TECHNOLOGY AND COMMERCIAL SUPPLY OF COMPONENTS FOR THE LHC PROJECT

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Abstract

After a brief reminder of the motives and the outline of the Large Hadron Collider (LHC) project, one will review the technology and the hardware to be built up. The LHC calls for High Tech innovations in superconductivity, cryogenics with superfluid helium, ultra high vacuum, surface treatments, etc. which have to be transferred to Industry and produced on a large scale. It will also make extensive use of more conventional technology, but because of the intrinsic complexity of the machine and of the international nature of its funding and procurement sources, it will require sophisticated management and logistics tools to minimize costs and installation time. The planning for the whole project will be given with an indication of the nature and time schedule of the major contracts.

1 INTRODUCTION

Particle Physics beyond the domain explored with the LEP machine calls for an energy range of 1 TeV or more for the elementary constituents of matter, i.e. leptons or quarks. This cannot be achieved by upgrading LEP or by building larger circular e^+-e^- colliders, as the energy loss due to synchrotron radiation varies with the fourth power of the particle energy and becomes prohibitive for these light particles. Linear e^+-e^- colliders are not limited by synchrotron radiation but are not practical either: the accelerating RF fields technically attainable in the near future would require two linear machines, each 10 to 20 km long, to reach 1 TeV.

To-day, there is thus no other choice than accelerating and colliding hadrons: still emitted, synchrotron radiation is much weaker and no longer limiting, because of the 2000 times larger proton mass. Acceleration of protons is then only limited by the maximum magnetic guiding field and the proton trajectory radius. With superconducting magnets cooled by superfluid helium and producing some 8.3 Tesla, it will be possible to accelerate and collide 7 TeV proton beams in the actual LEP tunnel. This is the main motivation for the Large Hadron Collider Project (LHC), which was approved by the CERN Council in December 1994. The construction phase of LHC is now well under way, and commissioning is foreseen for 2005.

2 OUTLINE OF LHC

After the removal of the LEP machine, the LHC will be installed in the existing tunnel of 27 km circumference. As shown in fig. 1, its configuration will be very close to that of LEP, [1]. Eight identical circular arcs, each about 2.9 km long, house the superconducting guiding magnets. The arcs are separated by 8 long straight sections and the two counter-rotating beams will cross each other at the centre of only four straight sections. The beams will be focused and brought into collisions onto these points with special “insertion” magnets and the experiments will be installed around them. The other long straight sections are devoted to machine utilities such as the accelerating system, the beam dumping system and two “cleaning” insertions, whose purpose is to remove the halo from the beams and avoid parasitic irradiation of the machine.

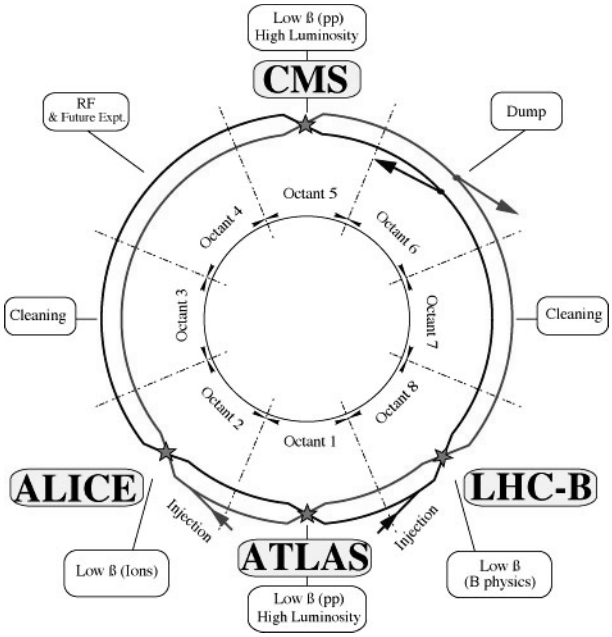

Figure 1: Overall layout of the LHC machine

As for former CERN projects, one will make maximum use of existing facilities. Civil engineering work will be limited to the construction of two new large experimental caverns required for housing the two high luminosity experiments ATLAS and CMS, at opposite points 1 and 5. The other experiments ALICE, devoted to heavy ion physics and LHC-b, for beauty physics, will be located in existing LEP areas. In addition, two new transfer lines will link LHC to its injector, the SPS. Finally, enough space will be kept free in the standard tunnel, to keep the possibility of reinstalling an electron ring above LHC, should e-p physics become attractive at a later stage.

