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Recently R. B. Flippen[1] reported a rather puzzling pulsed magnetic field experiment in which he observed a drop in the transition field of Nb 25% Zr wire from a static H_{c2} of 78 kOe to values in the range 15-30 kOe for pulse rise times in the range 5-50 μ seconds. The transitions were approximately reversible, indicating eddy current heating was negligible.

We intend to show that the transitions were caused by the generation of critical eddy currents in the specimen by the rapidly pulsed magnetic field. Flippen briefly considered this explanation, but rejected it because the effect was independent of the longitudinal current for densities up to 10^4 A/cm^2. However, there is no reason to expect the effects of superimposed longitudinal and transverse currents to add in any simple vectorial manner, but one does expect the longitudinal critical current to greatly exceed the transverse critical current.[2] Since the largest longitudinal current density applied was smaller than the transverse eddy currents actually present in Flippen's specimens, it is not surprising that varying the longitudinal current had no noticeable effect.

"Current" hereafter will mean transverse eddy current; the only role played by the longitudinal current is to signal the completion of the phase transition. Unfortunately Flippen reported the fields at which resistance appeared rather than the fields at which resistance became normal. However, the difference was reported to be only "a few kilo-oersteds" so perhaps we can use Flippen's published data and still get sensible results.

We wish to emphasize that the "critical current" which we shall consider is that current at which a phase transition into the normal state occurs; i.e., the resistance becomes normal. We shall call this the "transition critical current", or simply the critical current. We distinguish sharply between the critical current and the current at which resistance becomes appreciable, which we shall call the "resistive critical current", or simply the resistive current. We use the obvious notation J_{c2} and J_{c1} for the critical and resistive currents respectively, in analogy to the loosely associated critical fields H_{c2} and H_{c1}.

To fix our ideas, we consider a hollow cylinder of wall thickness d, radius r, with $d \ll r$. We impose a longitudinal field H with rise rate $\dot{H}$, assuming complete flux penetration. Then the electric field in the wall is

$$E = \frac{r\,\dot{H}}{2c} \qquad (1)$$

The eddy current J_n in the normal metal provides a lower bound for the eddy current J_e in the superconductor, which in turn must not exceed the critical current $J_{c2}(H)$; that is,

$$J_{c2} \geq J_e \geq J_n = 5\times10^{-3}\ \frac{r\,\dot{H}}{\rho} \qquad (2)$$

where r, $\dot{H}$, and the normal resistivity ρ are in cm, Oe sec^{-1}, and μΩ-cm respectively. The field H at which equality holds provides an upper bound for the transition field.

Mean values of r, $\dot{H}$, ρ appropriate to Flippen's experiment are 10^{-2} cm, 10^{10} Oe sec^{-1} and 30 μΩ-cm. Substituting in Eq. (2), we find

$$J_{c2} \geq 2\times10^{4} \frac{A}{cm^2} \quad (3)$$

The field H corresponding to this current for Nb 25% Zr wire was reported by B. B. Goodman et al.[3] to be as low as 20 kOe for $\dot{H} = 10^6$ Oe sec^{-1}. The fields reported by Flippen for $\dot{H} = 10^9$ to 10^{11} Oe sec^{-1} are in the range 15-30 kOe. The agreement is adequate, considering the crudeness of both the calculation and the data. (Flippen's specimen, for instance, was not hollow but solid. Eddy current effects should depend strongly on geometry. Furthermore, the "critical currents" reported by Goodman were J_{c1} rather than J_{c2}, but since in specimens with strong pinning the field difference for fixed J is only a few kilo-oersteds,[4] we hope that this error will merely cancel out the error involved in using Flippen's resistive fields.)

We assume in accordance with slower pulsed experiments[4] that the critical current satisfies a relation $J_{c2}(H+B_o) = \alpha$ similar to the familiar one discovered for resistive currents by Kim et al.[5] If we assume equality holds in Eq. (2), then it follows that H should be linear in the rise time τ for a given specimen, and H should be linear in $1/r$ for fixed τ. When we plot Flippen's data points for $H(\tau)$ and $H(1/r)$ respectively, we find that they are indeed linear. Moreover, the slopes and intercepts of the two plots yield values of B_o and α which are reasonably close together. This is too much of a coincidence to be accidental.

One very important conclusion can be drawn immediately: it is possible to get reliable values for J_{c2} undistorted by Joule heating from experiments in which either the current or field is pulsed, provided the rise time is sufficiently short. This is clearly demonstrated by the reversibility of Flippen's transitions. Subsequent experiments, however, should be performed on more ideal materials with a controlled geometry.

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