THE LARGE HADRON COLLIDER - PRESENT STATUS AND PROSPECTS

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Abstract

The Large Hadron Collider (LHC), due to be commissioned in 2005, will provide particle physics with the first laboratory tool to access the energy frontier above 1 TeV. In order to achieve this, protons must be accelerated and stored at 7 TeV, colliding with an unprecedented luminosity of 10^{34} cm^{-2} s^{-1}. The 8.3 Tesla guide field is obtained using conventional NbTi technology cooled to below the lambda point of helium. Considerable modification of the infrastructure around the existing Large Electron Positron collider (LEP) tunnel is needed to house the LHC machine and detectors. A brief status report is given and future prospects are discussed.

1 INTRODUCTION

The LHC project is now mid-way to completion. The LEP machine is now being removed and the tunnel infrastructure prepared for LHC installation. Most of the major contracts for the manufacture of machine components have been placed and hardware is beginning to arrive at CERN. A brief status report on some of the major systems is given below. The revised schedule for machine completion is discussed.

2 INJECTORS

The existing injector chain will be used for producing the LHC beams. In order to achieve the required performance in terms of bunch intensity and emittance with the nominal bunch spacing of 25 ns, a number of modifications are required, particularly in the PS complex. The classical technique of generating the 25 ns bunch spacing (h=84 in the PS) from the beam injected from the PS Booster (h=7) is by debunching and rebunching on the higher harmonic. This technique suffers from two major disadvantages. The 25 ns spacing is too small for the risetime of the extraction kickers, resulting in a number of bunches lost or with large betatron oscillations. In addition, the beam tends to become unstable during the debunching process when the energy spread becomes too low for adequate Landau damping. To overcome these problems, a novel technique has been developed [1] which consists of stepwise bunch splitting using intermediate harmonic cavities. By leaving out one Booster bunch, a large enough gap can be left for the kickers and the beam never gets unstable since the energy spread is too large. Using this technique, beams satisfying the LHC specifications on emittance, intensity and bunch length have already been obtained (Fig. 1) [2].

This beam is now available for commissioning the next link in the injector chain, the SPS. Machine studies have already started and have clearly demonstrated the onset of the electron cloud instability (see below) as predicted.

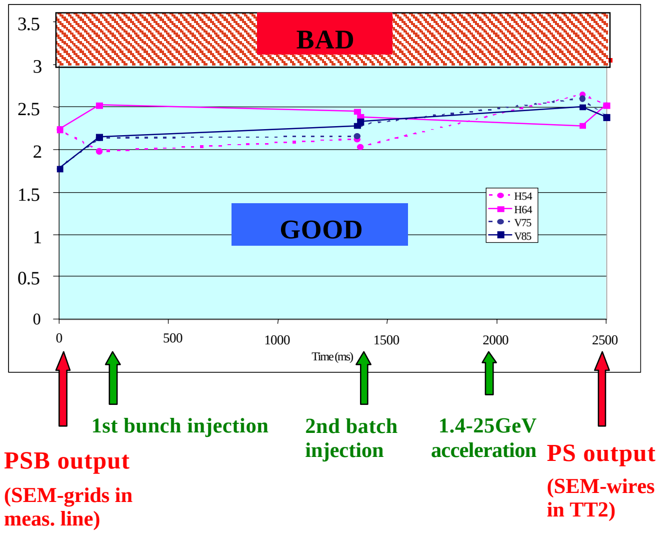

Figure 1: Transverse emittance in the PS from injection to extraction for the nominal LHC beam.

3 MAGNETS

The LHC will require more than 8000 superconducting magnets of different types. The most challenging are the 1232 superconducting two-in-one dipoles, which must operate reliably at the nominal field of 8.3 Tesla corresponding to a centre-of-mass energy of 14 TeV, with the possibility of being pushed to an ultimate field of 9 Tesla.