2 THE LHC CRYOMAGNETS

Hadron colliders require that beams travel into two separate channels and be guided by magnetic fields of equal strength but opposite in directions. To cope with the available space in the existing tunnel and to minimise the cost, a “two-in-one” configuration, [2], was adopted, in which the two beam channels and their associated sets of coils are inserted in a common magnetic yoke and share the same mechanical structure and cryostat. The magnets in the LHC arcs consist of a periodic arrangement of three dipoles for guiding the beams followed by a short straight section which house a quadrupole, for beam focusing, as well as corrector magnets, beam monitors and cryogenic equipment. Less regular arrangements of dipoles and of quadrupoles, called dispersion suppressors, link the arcs and the long straight sections.

2.1 Cryodipoles

1232 dipoles, each of a magnetic length of 14.3 m, (16 m total) and weighting about 32 tonnes are required. The cross section of the cryodipole, [3], in its cryostat, [4], is shown on fig. 2.

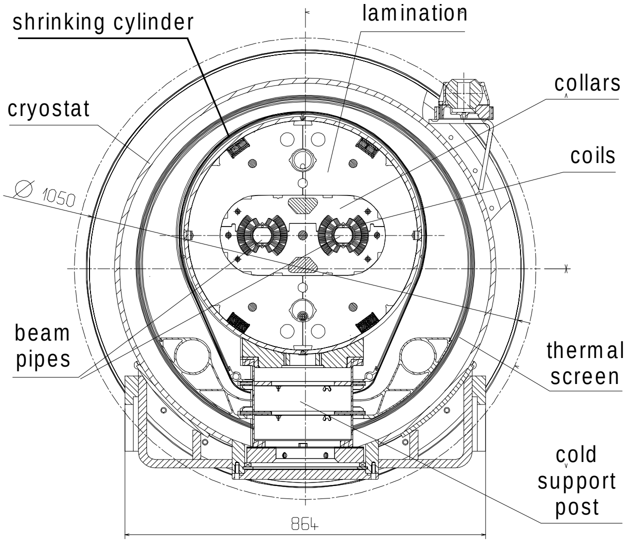

Figure 2: Cross section of a LHC dipole

The present magnet design is the result of an extensive development both at CERN and in Industry. The actual work is now mainly devoted to optimising the magnet structure to make it more robust and to define the best industrial procedures to avoid too delicate mechanical and electrical adjustments while insuring to produce reliable and identical magnets at minimum cost.

Assuming that the production of the dipoles will be split between 3 different assemblers, it is anticipated that the series production would extend over a period of 4 years. In fact, the production of the two types of superconducting cables is on the critical path: the total amount of NbTi superconducting alloy needed represents some two years of actual world production. Orders for the manufacture of the two types of cables for the inner and outer coil layers have already been placed with 5 firms (3 in Europe, 1 in Japan and 1 in USA) and first batches are expected in 1999, for a production ending in 2004.

It has also been decided that, in addition to the super – conducting cables, CERN will order itself the most critical components of the dipole cold mass, i.e.:

- the combined collars, which are precision-punched 3 mm thick non-magnetic sheets, and are used for containing the coils’ Lorentz forces,
- the iron lamination punched sheets, 6 mm thick, assembled in blocks to form the magnetic yoke,
- the cold bore tubes, 53 mm OD and 17 m long, which are seamless stainless steel pipes 1.5 mm thick and serve for the beam vacuum chamber ,
- the coil polyimide coil insulation,
- the electrical superconducting busbars,
- the outer shrinking cylinder, which also serves as the helium containment vessel.

