THE TEST OF THE QUENCH PROTECTION DIODES FOR HERA

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Abstract: The coils of all major superconducting magnets in the HERA proton storage ring are bypassed by diodes contained within the helium vessels. Each dipole is protected by two and each quadrupole by one diode. These diodes must operate in a temperature range from 4.2 K up to about 450 K (junction temperature). All diodes for the quadrupoles and by now most of the diodes for the dipoles have been tested at cryogenic temperatures prior to their installation in the magnets. Data is presented on the forward and reverse conductivity and on the distribution of the maximum forward voltage for the diodes.

Introduction

The quench protection of the HERA main magnets, described elsewhere [1], is based on the use of heaters and bypass diodes. These diodes are, following the ideas developed for ISABELLE [2], mounted inside the inner liquid helium vessel. This has a number of advantages, in particular an electrical connection from the cold inner part to the outside at room temperature is avoided. Connections of this type introduce heat leaks and tend to be very expensive. In contrast the connection of "cold" diodes to the coil can be made electrically highly conducting. This is of some importance: during a quench the current will be transferred into the parallel diodes and after some time be shared according to the ratio of resistance in the quenching coil to the total effective resistance of the diodes including connections. It is needless to say that the mounting of diodes inside the helium vessel on the other hand presents disadvantages which have, nevertheless, been accepted.

Choice of a suitable diode

A suitable diode has to fulfil the following, partially contradictory, specifications:

The diode has to operate safely down to very low temperatures, such that the onset of normal semiconduction occurs after a very short warmup time.

Obviously, as the diodes heat up during operation, they should withstand the expected thermal stresses.

The forward voltage drop at low temperatures should be as low as 4...5 Volts to enable a rapid switching of the current. In the case of asymmetric quenches, i.e. if only one half coil is quenching, due to magnetic coupling of both half coils, the current is increased in the rest of the magnet system and in the other half coil if both half coils are separately bridged by diodes. Under these circumstances a backward voltage is developing across the non-conductive diode. This voltage depends, amongst other things, on the details of the quench and the coil-coil coupling. Realistic extrapolations from the string test [3] for HERA dipoles indicate values around 100 V for currents below 5.5 kA.

The diode has to be mounted reliably, i.e. preferentially in a preassembled package, which can be screwed into the confined volume of the helium vessel easily. The helium tight seal should be easy to open and close.

Finally, close to the particle beam, radiation has to be expected of the order of 10^{11} n/cm^2 per year. This should not alter the performance of the diodes in any critical respect.

After some trials, the diode DS 1508-02A01 [4], a mechanically modified DS 6000, without protecting silicone rubber on the wafer, was selected because it proved to have the lowest on-resistance, minimizing the heat generation and associated thermal stress problems. It was hoped and expected that the heavily doped and thin wafer would be optimal with respect to radiation insensitivity. Our own tests [5] and more elaborate measurements by Zeigler et al. [6] have indeed demonstrated a remarkable degree of insensitivity to radiation, in contrast to other diodes.

Mounting and test procedure

The diodes come pretested in their original hockey puck packaging from the manufacturer. The contact surfaces are visually inspected, the metal seals of the package cut open, and the diodes mounted together with likewise inspected copper blocks into an assembly, as shown in Figure 1.

Fig. 1 Photograph of a diode assembly for a dipole

Copper beryllium spring washers and the spring action of four steel rods press the copper blocks, which act as both the current connections and heat sinks, against the diodes. Locating pins and guidance steel pieces at both ends guarantee the centricity of the compressional force. G10 endcaps insulate the steel blocks at the top and the bottom from the electrical connections and the springs. To detect long term changes in the production of all parts every fifth diode package is packed with pressure sensitive film [7] between the diodes and the copper pieces. Next the contact force is adjusted to 18 kN by measuring the change in length as a function of the applied force. As both the washers and the rods act as springs, the effective strength of the combined spring depends on the length of the rods. The screws of the steel rods are normally adjusted such that the washers apply a force of 18 kN. If the copper blocks thermally expand, the steel rods are pulled and the contact pressure is kept roughly constant. After a proper adjustment the packages with the pressure sensitive films are reopened. The uniform colouring of the film indicates a uniform pressure distribution. Surface defects or systematic skewness are detected down to about 3 µm. (These packages have to be repacked again.) This completes the mechanical measurements.

