LHC: Status, Commissioning and Engineering Run

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Abstract — Most parts of the components and the technical systems of the Large Hadron Collider (LHC) are, at present, already installed in the tunnel. The progress is clearly indicated by the fact that 924 dipole magnets (out of a total of the 1232) are in the tunnel and the very last one should be positioned by the end of March 2007. The LHC Project is entering a phase which will be dominated by the commissioning activity: the pressure test of sector 78 at the end of November will be followed by the cooling down to a nominal cryogenic temperature (1.9 K) of the first of the eight sectors; as for the remaining ones, installation and assembly are proceeding at a satisfactory pace and the closure of the last one is programmed for August 2007. An Engineering Run with beams at 450 Gev is foreseen for the last months of 2007, with the aim of checking both the machine as a whole and the experiments. During the first months of 2008 the commissioning of the technical systems of the LHC at nominal energy (7 Tev) and luminosity ($10^{34} cm^{-2} s^{-1}$) will be completed.

1 Layout of the Machine

The LHC [1] is composed of eight 3 kms long arcs, separated by straight sections, each 528 m long. Four of these straight sections host the experiments and two of them include the injection of the beams from the SPS: the other four straight sections contain fundamental systems required for the operation of the collider: accelerating cavities, extraction systems and two collimation sections.

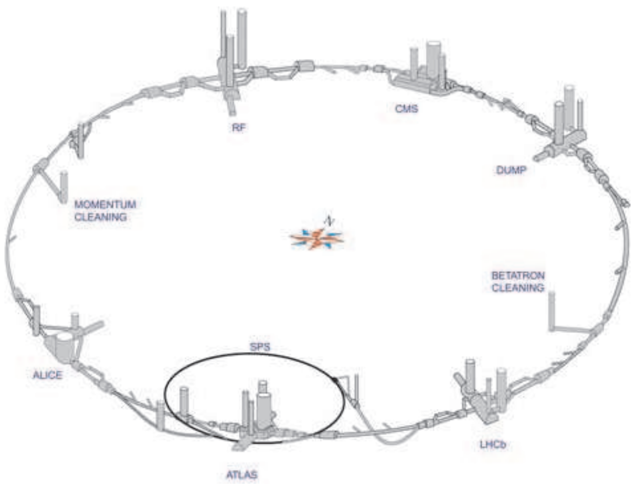

Figure 1: Layout of the LHC.

2 Implementation

2.1 Magnets

The LHC's superconducting magnets [2] have been produced by European industry, with a few exceptions, notably the focalisation quadrupoles and the recombination dipoles situated on either side of the experiments; these were manufactured in the United States and Japan. All are at present at CERN, most of them already in place or at an advanced stage of preparation (cryostating, configuration of the mechanical interfaces, beam screens, etc). Before being transported into the tunnel each magnet is tested at warm (field quality) and at cold (maximum current) before being accepted; the magnets are then sorted and positioned if necessary so as to compensate for any structural imperfections.

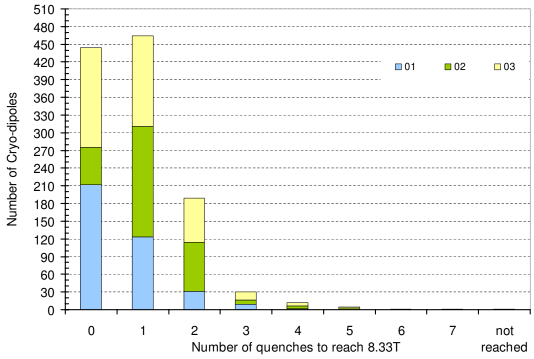

Figure 2: Dipole Statistics (1147 dipoles tested).

Fig. 2 shows that most of the dipoles required less than two training quenches in order to reach the nominal field (8.3 T). The same test, after a thermal cycle (1.9 K, 300 K, 1.9 K), indicates that, once installed in the machine, only a small number of the magnets are expected to develop training quenches before they reach nominal field.

2.2 Interconnections

After the installation of the magnets in the tunnel, they are interconnected. This operation includes various steps, which start with the preparation, the alignment, the brazing of the superconductive cables, the welding of the various tubes (beam, cryogenic connections) and finally the validation of each step, by means of an electrical quality control and of the leak tests. Each of these operations, which are done by external firms, is staggered with respect to the following one and each one is done in parallel on various fronts in the same sector or even at the same time in several sectors. An organisation, based on an industrial model, ensures stock control, logistics, the tracking of the progress and quality control. The end of interconnection activities is scheduled for August 2007.

