THE LHC PROJECT: STATUS AND PROSPECTS

P. Faugeras, CERN, Geneva, Switzerland

Abstract

The Large Hadron Collider (LHC), CERN's future major facility for high-energy physics, has entered into the construction and preparation for installation phases. After recalling briefly the main machine design choices and challenges, one will review the progress of civil works for the machine and experimental areas and the status of the main LHC components, which are presently series-built and for some of them procured in kind through world-wide collaborations. Report will also be given on the full-scale prototype of an elementary LHC lattice cell, called String 2, which is being commissioned and used for optimising the installation and testing procedures of the LHC. The size and duration of the LHC Project, its intrinsic complexity and the large number of world-wide collaborations involved require rather elaborate project management tools, which will be shortly described. Finally, following the extended running of the LEP and the delay for emptying of the machine tunnel, a new planning for project completion had to be established and will be presented, which aims at a first physics run in 2006.

1 INTRODUCTION

The LHC schematic layout, which is reproduced here for convenience on fig. 1, has not changed since the original design report, [1]. Basically, this new collider, which will be installed in the existing tunnel of the former LEP, will make use of two counter-rotating beams of protons or heavier ions, guided and focused in the arcs with twin-aperture magnets working in a static bath of superfluid helium. The superconducting dipoles and quadrupoles of each arc are all connected in series and form a continuous cryostat, about 3 km long. In between arcs, 4 of the long straight sections are used for housing machine facilities as shown on Fig. 1. The other 4 straight sections are devoted to focusing and making the beams to collide in the physics detectors. Two new underground experimental caverns are being made for the largest detectors ATLAS and CMS. At the nominal field of 8.35 T in the lattice dipoles, the LHC should provide head-on collisions of 7+7 TeV protons, with a luminosity of 10^{34} $cm^{-2}s^{-1}$.

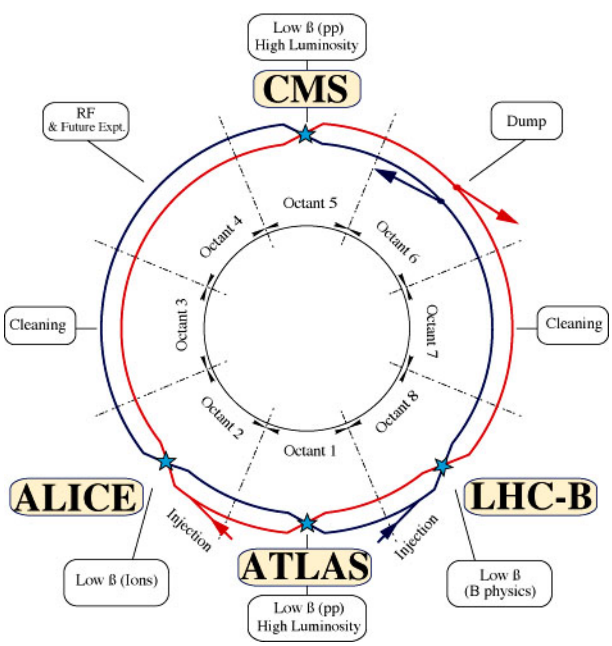

Figure 1: Overall layout of the LHC machine

2 ACCELERATOR PHYSICS

2.1 Optics and Machine Layout

The regular lattice of the arcs is made of 23 identical FODO cells, each about 107m long and with 3 dipoles and 1 quadrupole per half cell. The quadrupole and correction elements of a particular half-cell form a so-called Short Straight Section, SSS, and are housed in a common cold mass and cryostat. The insertions in the long straight sections are optimised independently and the dispersion suppressors on either side of each of them are used for matching them with the regular arcs. Although this basic scheme has been frozen for the past few years, studies are continuing, [2], for:

- Optimising the different corrector systems to cope with all geometrical errors: spool pieces alignment in the main dipoles, insertion triplet correctors and stability of the tunnel floor.
- Assessing the lattice robustness with respect to mis-powering of correctors and to magnet error tolerances, [3].
- Tracking studies on the sensibility of the dynamic aperture to linear imperfections and to long range beam-beam effects, [4], [5].