To test the electrical performance the packages are fixed in a special cryostat. While still at room temperature and in normal atmosphere the forward and backward conduction voltages are tested. The acceptance limits are i_r < 0.5 mA at U_R = 500 V.

After pumping and cool down in liquid helium (about one hour) the voltage test is repeated. Now only diodes with less than 3 mA at 300 V are accepted. To test the electrical connections an exponentially decaying (τ = 18 sec, as in HERA) current pulse of 800 A is applied to the series connected diodes. All voltages, the current and the temperature of the middle copper connection block are recorded. If all appears normal 19 current pulses of 6400 A are applied to the package. For all pulses, current, voltages and temperature are recorded. After this treatment the backward current is remeasured. Normally no change is observed. In 45 min the cryostat can be warmed up. The various parts and surfaces of the package are now labelled, to facilitate identical package reassembly at a later date, should it be necessary. The packages are sealed in a PVC bag together with a dessicant. The data of the last current pulse are saved on the disk of an IBM-AT and copied to a backup diskette. In addition a short-form protocol is sent and saved on VAX. In parallel plots are prepared and kept in a folder together with a copy of the protocol.

Because the fixture used is unable to withstand high currents for longer period of times, no burn-in at room temperature is performed. Furthermore, it seemed inappropriate to use a dedicated test stand for this purpose, given that the test with the current pulses more closely approaches the real application of the diodes.

Results

Out of 590 diodes tested to date 24 have had to be rejected. Four developed scratches on the surface due to inappropriate handling. Twenty were rejected because of high backward current or even breakdown at 300 V. In some cases this was due to the test procedure applied to the first 100 diodes. At that time the backward voltage of the diodes was remeasured at room temperature, neglecting the fact that the diodes were by that time still flushed with helium. A few diodes were consequently destroyed by flashovers. The diodes show a very narrow distribution of forward voltages, as plotted in Figure 2.

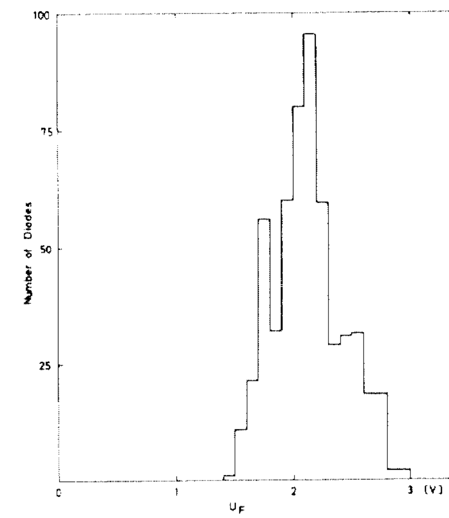

Fig. 2 Forward voltage drop of the diodes

On average the voltage is 2.12 ± 0.3 V, taken at a current of approximately 20 A, the lowest practical current of the 8000 A power supply. The temperature has been estimated to be around 10 K under these circumstances.

In a test with a string of magnets [6] six diodes could be repeatedly tested at various currents. A typical example is shown in Figure 3. As expected, the voltage increases slightly with the current. The error bars indicate the statistical fluctuation of repeated measurements. All diodes tested have forward voltages between 3.7 and 5.0 Volts.

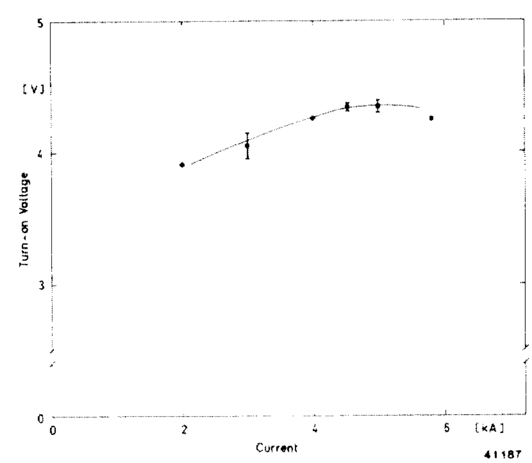

Fig. 3 Turn-on voltage as a function of current of a typical diode at 4.6 K

Conclusions

By the end of April 590 diodes had been mounted in a fixture and tested. 4% of these diodes had to be rejected. The tests of the diodes for the quadrupoles is finished.

69 single packages for the quadrupoles and 42 twin packages for the dipoles have been shipped to the various magnet manufacturers. The tests will be completed by the end of 1988.

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7 Fuji Film, prescale pressure type medium