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RESULTS FROM COMMISSIONING OF THE ENERGY EXTRACTION FACILITIES OF THE LHC MACHINE

G. J. Coelingh, K. Dahlerup-Petersen, K.H. Meß

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The risk of damage to the superconducting magnets, bus bars and current leads of the LHC machine in case of a resistive transition (quench) is being minimized by adequate protection. The protection is based on early quench detection, bypassing the quenching magnets by cold diodes, energy density dilution in the quenching magnets using heaters and, eventually, energy extraction. For two hundred and twenty-six LHC circuits (600 A and 13 kA) extraction of the stored magnetic energy to external dump resistors was required. All these systems are now installed in the machine and the final hardware commissioning has been undertaken. After a short description of the topology and definitive features, layouts and parameters of these systems the paper will focus on the results from their successful commissioning and an analysis of the system performance.

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TOPOLOGY OF THE SYSTEMS

Similar to other accelerators [1], [2], [3], all magnets in the LHC that are connected in series utilize energy extraction systems to locally protect each magnet in case of a quench from the stored energy of the remainder of the circuit. Three current ratings are used to categorize the magnet circuits, and the associated protection systems. The 13kA circuits utilize a quench detection system [5], a cold bypass diode, quench heaters internal to the magnet coil [4], and stand alone energy extraction devices. The 600 A circuits utilize a global quench detection system, local bypass resistors and an energy extraction system mounted in racks close to the power converter. For the remaining lower current circuits energy extraction is done using the power converters only. This paper describes the performance of the 13 kA and 600 A systems only.

THE 13 kA EXTRACTION SYSTEMS

The LHC is subdivided into eight independently powered and protected sectors. Within each sector, the electrical circuits of the dipole magnets are further subdivided into two units, one on either side of the sector, to reduce the maximum voltage to ground. The two 13 kA quadrupole circuits in each sector are protected by two smaller units.

In each sector, each of the four protection units consists of eight mechanical breakers in four parallel branches, bypassed by a set of indirectly cooled stainless steel resistors [6].

The maximum temperature and maximum voltage reached during an extraction cycle, and the re-cooling time of the resistor, are of particular interest. The length and variation of the opening and the arc time of the switches have an influence on the lifetime and the reliability of the system.

Figure 1: A view on the 13 kA switch unit for the dipoles.

An 11 kA dipole quench during which more than 930 MJ must be extracted and absorbed is used as an example. Figure 1 shows the voltages across the switch assembly as a function of time. It can be seen that the opening of the four heavy and bulky switches starts simultaneously, followed by arcs flaring for a few milliseconds, and then all switches firmly open after only 13 ms.

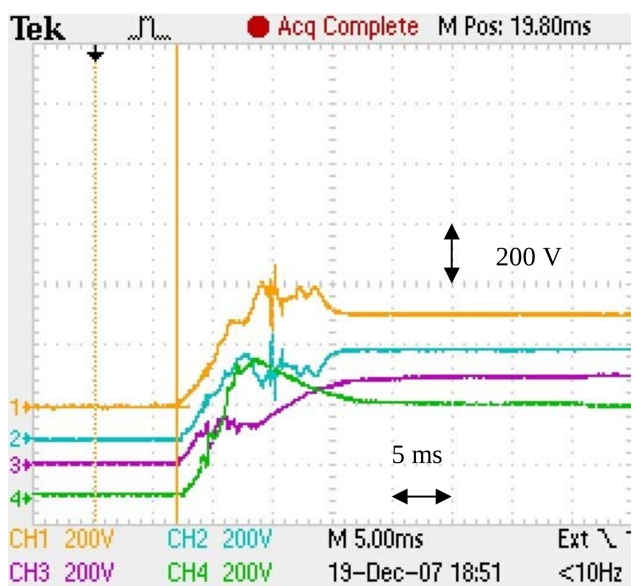

Figure 2: Voltages across the opening switches for an 11 kA quench.

Figure 3 shows in one plot the decay of the current after an 11 kA quench. The voltages follow closely each other, indicating a good match. The temperatures of the resistor blocks, absorbing more than 930 MJ all together, stay below 200 C. Finally, Figure 4 show the return of the temperature of the dump resistors to nominal operating levels within 1.5 hours, much shorter than the cryogenic recovery time.