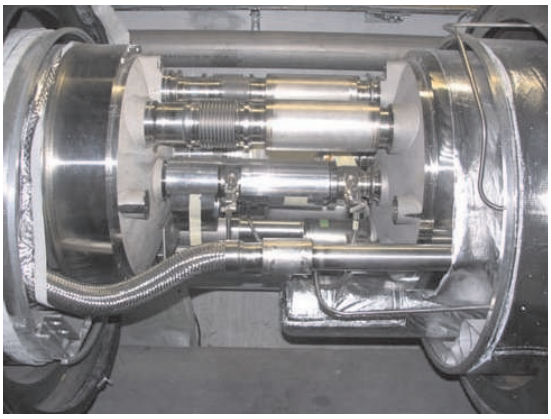

Figure 3: Interconnection of two superconductor magnets.

2.3 Cryogenics

The cryogenic installation [3] is composed of 8 nearly identical plants located, with the exception of one, in the even points of the LHC. The part of the plant operating at 4.5 K is on the surface and is connected by means of vertical piping to the underground pumping group at 1.9 K and then to the interconnection box; the latter, ensure redundancy and faster cool down or warm up speed when two plants are coupled onto the same sector.

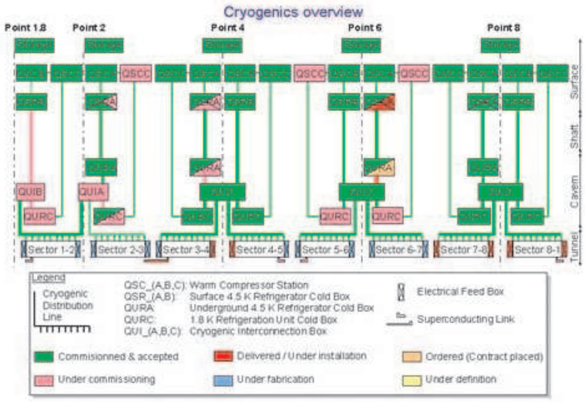

Figure 4: Synoptic showing the readiness of the cryogenic plants.

The superconducting magnets are located along the whole arc and in a large part of the long straight sections. They are connected to a cryogenic pipeline, the QRL, which contains four lines through which helium is fed or evacuated to and from the cryomagnets. The pressure test of the whole system and the cold commissioning of one of the eight sectors (3.3 km) will enable the validation of the design of this cryogenic distribution line which has required 2100 internal welds all done by automatic orbital machines.

Figure 5: Special zone of the QRL near a rectilinear section.

2.4 DFB

The Electrical Distribution Boxes (DFB) ensure the thermal transition of the electrical circuits to the superconducting magnets. They have been produced in collaboration with the Protvino High Energy Physics Institute. The current leads have been assembled at CECOM (Italy) and at the Budker Institute of Nuclear Physics (BINP) of Novosibirsk. Every single current lead was individually tested by the ENEA at Frascati and at the University of Southampton (GB).

The DFBs are complex cryostats which contain the current lead equipped with a high temperature superconductor part. Each one of the DFBs is different because each is characterised by the circuits which pass through it; the 52 DFBs which contain the 1070 current leads [4], operating with currents that range from 600 A to 13 kA are presently being installed. The DFBs are interfaced with the QRL and with the magnets. The commissioning of the

Figure 6: One of the biggest of the DFBs being lowered into the tunnel.

DFBs [5] will be a delicate operation because no prototype has ever been type tested i.e. neither cooled down nor powered.

2.5 The Straight Sections

As previously described, the straight long sections contain not only the experiments but also systems essential for operating the collider.

Figure 7: Junction of the injection line at Point 2.

One of the two injection lines from the SPS which reaches the machine at the Point 8 has already been commissioned with the exception of a few components located in the LHC tunnel. Recently installed, their commissioning is programmed for the beginning of 2007.

The 400 MHz RF system is located at the Point 4 and is made of two independent sets of accelerating cavities, one for each beam. These copper cavities are sputtered with a niobium film on their inner surface. Each system generates a 16 MV field; each beam is subject to the action of eight cavity cells which have been conditioned up to 8 MV/m. All these cavities have already been installed in the tunnel. The commissioning of the control systems and the connection to the cryogenic system are under way.

2.6 The Collimators

In addition to the collimators which protect the experiments, the injection and the extraction systems, two points of the LHC are equipped with collimators designed to capture off-momentum particles and to control the beam halo. The collimators [6] will be installed in two stages: the first set of 28 collimators for the run at 450 GeV and the

Figure 8: Acceleration cavity at Point 4.

remaining 100 during the first months of 2008, for the first run at the nominal energy and intensity. As with most of the components of the LHC, the production of the collimators was entrusted to European manufacturers. They initially had some production problems: the leak tightness of the instrumentation feedthroughs and contamination of the parts exposed to the beam. At present only a small number of the 28 collimators required for the engineering run have been installed in the machine.