Extensive R&D with short models culminated in the production of six prototypes where the coils were manufactured at three different firms and cold mass assembly at CERN. After satisfactory performance of these prototypes, series production has started. The first series dipole has been tested at CERN (Fig. 2), with a good performance (Fig. 3). Production will now slowly ramp up to the required rate of six dipoles per week. The prototype magnets are being assembled into a full cell of the LHC (six dipoles and two quadrupoles) in its final configuration, including an external cryoline, in order to refine installation procedures and to cold test the string as an integrated system (Fig. 4).

The 400 main quadrupoles are integrated into Short Straight Sections (SSS) also containing sextupole and dipole for chromaticity and orbit correction respectively. The quadrupoles have been designed at Saclay in the framework of a collaboration with CEA. Three prototypes have been built; all meet the design performance. The integration of the SSS into their cryostats has been made in collaboration with CNRS. Orders have now been placed for series manufacture and for cryostat integration. The first series units will arrive by the end of the year.

Figure 2: The first series dipole being transported to the measurements bench.

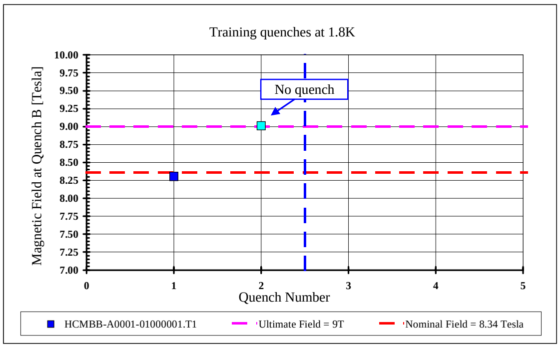

Figure 3: Training curve of the first series dipole.

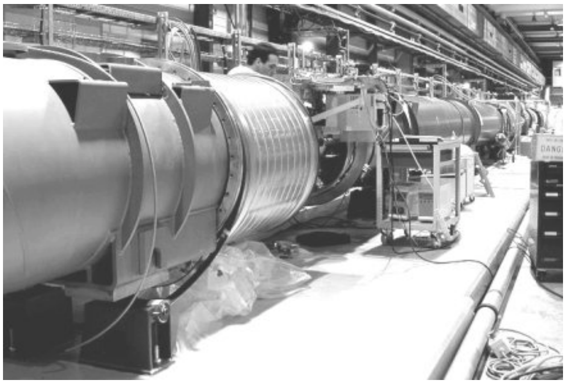

Figure 4: Assembly of a full LHC cell (the "string").

The dispersion suppressors, long straight sections and insertion regions contain many special magnets, the most challenging of which are the high gradient (220 T/m) large aperture (70 mm) quadrupoles for the inner triplets of the low-beta insertions. Two different versions of these quadrupoles have been designed at FNAL and KEK, and have been validated through short models. The first full-length prototypes have now been built and are being prepared for testing (Figs. 5 and 6).

Each insertion triplet will contain a mixture of US and Japanese magnets. The final integration into the cryostats will be made at FNAL in collaboration with LBL.

Figure 5: A full-length insertion quadrupole being lowered into a vertical cryostat at KEK.

Figure 6: The first full-length prototype at FNAL.

Many other superconducting magnets are needed for trimming the optics and for correcting lattice imperfections. A full list is given in Table 1.

Contracts for all elements have been placed in industry and series production has started. Half of the MCS and MCDO magnets are being manufactured in India in the framework of a collaboration agreement.

A large number of conventional magnets are also required. In the two transfer lines from the SPS to LHC there are 360 six metre long dipoles and 180 quadrupoles, all manufactured at BINP Novosibirsk in the framework of the CERN/Russia agreement. The delivery of these magnets is now nearly complete. Also from Russia are the warm separation dipoles (BINP) and the septum magnets for the beam abort channels (IHEP, Protvino, see Fig. 7).

