X-rays probe LHC for cause of short circuit

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Engineers Aline Piguiet and Markus Albert take X-rays of the shorted superconducting dipole in sector 3-4 in the LHC tunnel . Credit: Maximilien Brice/CERN

The LHC has now transitioned from powering tests to the machine checkout phase. This phase involves the full-scale tests of all systems in preparation for beam. Early last Saturday morning, during the ramp-down, an earth fault developed in the main dipole circuit. Full evaluation of the situation is ongoing.

The machine checkout is an important coming together of all LHC systems. During this final phase before beam, the operations team tests all of the LHC subsystems to make sure the entire machine is ready for beam.

The various systems are put through their operational paces from the CCC. This includes important tests of the beam dump system and full-scale tests of the beam interlock system (BIS) and its many inputs from other systems around the ring. All magnetic circuits are driven through the ramp, squeeze, ramp-down, and pre-cycle along with the collimators and RF. Instrumentation, feedbacks, and the control system are also stress tested. Inevitably there is some final frantic debugging but, up to now, things seem to be in reasonable shape.

The powering test phase has left all but two of the 1700 or so magnetic circuits fully qualified for 6.5 TeV. This is the result of a six-month long programme of rigorous tests of the circuits involving the quench protection system, power converters, energy extraction, UPS, interlocks, electrical quality assurance, and magnet behaviour. Outstanding from this phase are the final quench training of sectors 34 and 45. The sector 45 dipoles have proved a little stubborn but are now at the equivalent of 6.51 TeV (10,990 A) after some 45 training quenches.

The sector 34 dipoles were very nearly fully trained to the 2015 target value of 11,080 A (6.5 TeV + 100 A). However, early last Saturday morning an earth fault developed in the main dipole circuit during the ramp-down following what was probably the ultimate training quench of this sector. All the protection systems functioned properly and there was no harm done. The fault developed at relatively low current and was intermittent in nature at this stage.

In-situ measurements by system experts have located the fault to within 10 cm by injecting current locally and using the standard cold mass instrumentation, which includes voltage and current taps. The fault is located in the vertical tube that leads from the magnet enclosure to the diode box situated under the magnet (see below). The most probable scenario is that a small piece of metallic debris has inadvertently found its way into this tube and is making contact between the tube (earth) and one of the cables that leads to the diode.

X-rays have been taken of the region. It's a difficult location and although some debris can be seen, the results are inconclusive.

Credit: Arjan Verweij

Three main options are being explored. The first would inject an energylimited pulse of current and attempt to melt the offending object. The second option would involve pressurising the helium in the local cryogenic sector and then performing a fast pressure discharge to generate turbulent flow and so dislodge the object. Studies and preparation for both these options are ongoing and both could be attempted relatively quickly.

The third option involves a partial warm-up of the sector and opening the magnet interconnect concerned. This would allow direct access to the diode box. The warm-up, intervention, and subsequent cool-down would take around six weeks.

Full evaluation of the risks of each option is ongoing. It's an interesting and frustrating problem; care is being taken that the only eventual cost is time.

Diode box

An essential element for the protection of the dipoles is a high-current bypass diode mounted under the magnet. The diode operates at a temperature of 1.9 K. The diode box that holds the diode contains superfluid helium and is connected to the main helium enclosure of the magnet.

When a magnet quench occurs, the current in the quenched magnet diverts to the diode in about 0.5 s, and the rest of the magnet chain in superconductive state slowly ramps down with time constants of the order of 100 s. Thus the diodes conduct a current pulse of up to 13 kA, which decays exponentially with a time constant of about 100 s. This can lead to a temperature rise inside the diode of up to 300 K.

Provided by CERN