetic field above the type-II high-temperature superconductor (HTSC) YBaCuO films in a remanent magnetization state have been carried out. Using the Biot-Savart's law and continuity equation, integral equations (of 2-D convolution type) for two components of current have been obtained. These equations have been solved on the basis of Tychonoff method of generalized discrepancy, and sheet currents pattern in superconductors has been retrieved as well as the magnetic field distribution on the film surface. The current peculiarities related to laser pulse effect have been retrieved from measurements. A new physical effect of the redistribution of currents after the laser pulse impact without the change of the total vortices number has been observed.

MEASUREMENTS The method for measuring the perpendicular component of magnetic field $H_z(x,y)$ at arbitrary height level z above the film surface uses a Hall scanning probe. The perpendicular external magnetic field was generated by a solenoid coil, which is cooled with liquid nitrogen and produces a maximum field of 500 gauss. The magnetic field increases linearly up to its maximum value during 20 seconds and, then, decreases in the same way down to zero value. The thin film (about 0.1μm with a diameter of 20 mm was chosen for measurements. A Hall probe with the sizes 100 and 50 μm in the *x-y* plane and 10 μm in the *z*-direction was applied in experiments. The height z of measurements was chosen in 200-300 μm interval to ensure non-invasive conditions. The lateral resolution of measurements (pixel size) was chosen 250 μm (comparable with the Hall probe size). The time of the one-pixel integration was 0.25 s at the integration time constant $\tau_0 = 1$s. The noise level was about 0.1 gauss, and it was uncorrelated at the adjacent pixels.

INVERSE PROBLEMS

The integral equations (of the 2-D convolution type) for two components of current for the inverse problem formulation have been obtained in [1] using the Biot-Savart's law and the continuity equation:

$$H_z(x,y,z) = \frac{1}{c}\iint j_x(x',y')\,\frac{Y\left[z^2(X^2+Y^2+2z^2) - X^2(X^2+Y^2)\right]}{(X^2+Y^2+z^2)^{3/2}\left(X^2+z^2\right)^2}dx'dy', \qquad (1)$$

$$H_z(x,y,z) = -\frac{1}{c}\iint j_y(x',y')\,\frac{X\left[z^2(X^2+Y^2+2z^2) - Y^2(X^2+Y^2)\right]}{(X^2+Y^2+z^2)^{3/2}\left(Y^2+z^2\right)^2}dx'dy', \qquad (2)$$

where j_x, j_y are the components of sheet current $\vec{j}$, $X = x-x'$, $Y = y-y'$. Deconvolution of (3) and (4) yields a solution of the inverse problem of 2-D current pattern retrieval from

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2-D magnetic-field distribution measured in x – y plane at some arbitrary vertical distance *z*. Special regularization methods should be applied in this case. Convolution equations (3) and (4) have been solved using Tikhonoff's method of generalized discrepancy [1]. Our numerical simulation gave the following results. The *rms* of random errors of retrieval related to the random "data" noise with the *rms* of 0.1 gauss changes from 0.1 A/cm for the low current values (about 2 A/cm) up to 0.5 A/cm for the strong currents (about 20 A/cm).

To reduce the measurements time till about 3 hours instead of 48 hours the retrieval of the true magnetic field $H(t)$ from the measured time dependence $H_m(t)$ has been carried out from the deconvolution of the equation

$$H_m(t) = \frac{1}{\tau_0} \int_{-\infty}^{t} H(\tau)\, e^{-\frac{t-\tau}{\tau_0}}\, d\tau\,, \qquad (2)$$

where τ_0 is the integration time constant. The equation (2) has the exact solution

$$H(t) = H_m(t) + \tau_0 \frac{dH}{dt}(t)\,, \qquad (3)$$

but this solution of ill-posed equation (2) has a property to amplify the random noise. To solve the problem the Tichonoff method for the initial convolution equation (2) has been used as a preliminary data processing shown in Fig.1, 2.

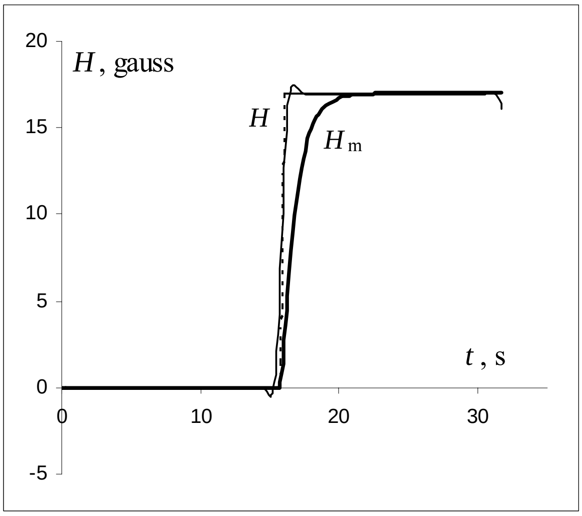

Fig.1. Numerical simulation. Retrieval of the step-function.

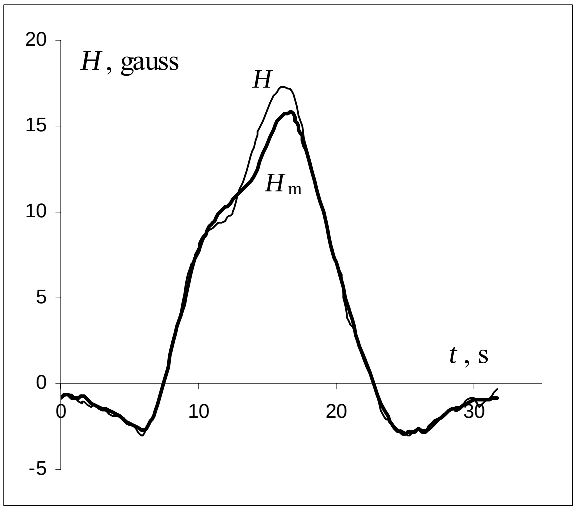

Fig.2. Retrieval of the measured magnetic field.

