WHAT DID WE LEARN WITHOUT BEAM IN 2008?

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Abstract

The lessons learnt without beam in 2008 are those learnt during the first campaign of hardware commissioning. In addition to these, during this session, the different speakers described the modifications required on the hardware and on the test procedures following the September 19th incident.

TRAINING THE DIPOLES

Chronologically, the first surprise was the assessment that the training of the dipoles was taking much more time than expected. The figure below shows the observations in Sector 56 where an extensive training campaign was carried out and interrupted at 6.6 TeV.

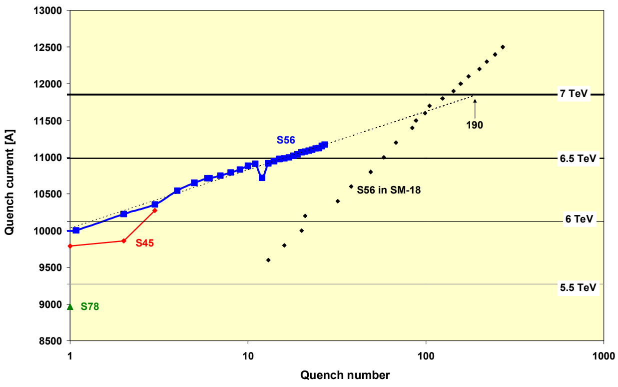

Figure 1: Training in the tunnel versus training at the test benches

The estimates and the arguments behind them are given in detail in [1].

SUPERCONDUCTING ELECTRICAL CIRCUITS

During the commissioning campaign a number of unexpected observations were made; these are reported in detail in [2]. A number of these, the easy ones, were understood, corrected or compensated for: they range from the difficulty to understand some measurements to clear non-conformities (e.g. short inside a dump resistor halving the time constant of a circuit, insufficient wetting of bus-bar inside of a DFB due to a levelling problem). Some observations will recur and are expected to slow down operation because of the effect they have on the magnets themselves or the protection systems (e.g. demagnetization of a quenching magnet which is used as a reference in the quench detection system). More serious are the observations which could evolve in potentially dangerous situations: some of those are being dealt with during this shutdown (like the upgrade of the quench protection system to include the detection of symmetrical quenches) others like quench back on some corrector circuits must be carefully investigated and understood in the long run. Cases of intermittent faults like voltage tap non-conformities were also reported.

A number of observations like the fast quench propagation over very long distances (1.5 km) remain to be studied and resolved.

THE SECTOR 34 INCIDENT

After September 19th incident, a task force [3] was set up and given the mandate to establish the sequence of facts, analyse and explain the development of events and recommend preventive and corrective actions to avoid a further incident of the same type.

The task force established that the initial fault developed in an interconnect splice on the dipole circuit where both the longitudinal continuity of the copper stabilizer and the bonding of the superconducting cable to the stabilizer were missing. This assumption was confirmed by simulation.

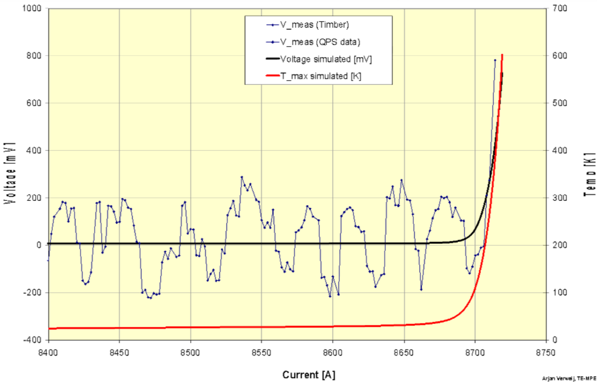

Figure 2: Measured versus simulated incident with 220 nΩ joint and bad contact with U-profile and wedge

A study of how the energy stored in the magnets was dissipated at the time of the event where the circuit was energized with 8710 A showed that almost half of the energy (275 MJ) was used to create electrical arcs which punctured the helium vessel. This caused a helium discharge from the cold mass into the insulation vacuum with a flow that was calculated to be as high as 23 kg/s. This is well above the nominal design value of 2 kg/s for which two DN90 relief devices were installed on each insulation vacuum subsector. The pressure rise was responsible for the forces on SSS vacuum barrier, which displaced the cold masses and caused the collateral damage. Secondary arcs were also created in two different positions. Certain regions of the beam vacuum were heavily contaminated with soot.

The task force formulated recommendations on two axes: the first ones aim at the prevention of initial fault and the second ones aim the mitigation of consequences. They concern actions, hardware upgrades, improvements of test procedures as well as personnel access rules. Many of these are already implemented during the present shut down, others will be implemented during the commissioning and operation of the collider.