Cold mass assembly will proceed into two steps. Next year, the selected firms will be asked first to quote and start to produce what is necessary for a machine octant. After successful production of 20 cold masses or so, they will be asked to bid again, but for the rest of the supply. The aim of this unusual procedure for CERN is to better balance the different orders between the CERN Member States, to avoid systematic differences between the firms and to keep the competition open between them.

A similar strategy will be followed for the cold mass installation in its cryostat: CERN will order bare tubes for the outer vacuum tank (36” OD, 15m long each), blankets of superinsulation, aluminium extrusion for the thermal shield, support posts, etc., and will place orders, with competitive tendering, for machining the vacuum tanks and for cryostating the dipoles.

2.2 Short Straight Sections

These complex elements are designed in the frame of a tripartite collaboration between CERN and the two French organisations CEA and CNRS, [5], but will be built following the same strategy as for the dipoles.

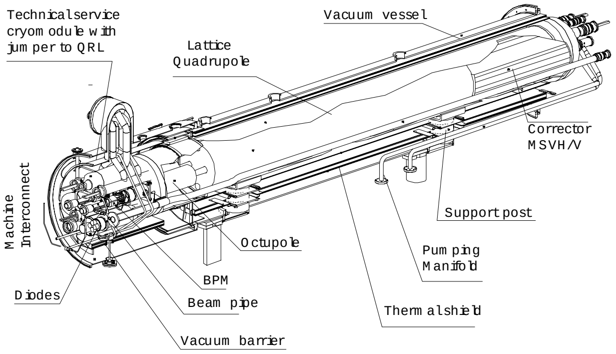

Figure 3: Axonometric view of a LHC standard short straight section

More than 400 units are required. Although they are all similar, the problem here comes from the great number of versions required which differ by the nature and length of the corrector installed, the presence or not of a jumper connection with the external cryoline (see below), etc. Note that the various correctors installed in the SSS will all be of the single aperture type. They will be ordered separately and supplied to the SSS assembler(s). The rate of production of the SSS must follow that of the dipoles, and their composition will be matched to the installation requirements, to minimise spare units and storage space.

2.3 Insertion Magnets

The quadrupole triplets which will be used in the high luminosity insertions are designed by Japanese and American laboratories and will be supplied to CERN as in-kind contributions from Japan and USA. Some more special quadrupoles, single and twin aperture, will be needed for completing the insertions and will be ordered later when their parameters are finalised.

3 CRYOGENICS

More than 40’000 tons of materials all around the LHC ring have to be cooled down to 1.9K. This temperature level has been chosen as it allows to increase the maximum attainable dipole field by some 2.6T as compared to the more conventional helium at 4.5K. Superfluid helium has also some big advantages like absence of viscosity, very large specific heat and incredibly high heat conductivity, which in total largely balance the technical problems for producing and using it.

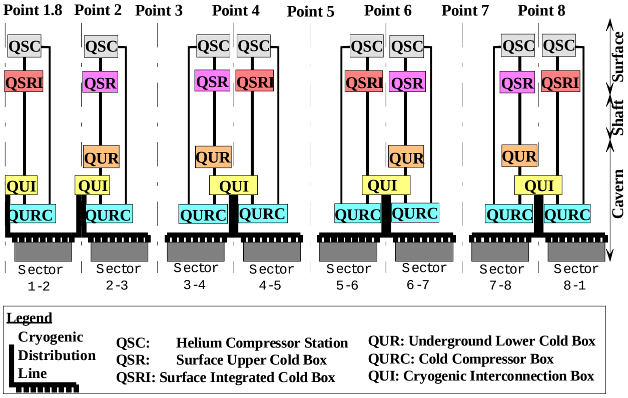

Figure 4: Architecture of the LHC cryogenics

Four large cryoplants were constructed for the LEP superconducting RF system at even points, and will be upgraded for LHC to an equivalent refrigeration capacity some 18 kW at 4.5K each. As shown on fig. 4, each plant is split in a surface cold box (He cooling 300-20K) and an underground cold box (20-4.5K). It will be necessary to double this system with four additional plants, but with an integrated design, installed at the surface of the different points. In addition cold compressor boxes in underground caverns will compress helium gas up to atmospheric pressure at cryogenic temperatures, in order to obtain the superfluid helium at 1.9 K, [6]. Finally, interconnecting boxes should allow to couple two cryoplants to provide some redundancy and to speed up the cooling process if necessary.