2.2 Electron Clouds

Synchrotron radiation emitted by LHC protons induces photoelectrons when impinging on the beam screen wall. The photoelectrons can be accelerated by the next proton bunch and hit the opposite wall of the beam screen, thus creating secondary electrons which may in turn trigger some kind of electron multipacting, called electron clouds, if the proper resonance condition is fulfilled, [6]. Detailed theoretical and simulation studies on this effect have been performed, including real tests in the SPS accelerator, [7]. Electron clouds should be avoided, as they cause heating of the cold vacuum chamber and may even trigger beam instability. Various cures have been devised, such as acting on the beam screen wall reflectivity, lowering the electron production yield by coating, or using beam scrubbing or even doubling the bunch spacing to kill the resonance.

2.3 LHC Injectors

The nominal LHC parameters call for high brightness beams, correctly spaced in time. The LHC pre-injectors, made of Linac2, Booster and CPS, have already produced proton beams with the required transverse emittances, but the correct time distribution of bunches has required a new bunch splitting scheme through RF manipulations, which was successfully tested recently, [8].

Beams from the CPS are injected in the SPS, to reach their LHC injection energy of 450 GeV. To preserve their brightness, it is necessary to reduce the SPS impedances, which is being done by suppressing as much as possible the discontinuities in the SPS vacuum chamber. Also, the bunch density in the SPS is limited by the electron cloud problem, but cures are being implemented, [7].

3 CIVIL ENGINEERING

Although one will make use of most of the facilities built for LEP, civil engineering works are needed for the two new experimental areas at Points 1 and 5, and for two new transfer tunnels TI2, TI8 to inject the two counter-rotating beams from the SPS, (see Fig. 1). Additional work is also needed on the surface for cryogenics and at some locations in the tunnel, to house power converters and to allow the magnets be transported round the ring, and finally for the beam dumping system around Point 6.

The underground work at Point 1 is well advanced: the first underground cavern, 64m long, 20 m diameter, has been handed over to CERN and is being equipped, while the main ATLAS experimental cavern, 53m*30m*35m, has its roof completed and starts to be excavated, (Fig. 2).

Figure 2: Vault concreting of ATLAS experimental cavern

Underground work at Point 5 is less advanced, because of geological problems, in particular a double water table, which required ground freezing techniques for digging the two shafts. However, the construction of a large hall on the surface permits the pre-assembly and test of the CMS detector prior its final installation underground, (Fig. 3).

Figure 3: First CMS barrel yoke element in building SX5.

The two 2.5 km long tunnels for the transfer lines from the SPS to LHC are now excavated and connected to the main tunnel and their secondary lining is under way. Other underground works for the machine proper are being performed round the ring and will be completed mid 2003, with the two 700 m transfer tunnels and the two caverns needed for the beam dumping system around Point 6.

4 MACHINE COMPONENTS

4.1 Superconducting Magnets

Several review papers have recently been published on the status of the LHC lattice cryodipoles and short straight sections, SSS, [9],[10],[11],[12], and the reader is kindly referred to them. It is sufficient to mention here that most of the recent work was aimed at verifying the robustness of the dipole cold mass design and at assessing the quality of the heavy tooling and of the workmanship through the production of several pre-series magnets at the premises of each three cold mass assemblers. The final adjudication for the series production of the 1200 cold masses is being made, while the facility for inserting at CERN the dipole cold masses in their individual cryostat has been prepared and the associated contract already signed.

The SSS will also be made by industry, through two main contracts: one for the cold mass assembly proper, the other for their insertion into individual cryostats.

In the dispersion suppressor regions, which connect the regular machine arcs to the long straight sections, the SSS require individually powered quadrupoles. These special SSS and the isolated quadrupoles of the matching sections of the insertion regions will be assembled at CERN.

It is planned to test cryogenically all dipoles and SSS, in a dedicated facility, which is being set up at CERN, close to the dipole cryostating hall. Various test scenarios are being worked out, [13], as this will be on the critical path for the availability of magnet for installation in the tunnel.

In the experimental insertions, the beams are focused through low-β insertion triplets, which form an important part of the American and Japanese in-kind contributions to the LHC machine. These triplets will make use of two types of high-gradient wide-aperture quadrupoles, which have been designed and developed at KEK and Fermilab, [10]. The final insertion elements will arrive at CERN in their own cryostats, fully tested and ready for installation.

