IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

SUPERCONDUCTING MAGNET QUENCH PROTECTION FOR ISABELLE*

K.E. Robins, W.B. Sampson and M.G. Thomas
Brookhaven National Laboratory
Upton, New York 11973

SUMMARY

A system is described which allows the main series current in the ring magnets to automatically bypass a quenching unit. The method employs the switching capabilities inherent in silicon diodes operating at very low temperatures. Experimentally determined parameters are given for a high current diode suitable for use in superconducting accelerators and storage rings.

INTRODUCTION

High-energy particle accelerators invariably involve the operation of large numbers of magnets in series. If these magnets are superconducting the possibility of one of the units quenching at full field must be taken into account in the design of the circuitry. The current must be able to bypass the quenching magnet or the total stored energy of all the series units can be deposited in this one magnet with potentially disastrous consequences. Quench protection schemes can be active (the quench is detected and suitable switching performed by elements in the protection circuit), or passive (no detection is required), with the current shunting occurring automatically. In this paper we describe a passive system which uses diodes operating at very low temperatures.

DIODE PROTECTION

The quench protection method originally proposed for ISABELLE[1] consisted of shunting each magnet by a series of room temperature diodes connected between "protection" leads as shown in Fig. 1a. Under normal

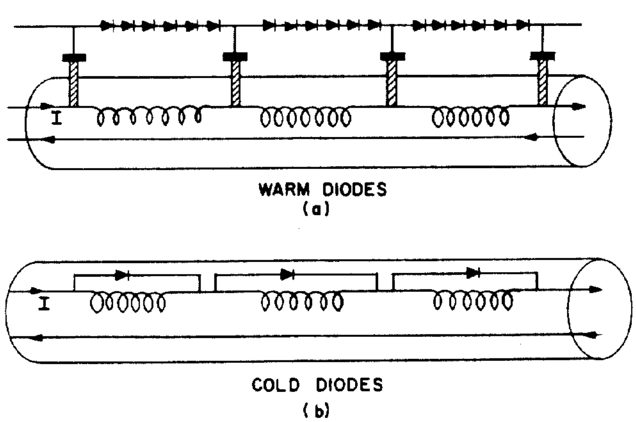

Fig. 1. Diode connection for quench protection - a) ambient temperature diodes, b) cryogenic diodes.

conditions the forward bias voltage of these diodes is high enough to prevent any leakage current but when a magnet "quenches" the voltage across the diodes exceeds this bias voltage and the current passes through the diodes shunting the magnet. There are two difficulties with this scheme; a large number of expensive diodes are required (six are needed to withstand the inductive voltage across the magnet during energizing) and the protective leads represent a substantial thermal load. These difficulties can be overcome by installing the diodes directly on the magnets (Fig. 1b) in the low temperature environment thus eliminating the leads. The properties of high current silicon diodes operating at low temperature are ideally suited to this application since the forward bias voltage is large enough to make a single element more than sufficient to withstand the inductive voltage.

LOW TEMPERATURE PROPERTIES OF SILICON DIODES

The fixture used to test diodes at cryogenic temperatures is shown in Fig. 2. Only the rectifier

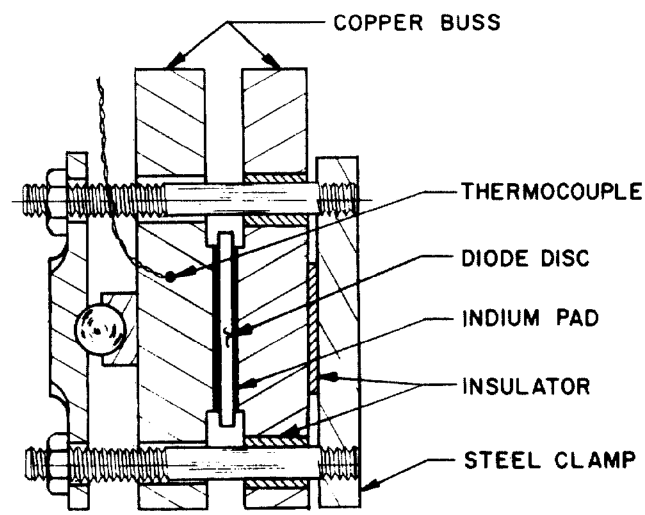

Fig. 2. Clamping fixture for low temperature diode testing.

disc is used and it is clamped between two copper blocks which act as both electrical connections and a thermal reservoir. Indium foil is placed on both surfaces to ensure uniform contact. The forward bias voltage is shown in Fig. 3 as a function of temperature for a diode rated at 3200 A at room temperature. The bias voltage increases gradually from approximately 0.7 V at room temperature to slightly more than 1 V at 30 K. Below this temperature the bias voltage increases rapidly and exceeds 20 V at 4.2 K. The leakage current is drastically reduced at low temperature as shown in Fig. 3. The combination of the very low enthalpy at reduced temperatures and the discontinuity at 30 K result in a switch-like behavior of the diode when it begins to carry current at 4.2 K. At 3000 A the diode reaches 30 K and "switches" to 1 V in about 10 μs when attached to a thermal sink of 7 kilograms of copper.

OPERATION OF THE QUENCH PROTECTION DIODE

The sequence of events occurring during a cycle in which one of the ring magnets quenches at full field is shown in Fig. 4.