The upgrading of the existing cryoplants is already under way, as it will be needed in the next two years for running the LEP machine to the highest possible energy. The new cryoplants have been specified and will be supplied as turn-key machines and the cold compressors development are progressing.

A compound cryogenic distribution line will connect each cryoplant to the cryomagnets in the arc and will supply them with helium at the required temperatures and pressures, [7]. As shown in fig. 5, this runs alongside the cryomagnets on the exterior side of the tunnel.

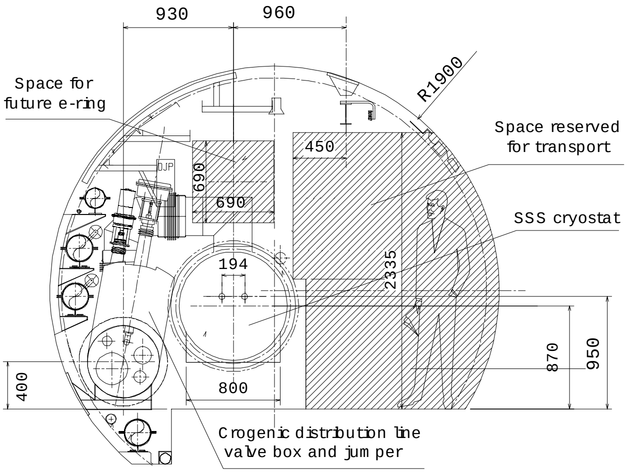

Figure 5: Standard cross section of the LHC tunnel

The cryoline has an outer diameter of 600 mm, mainly because of the cold pumping line which must be large for minimising the pressure drop over the length of an arc and also of the 20K quench recovery line which serves as a helium buffer in case of a quench of several magnets. The other internal lines serve to supply helium at 4.5K, 3.6 bars for filling the magnets and gas helium at 50K for the thermal screen. The cryoline is connected to the arc cryomagnet every second short straight section, i.e. about 106 m, through a U-shaped composite line, called jumper, which feeds the technical service module in front of the short straight section. Once the magnets are filled with liquid helium at 4.5K and 1.1 bar, superfluid helium at 1.8K is created in the service module by connecting it to the pumping line, and then sent in a linear heat exchanger running inside the magnets all along the string, which allows to operate them in a static bath of superfluid helium at 1.1 bar.

The detailed design, the fabrication, the installation and commissioning in situ of this compound cryoline with all the different jumpers will be performed by industry: firms have already been invited to quote for a 106 m prototype and for a ceiling price for the whole supply, but the final adjudication will be done by re-tendering after a full assessment of the prototype performances. The cryogenic service modules will be ordered separately, as they will be attached to the short straight sections. A large amount of additional cryogenic components will also be purchased, like valves of various types, heat exchangers, sensors, etc.

4 VACUUM

Two different vacuums must be considered for LHC.

4.1 Insulation Vacuum

The space between the magnet cold masses and the cryostat outer tanks is put under moderate vacuum in order to avoid heating the cryomagnet by conduction and by convection. In addition, one or two screens, covered with several superinsulation layers are used for reducing radiation heating. The insulation vacuum requirements are not very stringent: the magnet cool-down process can be started when the pressure is in the 10^{-2}-10^{-3} Torr range. When cooling down, the pressure decreases gradually to 10^{-6} Torr and the pumping units can eventually be turned off, the magnet cold masses acting as a cryopump.

However it is not so trivial to obtain this insulation vacuum: the volume to be evacuated is huge and the layers of superinsulation are often full of moisture, thus leading to very long pumping times. Moreover, magnets are interconnected with numerous welds and any leak is very difficult to detect, in particular in the case of a “cold leak” which appears at low temperature only. Active material, like charcoal, may be installed in the cryostats to alleviate these problems and increase the pumping speed.