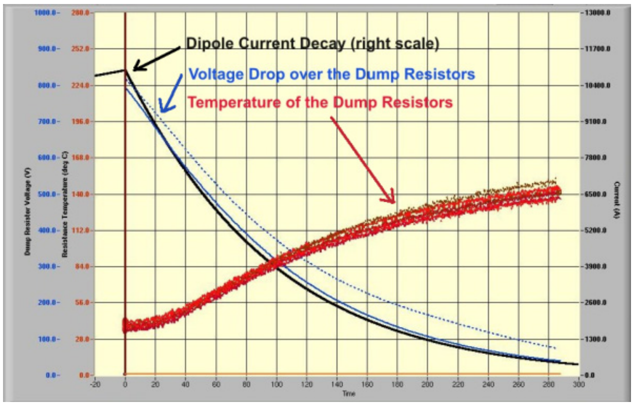

Figure 3: Current decay, voltage drop over the resistor and temperature rise during the first 300 s

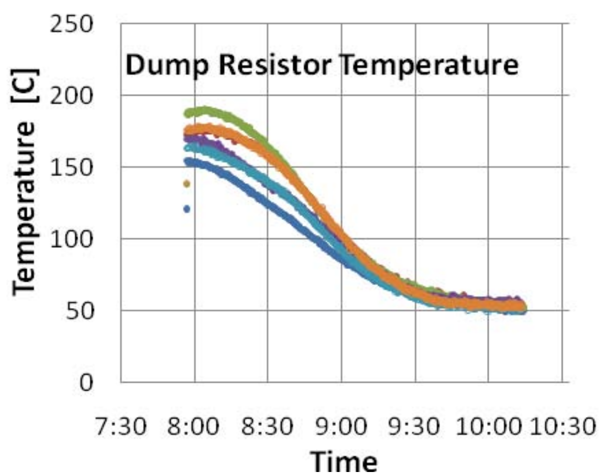

Figure 4: Cool down of the dump resistors.

THE 600 A EXTRACTION SYSTEMS

The LHC has two hundred and two 600 A circuits, and there is a separate extraction system for each. The 600 A extraction equipment is based on three individual, series-connected, high-speed electro-mechanical AC circuit breakers, with simultaneous operation of the three poles (Fig 5.). The circuit as a whole consists of three 440 μΩ equalizing resistors in series with the breakers, with the 0.7 Ω extraction resistor and the 0.8 mF snubber capacitor each in parallel across the breakers. The extraction resistors are made from thin sheets of stainless steel to ensure both a short cooling time and a small variation of resistance with temperature. Further details of their design can be found in [7]. Two extraction systems fit into an EURORACK, 43U.

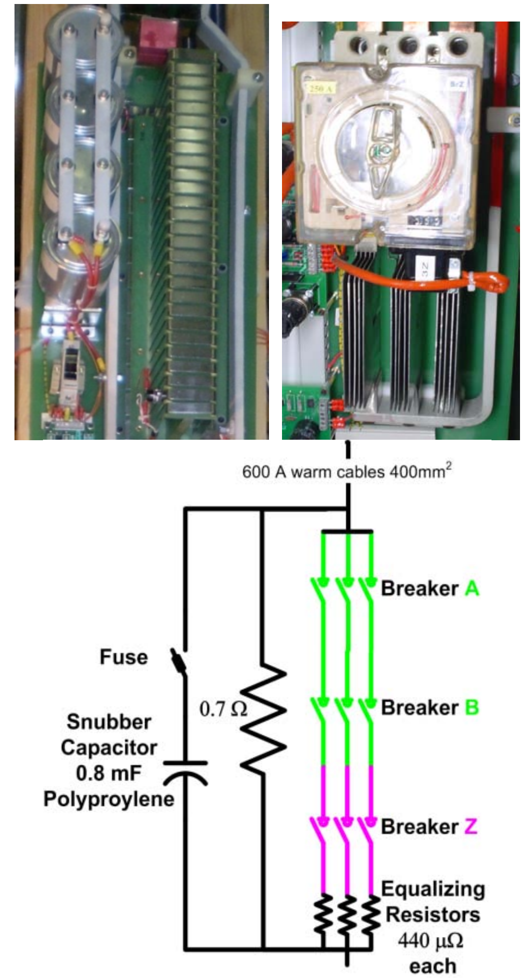

Figure 5: Extraction resistor (top left), breaker (top right) and the layout diagram.