*Work performed under the auspices of the U.S. Energy Research & Development Administration.

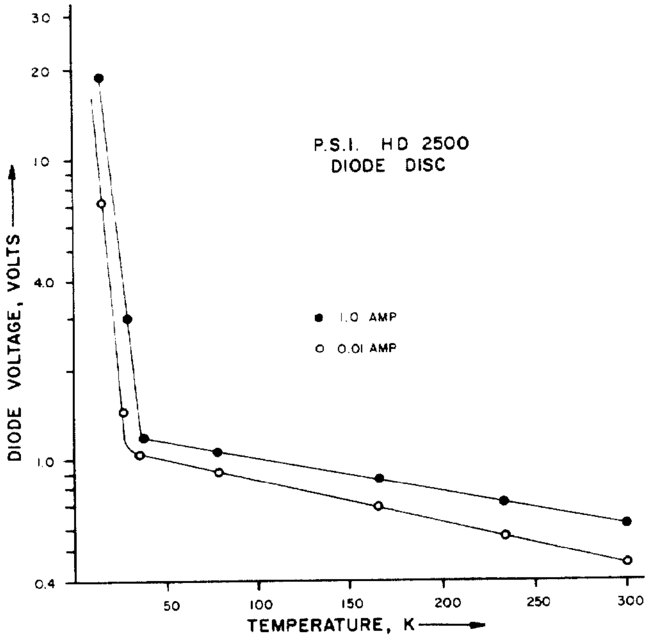

Fig. 3. Forward bias voltage for a high current silicon diode as a function of temperature.

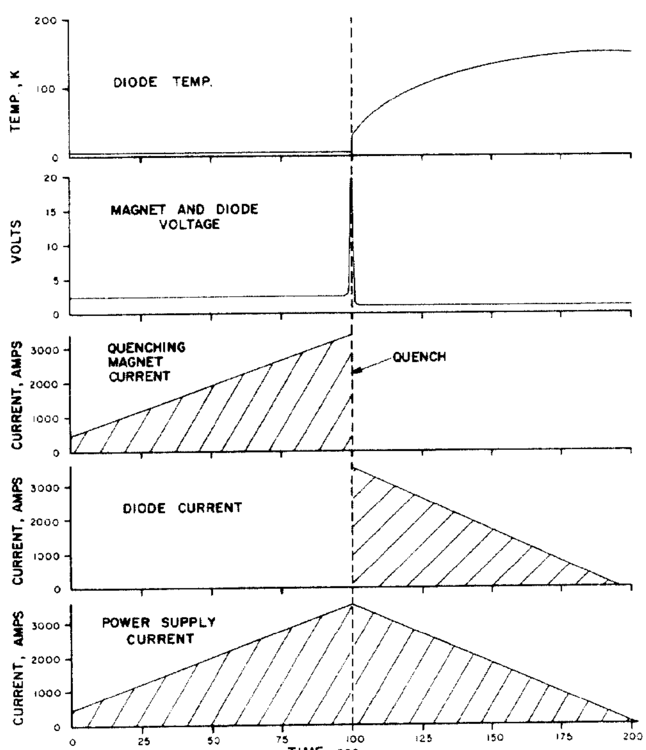

Fig. 4. Current and voltage waveforms for a diode clamped superconducting magnet.

1) The power supply current increases linearly from injection field until the quench occurs; the supply then changes polarity and runs the current down just as it would if the cycle had been completed without a quench.

2) The diode current which is zero during the energizing part of the cycle, rises to the full series current at quench effectively bypassing the magnet.

3) The magnet current increases until the quench, then it drops rapidly to a very low value as the current switches to the diode.

4) The voltage across the magnet and diode is constant during energizing but jumps to 20 V at quench and drops almost immediately back to the 1 V level.

5) The temperature of the diode rises rapidly at quench to about 30 K and then increases more slowly as the current decreases.

The final temperature of the diodes depends on the turn off time and the heat capacity of the thermal sink. Diodes such as the PSI HD2500 can carry a current considerably greater than their nominal room temperature rating when operating at reduced temperatures. It should be pointed out that the stored energy of the magnet which quenches must be dissipated in that magnet if the diode scheme is used.

While the diode will automatically shunt the current around a quenching magnet a number of other actions must be taken in an operating storage ring if one of the magnets goes normal. The beam must be dumped very quickly and the power supply polarity reversed. Warm gas from the normal magnet can cause other magnets in the system to quench unless it is vented. The ISABELLE cryogenic system employs a high pressure helium cooling loop which passes through many magnets in series. Vent valves which are electrically opened at both ends of the magnet when a quench occurs allow the warm gas to return to a storage without passing through neighboring magnets. The heat pulse requires approximately 200 ms to go from the center of a transitioning magnet to its nearest neighbor thus allowing sufficient time for blow-off valve operation.

Relatively little is known about the reliability of silicon diodes under these conditions, but our experience indicates that they can withstand repeated thermal and electrical cycling without damage. A welded port is provided in each magnet so that a shorted diode can be replaced if necessary.

References

1. ISABELLE - A Proposal for Construction of a Proton-Proton Storage Accelerator Facility, BNL Formal Report 50519 (1976).