DYNAMIC RESISTIVITY OF HARD SUPERCONDUCTORS IN A PERPENDICULAR TIME VARYING FIELD

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I. INTRODUCTION

Losses occur in type II superconductors when they are exposed to time varying fields or currents. In this paper we present the results of measurements made on a superconducting wire carrying a constant current while being exposed to a perpendicular field varying linearly with time.

II. EXPERIMENTAL SET-UP

The experimental arrangement is essentially the same as the one used by Taquet[1] and Rayroux.[2] The sample is wound bifilarly and placed inside a superconducting solenoid so that the magnetic field is perpendicular to the wire to be tested. The potential across the wire is monitored by a microvoltmeter (Keithley type 150) and recorded on a X-Y recorder (Moseley DR-2M). The transport current is first set in the bifilar wire, the field is increased up to some value below H_{c2} (about 20 kOe for NbZr and NbTi), kept constant for a while, and then set back to zero at about the same rate of change.

III. RESULTS

The shape of the voltage is identical for any type of hard superconductor. The general characteristics of the signal are the following:

- The magnitude of the voltage is proportional to the transport current and to the sweep rate of the magnetic field, dH/dt.
- There is a threshold field below which the voltage is essentially zero.
- The voltage vanishes abruptly for dH/dt = 0.
- The voltage polarity is independent of the sign of dH/dt. The sign of the voltage is the same as in the normal state.

The curves of Fig. 1 show the results obtained with a copper-plated Nb25%Zr wire (diameter of core 0.254 mm) when the field is increased from zero to some 15 kOe.

Instead of plotting the voltage one can express the results in terms of a dynamic resistivity in Ω·cm. The curves of Fig. 2 show that:

- The threshold field is a characteristic of the material itself as well as of its metallurgical treatment.

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1. B. Taquet, J. Appl. Phys. 36, 3250 (1965).
2. J.M. Rayroux, D.I. Itschner, and P. Müller, Phys. Letters 24A, 351 (1967).

- A possible size effect exists as seen from the 10 mil and 5 mil NbZr data.
- The magnitude of $\rho/(dH/dt)$ at 10 kOe is of the order of 10^{-15} $(\Omega\cdot cm)/(Oe\cdot sec^{-1})$ (compare with the Cu resistivity at $4^{o}K \approx 10^{-8}\ \Omega\cdot cm$).

The characteristics of the threshold voltages indicate clearly a possible relation between the dynamic resistivity and the magnetization. A more careful observation of the signal demonstrates the effect of the magnetic history of the sample. As shown in Fig. 3 the dynamic resistivity of a clean wire starts at zero field while the magnetic hysteresis is the apparent reason for the threshold field. A still more obvious hysteresis effect appears when the field is cycled from zero to H and back to zero (see Fig. 4).

IV. EXPLANATION

The first idea that came to our mind looking for an explanation of the hysteretic behavior of the dynamic resistivity[2] was of phenomenological order. We advanced the idea that the dynamic resistivity could be proportional to the product of the induction B by its time derivative dB/dt:

$$\rho(H) \sim B\frac{dB}{dt} \sim B\frac{dB}{dH}\,\frac{dH}{dt} \qquad (\Omega\cdot m) \quad . \qquad (1)$$

Qualitatively at least the graphical product of $B\cdot dB/dH$ results in a curve similar to Fig. 4. Druyvesteyn[3] used the Bean model and its resulting flux-transport concept across the wire to analyze our first experimental data. He found an equation for the observed electrical field which is in good agreement with the experiments:

$$E = \mu_o \cdot \frac{dH}{dt} \cdot \frac{J_t}{J_c} \cdot d \qquad (V/m) \quad , \qquad (2)$$

where $\mu_o = 4\pi\ 10^{-7}\ VsA^{-1}\ m^{-1}$, d = wire thickness, J_t = density of the transport current, and J_c = critical current density. Using basically the same approach but introducing the Kim equation for the density of the critical current $J_c = \alpha/(B_o + B)$, we found the following expression for the electrical field of a clean wire below the threshold field:

$$E \simeq \frac{(B_o + B)^2}{2\alpha} \cdot \frac{dH}{dt} \qquad (V/m) \quad , \qquad (3)$$

where B is the induction at the surface of the wire. Above the threshold field the same treatment gives:

$$E = \frac{\mu_o}{2\alpha}(B_o + B) \cdot J_t \cdot d \cdot \frac{dH}{dt} \qquad (V/m) \quad , \qquad (4)$$

which, in accordance with Eq. (2) and with the experiments, also stresses the importance of high critical current density and small conductor size d for low losses.

It is a pleasure to acknowledge very fruitful discussions with Prof.Dr. J.L. Olsen and Dr. W. Druyvesteyn throughout this work.

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3. W.F. Druyvesteyn, Phys. Letters 25A, 31 (1967).

