THERMAL SAFETY OF THE DØ SOLENOID AFTER POWER SUPPLY FAILURE

R. P. Smith

January 20, 1998

ABSTRACT

The DØ solenoid was shown to be completely safe when deliberately quenched without a protection resistor in factory trials at Toshiba. In the tests the power supply was turned off shortly after the onset of the quenches. In this note an examination is made of the consequences to be expected if the power supply fails to turn off after the onset of a quench.

1 NOMINAL QUENCH SAFETY OF THE SOLENOID

The specifications for the DØ solenoid required it tolerate quenching with no protection resistor. Quench modeling calculations showed [1] that whereas the peak temperatures in the coil after a quench into a 50 mOhm protection resistor would not exceed about 55 K, a quench without a protection resistor would lead to peak temperatures not exceeding about 165 K. (With a 5 mOhm resistor the calculations gave a peak temperature of about 145 K). These calculations ignored the helpful phenomenon of quenchback [2] so were judged conservative.

To deliberately quench the magnet without the use of a protection resistor during the factory tests at Toshiba, a 5 mOhm resistor (blocked by a series diode from the power supply charging voltage) was installed in the test circuit. The magnet was then charged at 6 V and forced to quench as the eddy-current heating from the rapid charging, and the rapidly rising current itself, finally exceeded the conductor critical margin. The magnet quenched at 4650 A (88% of full operating current) and the small protection resistor removed only about 12% of the stored energy. The test clearly indicated that the specified design safety of the coil had been achieved. Thermometry on the coil showed that the peak temperature was about 130 K.

The coil temperatures measured in the Toshiba quench test are shown in Figure 1.

2 EXTENDED QUENCH SAFETY OF THE SOLENOID

From the foregoing it is clear that the DØ solenoid will discharge safely in the unlikely event the dump switch fails to open due to a failure of the protection system. It is instructive to consider the added hazard of failure of the power supply to turn off in such an incident.

Figure 1: Toshiba Quench Test, 5 mOhm Protection Resistor

The Fermilab power supply is configured to provide at most 15 V in the event complete failure of the controlling circuitry is experienced. At room temperature the magnet has a resistance of approximately 1.5 Ohms. Clearly if the magnet is at this temperature the power supply cannot introduce significant current nor heating into the coil – about 10 Amperes and 150 W respectively. At low temperatures however the magnet resistance is 500 – 1000 times less and the possibility of significantly greater energy being supplied to the coil exists.

To quantify the consequences of such excess heating a calculation has been made, wherein the discharge of the magnet from full current with and without the presence of the power supply providing additional current, is modeled. The calculation assumes the entire coil is resistive at a temperature of 4.2 K, so the final temperature obtained is that of the uniformly heated coil, not the peak temperature of a realistic quench calculation which tracks the temperature of the region around the location where the quench began.

With no power supply in the circuit the final uniform temperature after magnet discharge with no protection resistor in the circuit is about 69 K, and with a 15 V power supply added to the circuit the final uniform temperature is about 72 K. The rapidly rising magnet resistance reaches a final value of about 120 mOhms in either case so the influence of the power supply is quite negligible overall.

The calculated behaviour of the magnet with the power supply continuously energized during the discharge is shown in figure 2. The total energy delivered to the magnet is about 6.3 MJ; the stored energy in the field was about 5.5 MJ so the power supply added only about 0.8 MJ during the discharge.

In the event of an actual quench under these quite abnormal circumstances one concludes

Figure 2: Calculated discharge heating with power supply active

the peak temperatures in the coil would be increased over those actually observed in the Toshiba test by only a few Kelvins at most.

It might be noted the final current in the magnet with the power supply operating is about 60 Amperes after the discharge rather than zero as it eventually is if the power supply voltage is zero at the outset. The heating power delivered to the magnet at 60 amperes is small and would continue to fall as the magnet slowly warmed if the power supply continued to operate for greatly extended times.

3 CONCLUSIONS

The quite extreme assumption of simultaneous failure of the magnet power supply to switch off and the dump switch to open in the event of a magnet quench is seen to be completely harmless to the magnet.

References

- [1] Toshiba Corp, Revised Preliminary Design TFD-026, May 31, 1995.
- [2] M. A. Green, "Large Superconducting Detector Magnets with Ultra Thin Coils for Use in High Energy Accelerators and Storage Rings", p. 429, Proceedings of the 6th Int. Conf. on Magnet Technology, Bratislava, 1977.