In normal operation, in the case of a discharge request only breakers A and B are opened. Breaker Z is a back-up that opens only in case of a failure of both breakers A and B. This mode of operation increases the overall system reliability to more than 99.99% over 20 years of operation, provided the system is tested at least once per month.

Performance of the system is demonstrated in Figures 6 and 7 on the next page. The figures show the rise and decay of the voltage over the external extraction resistor for the case of the energy extraction out of a family of twelve 36 mH sextupole correctors [4] powered at 550 A, corresponding to a total energy of 65 kJ

The event-trigger (red) and the dump-resistor voltage development (blue, inversed polarity) with a total opening time of 14.6 ms are recorded in Figure 6. Figure 7 shows the same dump voltage (proper polarity) on a longer time scale. Note the remarkable change in decay rate, from 860 ms to 60 ms time-constant, after 60 ms. This marks the beginning the quench of all magnets in the circuit due to excessive heating by eddy currents and of the by-pass resistor during the fast de-excitation. The decay corresponds to a coil resistance of 560 mΩ, indicating a coil temperature between 20 and 40 K during these thermally induced quenches.

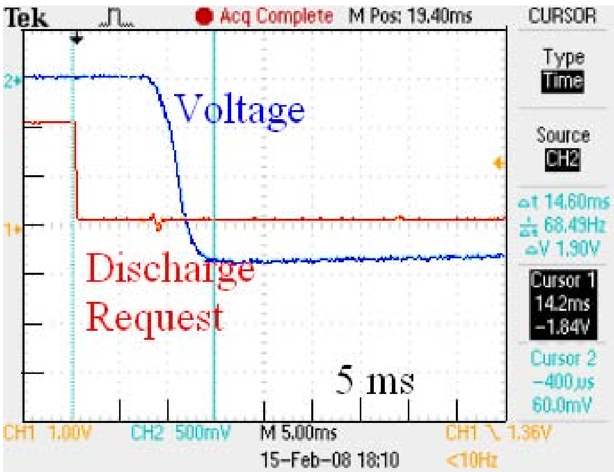

Figure 6: The rise and decay of the extraction voltage across the dump resistor at 550 A.

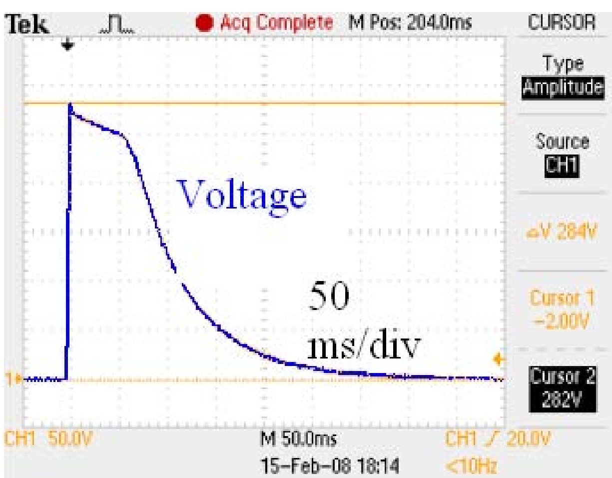

Figure 7: The rise and decay of the extraction voltage across the dump resistor at 550 A on an enlarged timescale.

CONCLUSION

At this time nine out of the twenty-four 13 kA systems were tested up to 11 kA. Sixty out of the 202 systems rated at 600 A were tested up to current levels of at least 200 A and many up to the nominal current of 550 A. Almost 500 switch openings under load were needed to reach this stage in hardware commissioning. All systems worked according to expectation and no opening failures or systems faults were reported.

ACKNOWLEDGEMENTS

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