4.2 Cryogenics

A comprehensive description of the cryogenic system for LHC can be found in [14]. In addition to the four LEP cryoplants, which will be recuperated and upgraded, four new 18 kW plants have been ordered and the first of those has been delivered and will be tested soon at CERN.

All the magnets of a regular arc and those of the two adjacent dispersion suppressors are connected together and form a continuous cryostat which extends over 3 km. To cool this long string of magnets, a composite cryoline, coming from the cryoplants at even points, runs alongside the magnet string and is connected to it at every lattice cell, through a jumper connection, which supplies helium at various pressures and temperatures, (Fig. 4).

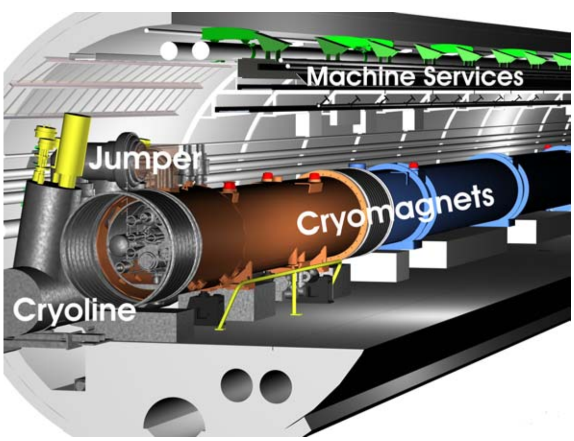

Figure 4: Isometric view of LHC tunnel

Three different prototypes, 110 m long each, have been successfully tested recently and the final contract for the cryoline fabrication and in-situ installation is being placed.

4.3 Other systems

With the notable exception of the 400 MHz accelerating cavities, all the other LHC components are conventional. Nevertheless, some are quite unusual, as for instance the special twin-aperture warm quadrupoles needed for the cleaning insertions around points 3 and 7, which are built in Canada in collaboration with TRIUMF.

Another example concerns the supply of all the dipoles and quadrupoles for the beam transfer lines from SPS to LHC, which have already been delivered from BINP, as a part of the agreement between CERN and Russia. The septum magnets for the beam abort channels will be built by IHEP-Protvino, under the same agreement.

4.4 String2

The former String 1, [15], was essentially built and used to ascertain the feasibility the cryogenic cooling scheme as well as validating the principles of the magnet quench protection system. On the contrary, String 2 is a full-size mock-up of a complete lattice cell of the LHC, making use of preseries dipoles and SSS and of one prototype of the cryoline, see Fig. 5. It purpose is to validate individually the final systems and investigate their collective behaviour in conditions close to those prevailing in the machine.