EFFECT OF LASER PULSE IRRADIATION

In Fig.1 the initial state of the magnetic field of a circular disk film with a diameter of 20 mm after the above magnetization process is shown (height of measurements was z = 225 μm). The current perturbation due to the laser pulse (with the beam footprint of 2 mm at the power density about 10 kW/cm^2) leads to a new distribution of currents and, hence, to a new magnetic field distribution shown in Fig.2. The pulse duration was $\tau = 10^{-7}$ s chosen comparable to the time of film-substrate heat exchange.

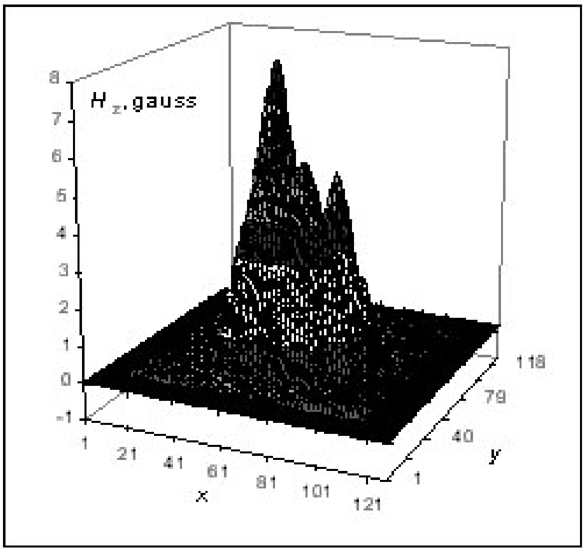

Fig.3. Initial magnetic field at z = 250 μm.

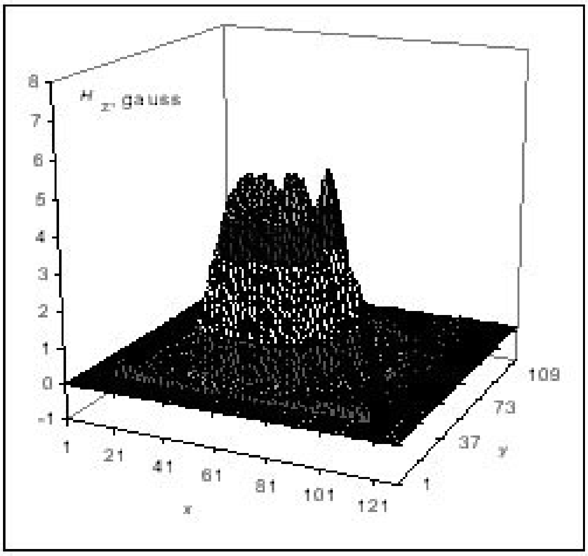

Fig.4. After a laser pulse.

The retrieved current patterns before and after laser pulse are presented in Figs.5, 6. One can see that the strong counterclockwise current rotation region near the center of the film (Fig.6) is disappeared. The magnetic field distributions before and after the laser pulse have been calculated using retrieved currents. The most unexpected result is that the mean (over the film surface) value of the change of the surface magnetic field is equal to zero inside the limits of measurements accuracy (see in Fig.7). It means that in the considered case the laser pulse redistributes the currents significantly without the change of the total number of current vortices in the film. So, the well-known Bean theory appears inapplicable in this case.

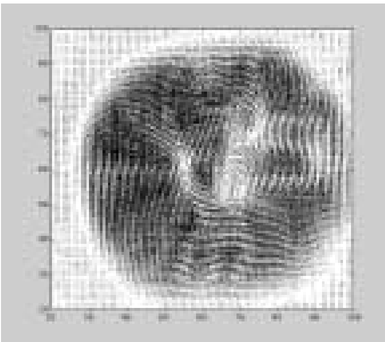

Fig.5. Initial currents.

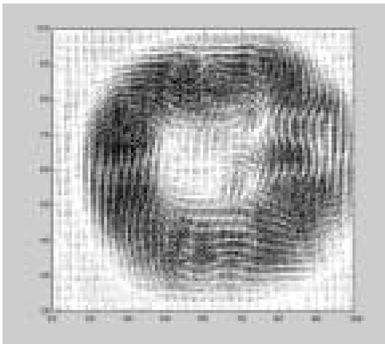

Fig.6. After a laser pulse.

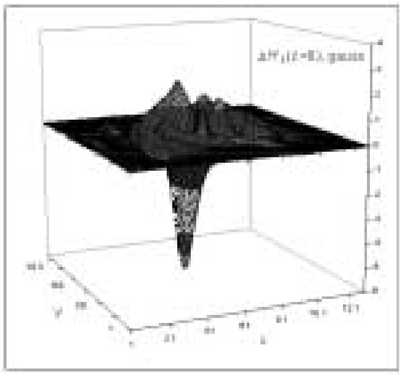

Fig.7. Calculated change of the surface magnetic field because of the laser pulse.

Thus, this effect gives the possibility to change the magnetization in the HTSC films using the optical emission and to switch or to change the polarization of the optical signal reflected from the film (by the same transmitted signal) using magneto-optical coating of the film.

REFERENCES

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