3 Commissioning of the Technical System

The commissioning of the technical systems of the LHC cover all the commissioning activities in the tunnel before operation with beams. The program [7], which was prepared in detail during the installation and in the last stages of production of the components, is composed of two phases: the commissioning of the individual systems and the commissioning of each sector as a single system. Furthermore, for the first system that has been commissioned a third phase has also been foreseen: its objective is the validation of the various processes (cooling, quench, recovery of a quench, etc.) at the level of one sector. The experience obtained in the LHC Test String [8] is very useful but is limited to one LHC cell (106 m). The commissioning program has been prepared together with the owners of the various systems and documented in detail for each phase. A computerized quality assurance plan is associated: it enables the recording of the data collected during each step, to publish it and finally to evaluate the phase itself. The overall installation schedule of the machine clearly indicates that 2007 will be the year of the commissioning. The commissioning of the sector 7-8 will start at the end of 2006 with the pressure test and the cool down. It will be followed by tests of the systems that are located in this sector and will end with a 24 hour run of all the circuits (both superconducting and warm magnets) at nominal current. As from April 2007, approximately every two months an additional sector will be available for commissioning. The schedule foresees the engineering run a 450 GeV at the end of 2007; the complete commissioning to the nominal current of all the systems will not be possible. A partial commissioning ensuring the operation in safe conditions for the components will be done and will be completed by a commissioning for operation at 7 TeV in the first months of 2008. This approach becomes possible because a run at a lower energy level requires lower magnetic fields hence lower currents; this implies shorter commission times but also larger tolerance to temperature variations hence less time to obtain the fine tuning and the precise calibration of the cryogenic system and its instrumentation.

3.1 The Power Converters of Superconducting Circuits

Each of the LHC's eight sectors contains a circuit for all the dipoles and two circuits for the quadrupoles (one of which to focalise and the other to defocalise in the horizontal plane) as well as a large number of circuits for corrector magnets. The power converters [9] for the hundred odd circuits of each sector are located in the underground caverns: the bigger ones are located around the even points where the converters for the three main circuits are located. Most of the 968 converters have already been installed in the caverns and 60% of these have already undergone the first phase of their commissioning in-situ. The purpose of this phase, which lasts from three to five weeks, is to validate the power converters together with the auxiliary services (demineralised water for cooling, ventilation, AC current supply, cables, etc.). It consists in the individual commissioning of each power converter in short circuit followed by a 24 hour run of all the power converters at nominal current in order to verify the system as a whole. The stability of the current and the trends of the temperatures of the demineralised water, of the air, of the electronics, of the cables are recorded in order to validate the correct functioning of the whole area. This operation ends when an interruption of the general AC supply is triggered in the cavern in order to check the correct implementation of the recovery.

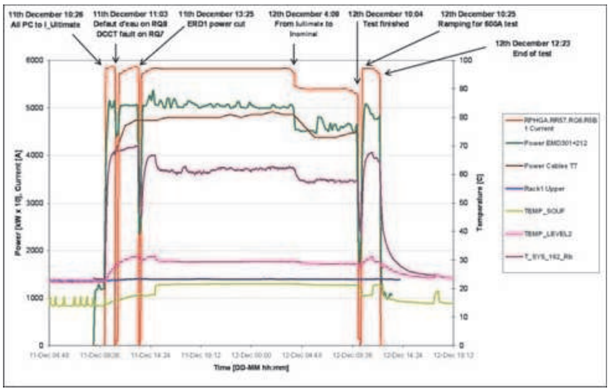

Figure 9: 24-hour run.

Each stage of these tests is recorded in the quality control system and is analyzed by those responsible of the system. A global analysis, in which all the specialists take part, ends this sequence of tests: in these meetings the non-conformities revealed by the tests are discussed and corrective measures are decided. In some cases, these decisions have resulted in the repetition of parts of the test sequence.

4 Engineering Run at 450 GeV

The object of the engineering run at 450 GeV [10] is to create a firm platform for the commissioning to 7 TeV and provide adequate lead time for problem resolution. It is obvious that, both for the accelerator and for the experiments, this run will allow the discovery of a large number of minor problems and perhaps even some serious ones: the shut down, programmed for the first months of 2008, will provide a time window to resolve them before facing the more serious 7 TeV run.

The main steps of this low energy run are:

- Commission essential safety systems
- Commission essential beam instrumentation
- Commission essential hardware systems
- Perform beam based measurements to check:
  - Polarities
  - Aperture
  - Field characteristics
- Establish collisions
- Provide stable two beam operation at 450 GeV
- Interleave collisions with further machine development, in particular, the ramp.

5 Conclusion

In these last months we have witnessed a solid increase in the rhythm of transport, of installation, of interconnections, of quality assurance (mechanical, electrical, etc) and of the commissioning of the LHC. The first sector is under vacuum and the pressure tests will soon take place. The cooling down of this first sector should start before the end of 2006.

CERN has proved its ability to solve the various problems that arose on the various components (such as QRL and DFB); the actual ones (i.e. collimators) are being solved. The run at 450 GeV for the end of 2007 appears at hand.

Table 1: The main milestones of the project.

Test of the last magnet	January 2007
Installation in the tunnel of the last magnet	March 2007
Closure of the continuous cryostat	August 2007
First collisions at 450 GeV	November 2007
First collisions at 7 TeV	June 2008

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