Table 1

Name	Quantity	Purpose
MSCB	376	Combined chromaticity/ closed orbit correctors
MCS	2464	Dipole spool sextupole for persistent currents at injection
MCDO	1232	Dipole spool octupole/decapole for persistent currents
MO	336	Landau octupole for instability control
MQT	256	Trim quad for lattice correction
MCB	266	Orbit correction dipoles
MQM	100	Dispersion suppressor quadrupoles
MQY	20	Enlarged aperture quadrupoles

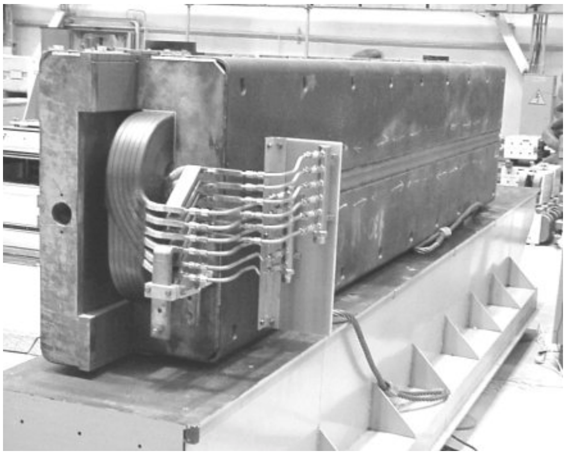

Figure 7: Extraction septum magnet from IHEP.

Two of the long straight sections of the LHC are used for beam collimation. In view of the high radiation levels these straight sections are equipped with special twin aperture warm quadrupoles (52 units) built in Canada in the framework of the CERN/TRIUMF agreement (Fig. 8).

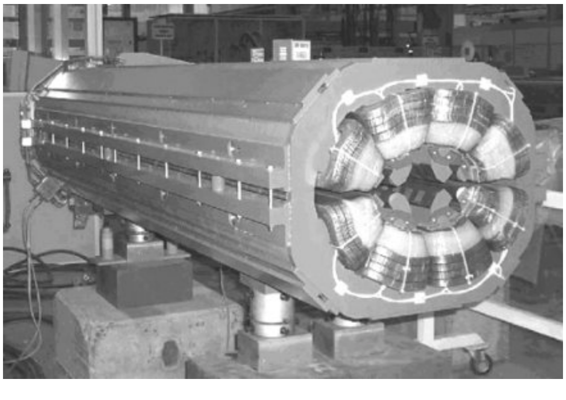

Figure 8: Warm quadrupole for cleaning insertion.

4 CRYOGENICS

The most important elements of the cryogenic system are the eight large (18 kW) cryoplants together with their associated cold compressors for the production of superfluid helium, and the distributed cryogenic line feeding the magnet system. Four of the 18 kW plants will be recuperated from the LEP cryogenic system with suitable upgrades. The first of the new plants has now arrived at CERN and is being prepared for testing (Fig. 9). It will be housed in the cryogenic building at Point 1, which is close to the magnet test hall. It can therefore be used to provide helium for the test benches as well as for cooling the machine. The first cold compressor, built by a German/Japanese consortium, will be delivered to CERN in the spring of 2001.

Figure 9: The lower cold box of the first 18 kW cryoplant.

The magnet system is cooled through an external composite cryogenic line which connects to the magnet cryostats through a jumper connection at the end of each 106 m lattice period. Three prototype sections of the cryoline, from three different manufacturers, have been successfully tested and a call for tender for the full production has been launched. One of the prototypes is being used to cool the string.

5 VACUUM

One of the most critical factors affecting the vacuum system is the electron cloud instability, now clearly observed in the B-Factories at KEK and SLAC as well as in the SPS [3] for “LHC type” beams. Depending on the bunch spacing and intensity and the size of the vacuum chamber, a resonant build-up of secondary electrons, seeded by synchrotron radiation or by ionisation of residual gas can occur. This electron cloud produces heating of the chamber wall and can even cause beam instability. A great deal of effort has been expended in understanding this effect, both through theory and numerical simulation as well as experiments on a number of machines. In the SPS, for the nominal 25 ns bunch spacing, the threshold for the build-up of the cloud is consistent with numerical simulations. The effect can be cured with gaps in the bunch train and by a reduction of the secondary emission coefficient of the surface, which will naturally occur by the cleaning effect of the synchrotron radiation and by the electron bombardment itself.