4.2 Beams vacuum

The required luminosity lifetime implies that the beams vacuum stays in the range of 10^{-9}-10^{-10} Torr. This should normally not be a problem, as the beams circulate in the cold bores which are at 1.9K and are then very effective cryopumps.

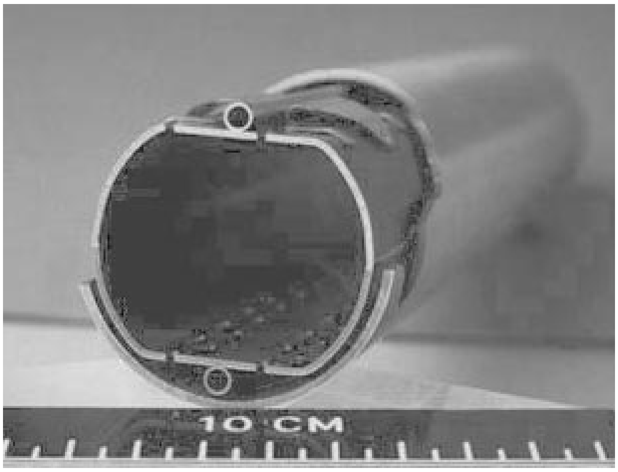

Figure 6: Beam screen in its cold bore

In fact, the circulating beams radiate quite some power: the total synchrotron radiation emitted from the two proton beams at 7 TeV amounts to 0.41 W/m. In addition, beam image currents circulating in the vacuum chamber wall add resistive losses. These two effects would be an excessive load to the cryogenic system and a beam screen, as shown in fig. 6, must be inserted in each cold bore to intercept the beam emitted power, [8].

The beam screen is a rather complicated object which is still under development in collaboration with industry. It will make use of colaminated sheets of stainless steel and copper, in which pumping slots must be punched. The sheets are then formed and welded. Cooling channels and spring supports are then fixed onto the screen. Some 50 km of beam screen are needed, in unit lengths of 16 m.

5 POWERING AND CONTROLS

All the dipole magnets of an arc are powered in series to a current of up to 12 kA, but the required voltage is low and determined essentially by the desired rate of rise of current. Power converters will then be installed close to the magnets, in underground caverns and galleries at the even points, to minimise the voltage drop along warm conductors. Other magnets like lattice quadrupoles and harmonic correctors will also be powered in series, with superconducting busbars running through the magnet cold masses, [9]. The connection of all magnet circuits to their associated power converter requires a large number of current leads, based on the use of high temperature superconductors ceramics produced by industry.

Because of the very large energy stored in the magnets (7 MJ in each dipole), an elaborate magnet protection system must be built, to avoid any damage in case of a sudden resistive transition, called a quench, and will be based on cold diodes installed in each magnet cryostat.

In all transverse directions, both proton beams are surrounded by more 300 mm of steel, which provide a relatively effective shielding against radiation. One then expects a dose lower than 2-3 Gray per year of LHC running under the central dipole of each half cell. One will then take advantage of this by installing in the tunnel as much control electronics as possible. This applies in particular to the quench protection detection and control, vacuum control, beam monitoring front end electronics, closed orbit correction, etc. All this equipment will be housed in small crates located under the central dipole and linked with the central control system through optical fibres, thus avoiding the installation of many expensive classical cables.

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, is planned to be kept running at top energy till October 2000.