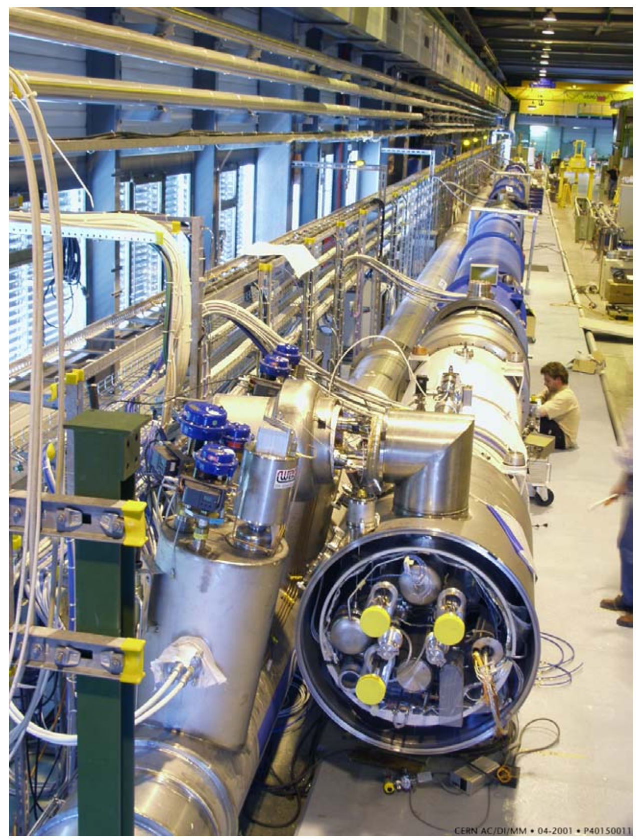

Figure 5: Assembly of String 2 with its cryoline on the left

In particular the assembly and test procedures for the magnet interconnects must be carefully studied, [16]. It should be mentioned that for the final installation of the machine in the tunnel, there will be about 1700 magnet interconnections, which will require in total some 50’000 TIG welds for cryogenic channels, 10’000 soldered joints for main superconducting cables and 20’000 ultrasonic welds for the SC auxiliary bus bars cables. In this context, assembling the String 2 elements has been taken as a test rehearsal for the tunnel installation and has already given invaluable results, [17], particularly on the early detection and repair of hardware non-conformities.

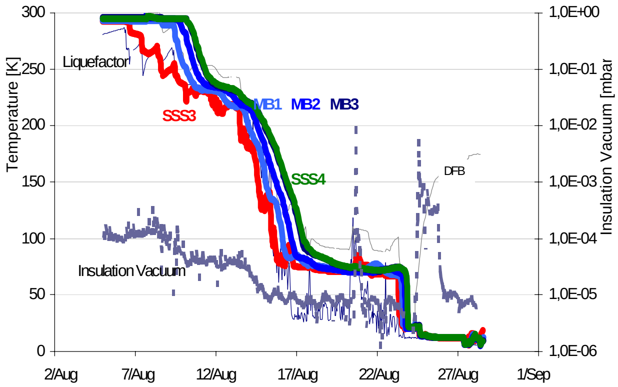

Figure 6: First cooling of String 2

In a first step, only three final prototype dipoles have been installed in between the 2 SSS of String 2, awaiting for the availability of one pre-series dipole from each cold mass assembler for completing the String at the end of this year. Figure 6 shows the first cool down of this reduced string, [18]: note that the 10 days plateau at 80K was deliberately made for electrical insulation tests and that the insulation vacuum has decreased by 2 orders of magnitude when reaching 4.5K.

It is anticipated that, once completed and commissioned String 2 will be used for various experiments, for instance on quench propagation studies and magnet protection, but also as a training bed for operation crews.

5 PROJECT MANAGEMENT

The size and duration of the LHC Project, its intrinsic complexity and the number of world-wide collaborations involved in both the design and construction activities require rather elaborate project management tools. These tools must be capable in particular of handling the huge amount of engineering information generated at all stages of the project and of insuring its coherence as the project evolves. An Engineering Data Management System was therefore set up and takes the form of a central repository for all the engineering data, such as tables of parameters, functional, technical and interface specifications, drawings, fabrication and test data, etc. It makes use of a commercial software system for data storage and retrieval, and of a dedicated World Wide Web interface, which enables truly global access to the data, [19]. Several structures are used for LHC data, as sketched on Fig. 7:

- The parameter and layout databases, which are the live and up-to-date version of the design report, [1].
- The Project Breakdown Structure, (PBS), which shows the breakdown of the LHC into sub-projects, each with its responsible engineer. The PBS more or less shows what has to be purchased.
- For each compound machine element, a cryodipole for instance, an Assembly Breakdown Structure, or ABS, gives the part list of individual components and of sub- assemblies and also all the procedures needed for the element construction and testing.

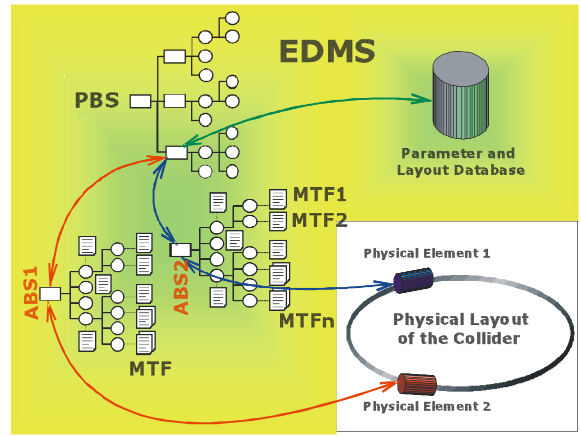

Figure 7: Principle of the EDMS for LHC

- The Manufacturing and Test Folder, MTF, is used during the fabrication, measurement and installation of each complex assembly or individual component, to record all pertinent data to allow to trace the history of each item throughout its entire life-cycle.

