

PROPOSAL FOR A FLUX PUMP UTILIZING THE INVERSE ETTINGSHAUSEN
EFFECT IN HARD TYPE II SUPERCONDUCTORS IN THE MIXED STATE*

W.H. Bergmann
Argonne National Laboratory
Argonne, Illinois

Most of today's superconducting magnets require large dc currents. Usually these currents are produced at room temperature and are transferred through leads into the low temperature environment of the magnet. The resulting heat losses are often a major component of the total losses. Therefore the attempt was made to equip the first superconducting magnets with thermally-operated superconductive switches. Such a device permits - in principle - operation of the magnet in a persistent mode, disconnecting the input leads. Unfortunately, it is nearly impossible to construct a superconducting magnet without normal resistive joints between the different superconductors. Therefore, most of the magnets operating in the persistent mode show a decrease of field with time. Thus devices with small heat losses which can charge the superconducting magnets and operate at liquid helium temperature are of interest. To these ends three different approaches have been made up to now. Giaever¹ demonstrated the principle of a superconducting dc transformer. Buchhold² introduces a small primary ac current, transforms and rectifies it with controlled power cryotrons at liquid helium temperatures. Volger³ proposed the first superconductive generator by which a "macroscopic fluxoid" by appropriate motion was threaded literally into the magnet circuit.

Especially the latter class of devices invites speculation as to whether the dynamic properties of the Abrikosov vortices in type II superconductors could not be utilized for charging a superconducting magnet. Otter and Solomon⁴ recently observed in type II superconductors two thermomagnetic effects analogous to the Ettingshausen and Nernst effects, which are associated with the motion of vortices. In particular, they measured the temperature gradient produced by the transport of entropy when vortices flow across a type II superconducting sample. They also established the existence of the inverse effect - the motion of vortices along an imposed temperature gradient. By this they demonstrated that thermal gradients are a driving force for moving vortices away from the warmer part of the sample,

We would like to propose, therefore, to connect the terminals of the superconducting magnet with a type II superconducting ribbon in the mixed state, much in the same fashion as it is done with superconductive switches for operation in the persistent mode. Under constant current operating conditions, this strip would act as a persistent mode switch. If we wish to change the field in the magnet, then we would have to apply a transverse temperature gradient across this strip. This would result in the vortices flowing either to the "inside" or to the "outside" of the strip and, since the vortices carry flux, it would transport flux either into the magnet circuit or out of it.

* Work performed under the auspices of the U.S. Atomic Energy Commission.

1. I. Giaever, Phys. Rev. Letters 15, 825 (1965).
2. T.A. Buchhold, Cryogenics 4, 212 (1964).
3. J. Volger and P.S. Admiraal, Phys. Letters 2, 257 (1962).
4. F.A. Otter, Jr. and P.R. Solomon, Phys. Rev. Letters 16, 681 (1966).

It is very difficult at present to estimate the efficiency of such a flux pump. Otter and Solomon made their experiments with a very "weak" type II superconductor, an alloy of In with 40 atomic percent of Pb. They give the critical current density at 600 G as 40 A/cm². But they demonstrated that the thermal driving forces are of the same order as the Lorentz forces.

Thus experiments with superconductors of high current-carrying capacity and variable pinning forces, as, for instance, niobium-titanium alloys, and niobium tin are indicated. But the important advantage of this flux pump would be that it could lead to an "autocharging" of superconducting magnets. The whole magnet could be constructed of one short-circuited superconductor of which only one short region has to be equipped with an appropriate temperature control. This region should preferably be situated in the low field region of the magnet winding where Lorentz forces do not compete with the thermal driving forces for the vortices. The Meissner-Ochsenfeld effect could possibly be utilized to initiate the charging process.