FROM STRING 2 TO SECTOR TESTS: GETTING READY FOR BEAM

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Abstract

An overview of the operations required to prepare the collider for beam injection is given. The vacuum and cryogenic conditions which must be established, as well as the checks and tests performed to verify the integrity of the powering and protection systems, are briefly presented. The relative relevance of the experiments at String 2 and on the first sector test are discussed, as well as the additional constraints and benefits of beam injection in the first sector.

1 FOREWORD

The LHC design and construction activities have so far focused on the main LHC components and systems, through finalisation of their design, validation of their construction on prototype and pre-series units, and implementation of their industrial procurement. Although operational aspects have constituted an integral part of design constraints from the onset, and in fact largely driven the design of LHC accelerator systems, their experimental validation could only be performed partially so far, either on single components or by means of system tests such as String 1, which was however based on equipment configurations prior to the "Yellow Book" [1]. The main role of String 2 is thus to validate the main accelerator systems – superconducting magnets, cryogenics, vacuum - in their quasi-final configuration, as well as to provide a first hands-on experience at running a full LHC cell, while the first sector test should extend this experience to a full machine sector including all accelerator systems, eventually crowned by injection of a test beam. String 2 is in its final phase of construction and will start operating in spring 2001, so it is no surprise that it already features a well-established experimental programme. This is however not yet the case for the first sector test, for which even the basic configuration, let alone the detailed programme and schedule, are still open issues. The considerations presented hereafter should therefore only be taken as first ideas, backed by little more than hand-waving arguments, aiming at triggering reflection and discussion on this important, yet unwritten chapter of our future work.

2 ACCELERATOR SYSTEMS: LHC VS. LEP

As an introduction to the question of LHC sector tests and commissioning, it may be useful to underline the main differences between the accelerator systems of the LHC and those of LEP, the reference accelerator which has been operated successfully at CERN over the last twelve years. Commissioning the LEP accelerator systems after installation of the machine in the late 80s proved rather fast and easy [2]. Most components used state-of-the-art technology and were therefore not critical, the systems were largely decoupled – with the exception of some interference which occasionally led to problems - and could thus be constructed, tested beforehand and commissioned independent of each other. Moreover, there was little or no influence of the first physics beams on the technical systems. All these circumstances led to a remarkably swift and successful start-up of the machine, allowing to reap first physics results after a few weeks of operation.

Commissioning superconducting accelerators, however, proved harder and longer, even before first beams could be injected. Superconducting technology and its ancillaries – cryogenics, insulation vacuum – are characterised by long time-constant processes, such as pump-down and cool-down, as well as long time delays to validate quality in construction and assembly. As examples of the latter, let us mention the possible occurrence of cold helium leaks on cryogenic circuits that have been satisfactorily leak-tested down to the 10^{-10} Pa. m^3. s^{-1} sensitivity at room temperature long before the first cool-down, and the consequences of even slightly resistive splices in the superconducting cables upon the first high-current powering, truly undetectable in the course of assembly at the required level of a few 10^{-10} Ω. More fundamentally, the intrinsic metastability of the superconducting state, leading to magnet resistive transitions ("quenches") [3], and the pronounced non-linearity and time-dependent behaviour of superconducting magnets, which exhibit effects such as remanence, saturation, current ramp dependence, decay and snap-back [4], at best strongly complicate the operation of the accelerator, and at worst hamper its operational availability.

Although building on the experience gained with its predecessors – the pioneer Tevatron at Fermilab, HERA at DESY and RHIC at Brookhaven National Laboratory [5] for their superconducting magnets, but also CEBAF at the Jefferson Laboratory and LEP2 at CERN as large cryogenic machines - the LHC pushes applied superconductivity and its ancillary technologies to unprecedented heights. The sheer size of the machine, the high energy and intensity of the colliding beams, the high-field, twin-aperture magnets operating in superfluid helium, the cryogenic vacuum system subject to beam-