6 ACCELERATING SYSTEM

The RF operates at 400.8 MHz, the second harmonic of the SPS frequency. Each beam has a separate system necessitating an increase of the beam separation from 194 to 410 mm. Eight single-cell cavities per beam operating at an average gradient of 5 MV/m provides a total voltage of 16 MV. The cavities are made from copper sputtered with a thin film of niobium. All cavities have been manufactured and are being assembled into four-cavity modules. The first module has been tested at full power with all ancillaries.

In order to ease injection tolerances and to provide damping of injection oscillations, an additional RF system operating at the SPS frequency of 200.4 MHz is required. The cavities are not superconducting in order to provide the large bandwidth needed. There are four cavities per beam with 750 kV per cavity. These cavities are now under construction.

7 CIVIL CONSTRUCTION

The civil engineering work consists of three main packages concerning the LHC machine and the experimental areas for ATLAS and CMS respectively (Figs. 10 and 11). For the machine, the work is distributed geographically, both for surface buildings housing the large cryogenic plants and in the underground areas. The most important underground work is the construction of two 2.5 km long tunnels housing the transfer lines from the SPS to the LHC. These tunnels have now reached the LHC ring and the junction caverns are under construction. The two experimental caverns are well advanced albeit with about six months delay.

8 SCHEDULE

The original schedule, made in 1996, foresaw ring closure in summer 2005 and a short pilot run before a three month shutdown to finish the installation of the detectors. Since then, a number of factors, in particular the delay in LEP dismantling and the late delivery of the experimental caverns, has necessitated a revision of the schedule in collaboration with the experiment spokes-persons. According to the revised schedule, the first sector, from Point 8 to Point 7, will be commissioned between March and September 2004, culminating in the transport of a proton beam through the sector. Successive sectors will be cooled down as they become available with the whole ring closed and cold by the end of 2005. Beam commissioning will start in March 2006 with the objective of a short pilot run to the end of April. This will be followed by a three month shutdown to finish detector installation followed by a physics run of seven months duration. At the end of the proton run, it is foreseen to have a six week run with Pb ion collisions.

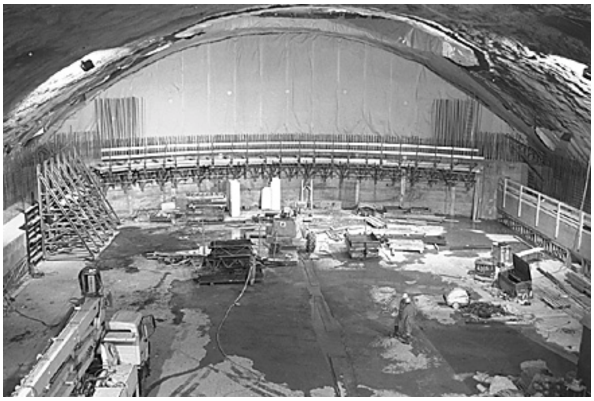

Figure 10: The vault for the Atlas experimental cavern.

Figure 11: Assembly of the barrel yoke in the CMS surface building.

9 CONCLUSIONS

The construction of the Large Hadron Collider is now well underway. Contracts for most of the major systems have been placed and hardware has started to arrive. A detailed installation schedule is being developed with the objective of completing the machine by the end of 2005 and a first physics run in 2006. Collaboration with laboratories in France, Canada, India, Japan, Russia and the United States has been highly appreciated and is vital for the timely commissioning of the machine.

10 REFERENCES

[1] R. Garoby et al., “Demonstration of bunch triple splitting in the CERN PS", 7th EPAC, Vienna 2000.

[2] K. Schindl, “Performance of the LHC Pre-Injectors” these proceedings.

[3] G. Arduini et al., “Electron Cloud: Observations with LHC - Type Beams in the SPS", 7th EPAC, Vienna 2000.