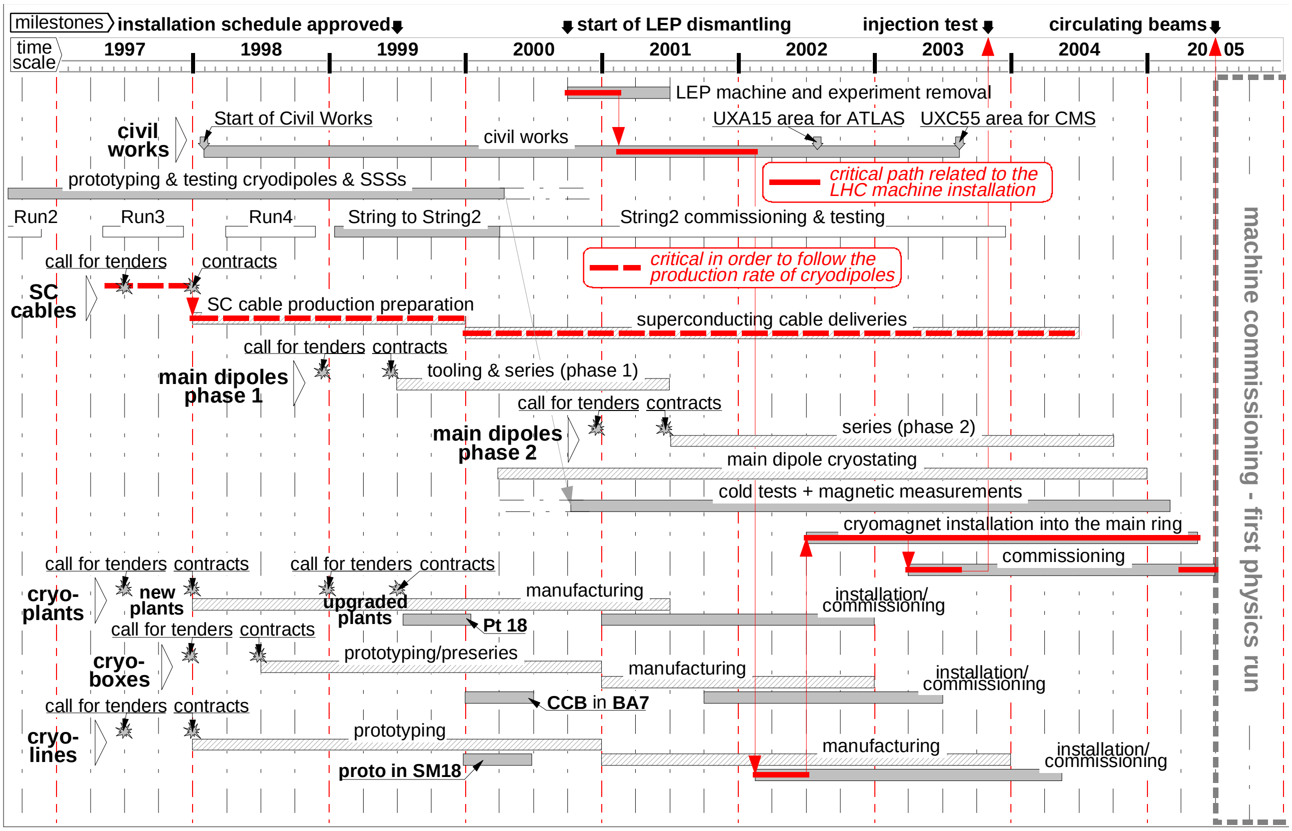

Figure 7: Schematic summary schedule of main LHC components

Quite obviously, the time span between LEP stop and the start of LHC must be kept to a strict minimum. A fast LEP deconstruction is then required while at that time LHC items will be produced at full speed. One then has optimised the overall planning, see fig. 7, by trying for instance not to order the LHC components but have them delivered just in time. This will also alleviate somewhat the temporary storage problems, [10].

LHC installation proper will proceed on several fronts in parallel, but will follow a well defined sequence: first general services, then the distribution cryoline and lastly magnet installation. This will 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 non destructive testing.

7 CONCLUSION

Only the most critical LHC components have been reviewed in this paper, but more conventional items and works will offer interesting opportunities to qualified firms. In fact, the LHC machine represents a formidable technical challenge not only for its designers but also for the whole industry that could benefit from the advance technologies used for building it. Its success depends on a fruitful collaboration between CERN, other Laboratories, and industrial firms all over the world and will open new frontiers for particle physics.

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