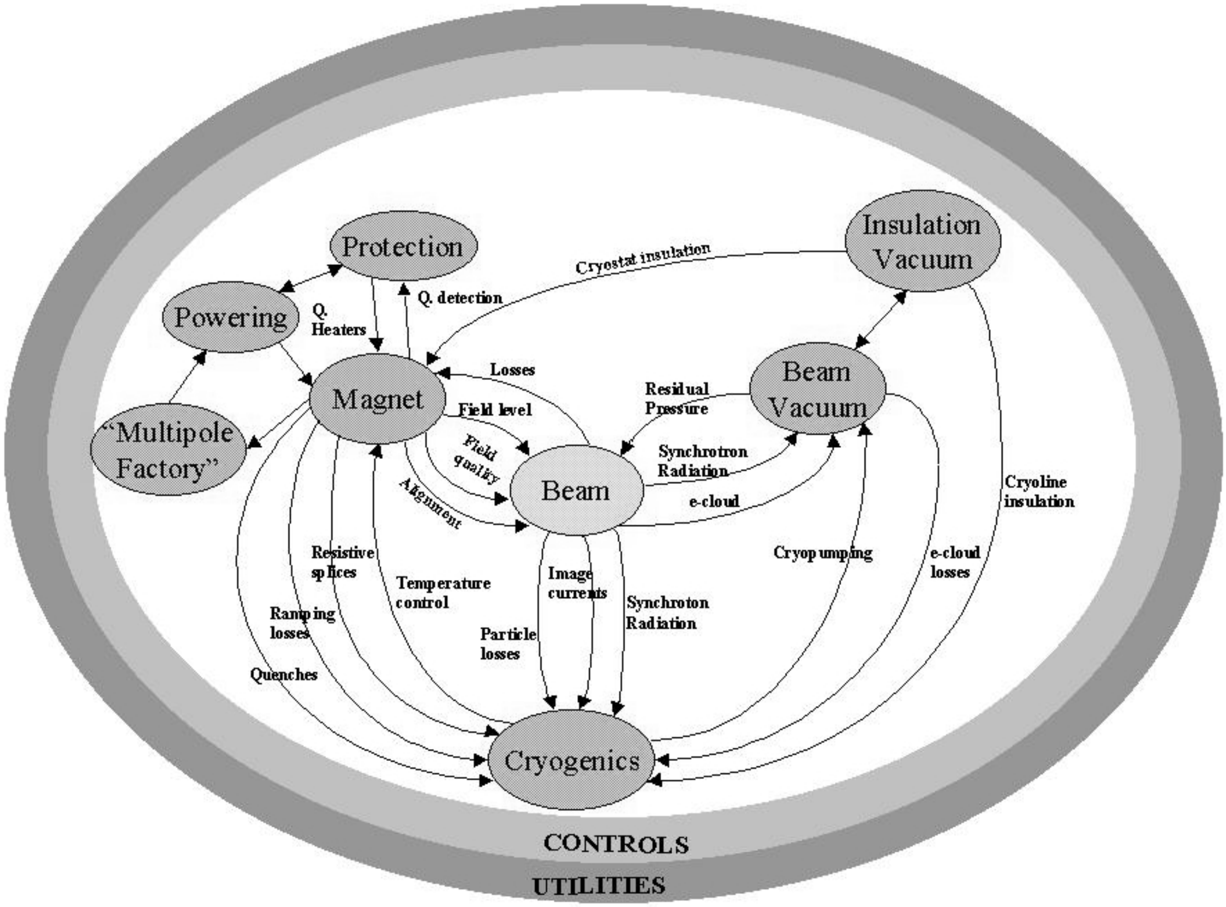

Figure 1: Interdependence of LHC main accelerator systems and beam.

induced loads, the interdependence and intricacy of the technical systems (Figure 1), together with the design compromises resulting from the siting constraints and reuse of LEP civil engineering and infrastructure, render the construction of the LHC a formidable challenge, far beyond simple extrapolation from previous projects. Injecting beam prematurely before the technical accelerator systems are properly commissioned would therefore certainly be counterproductive and unnecessarily delay the achievement of physics performance.