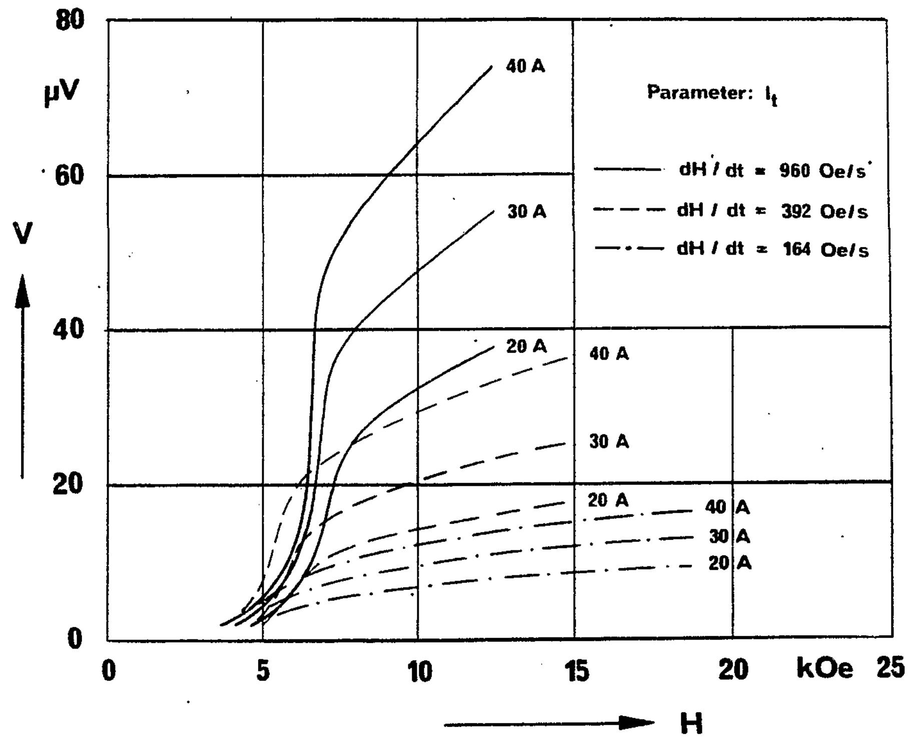

Fig. 1. General behavior of the voltage with transport current and sweep rate of the field as parameters. Sample: Nb25%Zr, diameter = 0.254 mm + 0.025 mm Cu, wire length = 12.8 m.

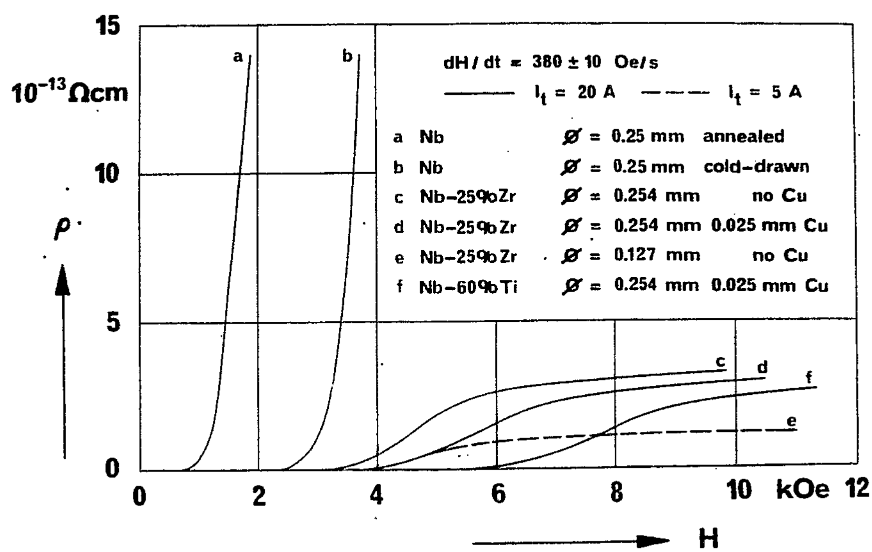

Fig. 2. Threshold field for various hard superconducting wires.

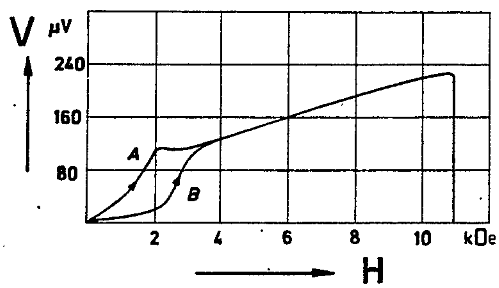

Fig. 3. Effect of magnetic history below the threshold field. Sample: Nb42%Ti cold-worked only, diameter = 0.250 mm + 0.025 mm Cu, length = 20 m; transport current = 10 A. A: magnetically clean wire. B: wire with magnetic hysteresis.

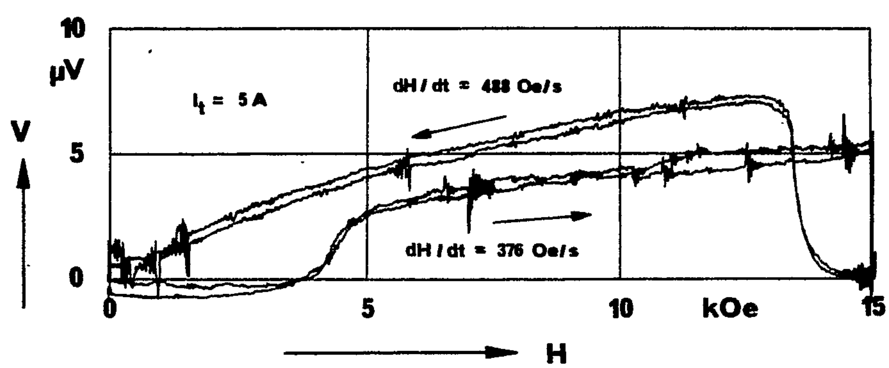

Fig. 4. Voltage on a Nb25%Zr wire (diameter = 0.127 mm, no Cu plating, length = 20 m).