Title
REVERSIBLE PHASE TRANSITION OF A TYPE-II SUPERCONDUCTOR INDUCED BY CRITICAL EDDY CURRENTS

Permalink
https://escholarship.org/uc/item/1rh1m9x0

Author
Boyd, R.G.

Publication Date
1965-09-01
REVERSIBLE PHASE TRANSITION OF A TYPE-II SUPERCONDUCTOR
INDUCED BY CRITICAL EDDY CURRENTS
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
REVERSIBLE PHASE TRANSITION OF A TYPE-II SUPERCONDUCTOR
INDUCED BY CRITICAL EDDY CURRENTS

R. G. Boyd

September 1965
REVERSIBLE PHASE TRANSITION OF A TYPE-II SUPERCONDUCTOR
INDUCED BY CRITICAL EDdy CURRENTS

R. G. Boyd

Inorganic Materials Research Division, Lawrence Radiation Laboratory,
University of California, Berkeley, California

Recently R. B. Flippen$^1$ reported a rather puzzling pulsed magnetic field experiment in which he observed a drop in the transition field of Nb25% 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

\[ E = \frac{r \dot{H}}{2c} \]  

(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,

\[ J_{c2} \geq J_e \geq J_n = 5 \times 10^{-3} \frac{r \dot{H}}{\rho} \]

(2)

where \( r, \dot{H}, \) and the normal resistivity \( \rho \) are in cm, Oe sec\(^{-1}\), and \( \mu\Omega\cdot\text{cm} \) respectively. The field \( H \) at which equality holds provides an upper bound for the transition field.

Mean values of \( r, \dot{H}, \rho \) appropriate to Flippen's experiment are \( 10^{-2} \) cm, \( 10^{10} \) Oe sec\(^{-1}\) and \( 30 \mu\Omega\cdot\text{cm} \). Substituting in Eq. (2), we find
The field $H$ corresponding to this current for Nb 25% Zr wire was reported by B. B. Goodman et al.\textsuperscript{3} to be as low as 20 kOe for $H = 10^6$ Oe sec\textsuperscript{-1}. The fields reported by Flippen for $H = 10^9$ to $10^{11}$ Oe sec\textsuperscript{-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, 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\textsuperscript{4} that the critical current satisfies a relation $J_{c2}(H+B_0) = \alpha$ similar to the familiar one discovered for resistive currents by Kim et al.\textsuperscript{5} If we assume equality holds in Eq. (2), then it follows that $H$ should be linear in the rise time $\tau$ for a given specimen, and $H$ should be linear in $1/\tau$ for fixed $\tau$. When we plot Flippen's data points for $H(\tau)$ and $H(1/\tau)$ respectively, we find that they are indeed linear. Moreover, the slopes and intercepts of the two plots yield values of $B_0$ and $\alpha$ 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.
ACKNOWLEDGEMENTS

I wish to thank Mas Suenaga for permission to use his unpublished work in this letter, and also Kenneth Ralls for helpful discussions of (pulsed magnetic field) critical and resistive currents in type-II superconductors. This work was supported by the United States Atomic Energy Commission.

REFERENCES

4. Mas Suenaga, private communication. In his experiments, however, reversibility has been achieved only over part of the range in J.
This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.