3 SYSTEM VALIDATION ON STRING 2 AND SECTOR TEST

The staged approach which will eventually lead to physics beams in the LHC has begun with String 1 and will continue with String 2, a full working model of a LHC cell, operated without beam from spring 2001 onwards. The first sector – sector 7-8 - will then be installed and its accelerator systems tested and commissioned in 2004. The crowning of this effort should be the injection of test beams at 450 GeV in one ring, and their transport along the 3.3 km length of the sector. The installation and commissioning of the technical accelerator systems in the other seven sectors will follow in a staggered fashion, so that the commissioning of the LHC will *de facto* start in 2004 and stretch over the 2004-2006 period.

The respective merits of String 2 and the sector test for validating the LHC technical accelerator systems are summarised in Table 1. While the basic component design will have been confirmed on individual tests, String 2 will permit to investigate the collective behaviour of the different systems at the level of the lattice cell, a scale intermediate between the individual component and the full sector, on which several functions – e.g. the superfluid helium cooling loop controlling the magnet temperature, or the external pumping of the beam vacuum – are sectorised by design. Phenomena developing on a larger scale or involving the complete sector – e.g. powering dynamics, quench recovery, or helium inventory management during transients – will only be observed for the first time and experimentally studied on the first sector test. The details of these tests will be discussed in the following presentations by the equipment specialists [6, 7, 8].

Table 1: System Validation on String 2 & Sector Test
(P: preliminary validated; V: full validated; C: confirmed)

	String2	**Sector**
Insulation & beam vacuum pumpdown	P	V
Insulation & beam vacuum leak detection	P	V
Insulation & beam vacuum sectorisation	-	V
Cooldown & warmup	P	V
Alignment stability	P	V
Magnet temperature control	V	C
Beam screen cooling	V	C
Flow stability in cryogenic circuits	-	V
Tuning of cryo distribution loops	P	V
Cryogenic heat loads	P	V
Cryoplant/accelerator dynamics	-	V
Power converter cycling & tracking	P	V
Quench detection & protection	V	C
Quench propagation	P	V
He discharge from quenched magnets	V	C
Quench recovery	-	V
He inventory management	-	V
Subsectorisation & interventions	-	V

A tentative schedule of the first sector test, after completion of installation and associated checks, is given in Table 2. This reasonably optimistic view, which however still requires confirmation through detailed input from the equipment specialists, leads to a total of some three months to get the technical accelerator systems of the sector commissioned and ready for beam injection. It is expected that each sector will be maintained in cold standby following its commissioning.

Table 2: Tentative Schedule of Sector Test

Vacuum pumpdown	1 week
Cooldown phase 1	2 weeks
Full and Final cooldown	1 week
Protection & interlock tests	3 weeks
Powering, tuning & tracking tests	3 weeks
Quench & recovery tests	1 week
Misc. adjustments & tests	1 week
Total	**~ 3 months**

4 FROM SECTOR TO INJECTION TEST

Injecting test beams in the first sector will bring significant added value on the way to full machine commissioning. It will provide a global verification that all accelerator technical systems, including utilities and services, are fully operational and performing as expected. Threading the first test beam – even at injection energy and low intensity – through only one aperture of the sector will permit to check the alignment, aperture and polarities of all magnets, the correct setting and control of the power converters, as well as the beam observation and steering systems. It also constitutes a major project milestone, important for internal motivation and external communication. The injection test however spans two adjacent sectors, namely 7-8 and 8-1, and would ideally require that the technical accelerator systems of both sectors are installed, tested and commissioned as a prerequisite. An alternative could be to design and install a temporary beam line, using warm magnets and *ad hoc* vacuum chambers, from the transfer line to the beginning of sector 7-8, through the experimental area. The choice between these options depends on general planning of the project and experiments, and the availability of additional resources during the construction phase. In any case, a detailed cost-to-benefit analysis of this important issue is required in the coming months.

REFERENCES

[1] The LHC Study Group, The Large Hadron Collider, Conceptual Design, CERN/AC/95-05(LHC).

[2] S. Myers, The LEP Octant Test, these proceedings.

[3] A. Siemko, What Happens during and after a Quench? these proceedings.

[4] L. Bottura, Field Quality in LHC Main Ring Magnets, these proceedings.

[5] F. Pilat, Experience with the RHIC Sextant Test, these proceedings.

[6] L. Serio, Cryogenics, these proceedings.

[7] P. Cruikshank, Vacuum, these proceedings.

[8] F. Bordry, Powering, these proceedings.