Configuration management is insured by a set of on-line procedures directly accessible from the Web interface, which allows to add information, check its consistency, request changes when needed and once approved, put them into force in an ordered way. A Quality Assurance Plan, defines the associated “rules of the game”,[20].

6 INSTALLATION AND LOGISTICS

For the first time in CERN’s history, one will have to install a new and expensive machine in an existing tunnel, where the preceding collider, LEP, was kept running at top energy till October 2000.

Quite obviously, the time span between the end of LEP physics and the start of LHC must be kept to a minimum. A fast LEP deconstruction is being completed to let civil engineering works in the main tunnel to be done as fast as possible. Actually, one is launching the series production of the main cryodipoles and of the SSS, with the view of having them delivered just in time for their measurement and final preparation before their installation in the tunnel. This will ease somewhat the temporary storage problems but a prerequisite is that the superconducting cables and all other magnet components are delivered as scheduled.

LHC installation proper will proceed on several fronts in parallel, but will follow a well defined sequence: once civil works are completed in a sector, the general services will first be restored and completed, then the distribution cryoline will be assembled and tested followed lastly by the cryomagnet installation.

This latter operation require special handling devices for transporting the long cryodipoles from their assembly location to their final position in the tunnel. Moreover, the magnet interconnections will mostly be made by welding pipes and expansion bellows together, which calls for reliable orbital welding machines and fool-proof testing.

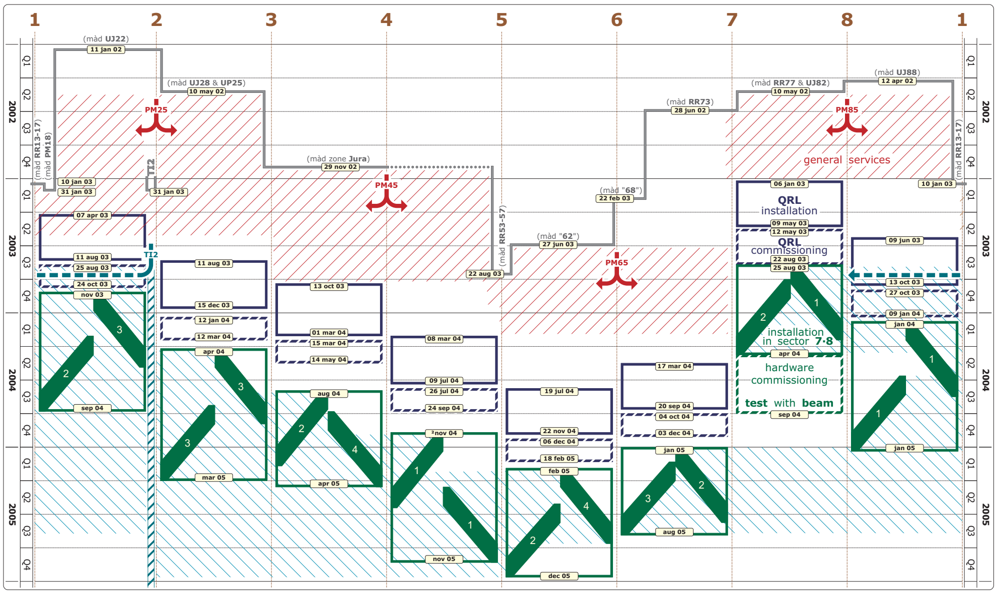

Figure 8: Principle of the LHC installation schedule.

Fig 8 shows the installation sequence of the machine, with the machine developed along the horizontal axis and with time along the vertical axis. This schedule was drawn assuming that magnets are transported during night shifts, to let the installation work proper be done during two daily shifts. Once a sector is completed, it will be cooled and fully tested: the first sector test will take place in 2004, with first beam injection at the end of the test. If the last main dipole arrives in summer 2005, the machine could be completed at the end of the year 2005, the first circulating beam could be obtained two months later and a first physics run could take place in 2006.

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