CALORIMETRIC AND ELECTRICAL MEASUREMENTS

One of the first studies of the task force was the examination of data recorded during the tests to assess whether there were precursors to the September 19th incident that had gone undetected. This analysis revealed [4] that some sectors indeed had shown an anomalous increase of temperature during high current plateaux. Among them Sector 34 which exhibited a parabolic increase of 30 mK per hour during a one hour-long plateau. The observations however were done in unstable conditions because of the activity of the temperature control loops. A method was developed to repeat these measurements in normalized conditions; the method was validated by simulating the heat load of a faulty splice with a heater located inside the cold mass. Clearly these measurements will have to be repeated during the recommissioning. This method revealed two additional regions in the collider (Sector 12 and Sector 67) where abnormally high heat loads were measured during current ramps in the dipole circuit.

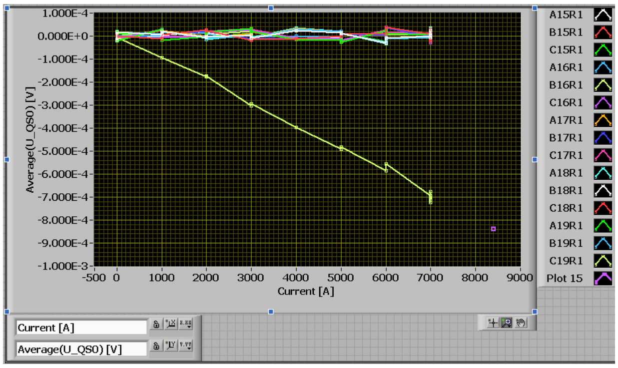

Figure 3: Confirmation of a100 nΩ resistance measured inside a magnet cold mass (B16R1) spotted by calorimetric measurements

These suspect regions were equipped with voltmeters to measure, with an accuracy of a few µV, the voltage drop across the splices in the interconnects. These electrical measurements did not reveal any non-conformity and only confirmed very good quality splices. It was therefore decided to measure the resistance of the splices inside the magnets: the splices in the coils, the inter-pole and inter aperture splices. This measurement could be carried-out with existing quench detection electronics. They indeed revealed faulty splices with resistances compatible with the calorimetric measurements. The data collected during the measurements at the test benches confirmed the findings.

CRYOGENICS FROM FIRST COOL DOWN TO FIRST BEAMS

The performance of cryogenic system [5] as a whole has improved with the experience gained after the cool down of each sector, the quench recoveries and the recovery from outages of the infrastructure systems or faults in the cryoplants themselves. The calculated estimates for a sector cool down of 14 days could not be confirmed; this figure is now revised to 30 days: they are split between the cool down from room temperature to 20 K which require 25 days, the filling of the cold masses which require 3 days and the cool down from 4.5 K to 1.9 K which takes another 2 days. It is worthwhile mentioning that towards the end of the year almost two months of continuous operation of the 1.9 K cold compressors could be achieved.

The possibility to run two sectors on one cryoplant was validated during powering tests on the sectors around Point 6. The power consumption could be reduced to 5 MW compared to the 2x4MW if the two cryoplants are operating. Although this method is not valid for large transients, it is an interesting alternative for low beam loads and it is a validated fallback scenario if serious problems are encountered with one refrigerator. Whether this is applicable to all the plants remains to be confirmed.

The very stringent requirements of the powering tests highlighted non conformities which required consolidation actions when possible or workarounds to continue with the tests: among those, the non conformities on the level gauges of the stand alone magnets, heat load on a superconducting link, valves on current leads, heat loads on the triplet, etc. The stability of the cryoplants and the infrastructures around them, the DFB, current lead and beam screen cooling loops as well as the coupling of the cold compressors after a fault are to be noted. A number of consolidation actions are taking place during the shutdown at the interface with the infrastructure systems (e.g. electricity distribution, cooling water, vacuum interlocks) to achieve better tolerance to short interruptions

WHAT ELSE DID WE LEARN?

To complete the picture of the lessons learnt during commissioning without beam the experience [6] gained with the procedures and the tools, which implemented them as well as the tools assisting the operators for the execution and the analysis, was described. All these guaranteed efficiency, automation and excluded any compromise; also, they ensure that the same test sequence and the same analysis of the data are repeated again and again on the different circuits of the eight sectors. A number of non-conformities discovered on some of the superconducting circuits were also mentioned for completeness.

CONCLUSIONS

Many surprises were encountered during the commissioning campaign: the training behaviour of the dipoles in the tunnel and the incident in Sector 34 were the biggest.

During most of the commissioning campaign the observations matched what was expected; in a few cases however, they revealed non-conformities some of which remain to be understood, followed and corrected.

Even if, during the commissioning, the equipment owners and the operation crews gathered the experience which they will apply to re-commission, run and debug the equipment, the incident in Sector 34 forces us to review and upgrade some of the protection and safety systems. This experience and the introduction of new hardware will now require additional test procedures.

REFERENCES

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[3] The Sector 34 Incident, Ph.Lebrun, this workshop
[4] Calorimetric and electrical measurements and related software, N.Catalan-Lasheras, this workshop
[5] LHC Cryogenics: What did we learn from cool-down to first beams, S.Claudet, this workshop
[6] What else did we learn?, M.Pojer, this workshop