The LHC during the Sector Test

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Abstract

An overview of the tests to be carried out during the LHC sector test are explained and their motivation given. The possible layouts of IR8 are detailed, along with the effects of the installation of LHC-b. The performance expected from the power converters, the cryogenic system, the control system, the timing system, the beam instrumentation and the interlock system are given. The importance of a beam based measurement program during the sector test is highlighted and possible measurements outlined.

1 INTRODUCTION

The LHC sector test will be a major challenge. It will involve the installation and integration of technical systems on a large scale and the commissioning of these system in situ. It will also provide the opportunity to inject beam, which will provide focus for beam-based instrumentation and control, interlock and access systems. Already here we see the natural division of the test into two: the commissioning of the technical services i.e. cryogenics, vacuum, machine protection and powering systems; and the test with beam.

The LHC will compose eight essentially separate sectors and as such the sector test will provide a representative test of the whole machine and thus must be regarded as a rigorous test of, what will be, reality.

2 OVERVIEW

As indicated above the major part the sector test will be the commissioning of the technical systems to allow a safe cool-down, pump-down and eventual powering of most of sector 8 to 1. Here the emphasis will be on the continuous arc cryostat.

Beam 2 will be injected in the LHC from TI8 which joins the LHC to the right of IP8. The beam will traverse the interaction region at point 8, and thereafter the continuous cryostat of sector 8 to 7. A beam dump will be positioned in the straight section before IP7.

A key concern already becomes apparent: the sector test will, in fact, involve not only sector 8 to 7 but also part of sector 1 to 8 from the injection point just to the right of Q5.R8 through to IP8.

At present the sector test is foreseen to start in the first quarter of 2004. Injection of beam will be blocked by the start of LHCb installation at present scheduled to start in November 2004.

3 LAYOUT IN POINT 8

3.1 Final configuration

The final configuration of the IR8 foreseen for the LHC is shown in figure 1. Here the injection point lies to the right of Q5 and Q4 (cold twin aperture insertion quadrupoles). The beam will then have to traverse:

- Outer ring of D2 right (twin aperture separation dipole)
- D1 right (single aperture separation dipole)
- Inner triplet right
- Vacuum pipe through what will be LHCb
- Inner triplet left
- D1, D2, inner ring of Q4 and Q5
- Dispersion suppressor
- Arc 8 to 7

The fact that the injection point lies to the right of IP8 and thus involves part of sector 1 to 8 complicates matters considerably because the cryogenics and vacuum system of this part of the sector will need to be installed and commissioned. Following this the cryogenics and protection systems of the combination dipoles and the inner triplets will need to be commissioned and powering tests performed before the insertion is ready to accept beam. This could provide an unacceptable overhead in the overall sector test.

On the other hand the installation of the inner triplets needs to be done at sometime and the LHCb installation will not necessitate their removal. It will be clearly extremely useful to system test them as part of the sector test representing as they do an essential feature of the final configuration. However, it could be argued that with the emphasis being placed on the arcs they are not essential for tests with beam.

3.2 Warm insertion

The idea here is to avoid the complication of the insertion all together by:

- installing warm quadrupoles right of IP8 to replace Q4 and Q5 and to install a temporary warm transfer line across the region (plus temporary vacuum system)
- beam would enter either the inner or outer aperture of Q4.L8

The virtue of this scheme is that it avoids the installation of cryogenics to service elements right of point 8 and that it also avoids the potentially lengthy commissioning of the inner triplets.

On the other hand, one doesn't get to commission and system test the full insertion (cryogenics, vacuum, power, protection).

3.3 Variations

Possible variations on the above schemes include:

- Installation of the inner triplets, D1 and D2 left and right of IP8. One could commission with beam in the first instance with the triplets cold but off using an appropriate de-tuned optics. Powering tests could then either be interleaved with beam tests or performed after tests with beam.
- As for the warm insertion detailed above but with Q4 and Q5 left of IP8 also warm.

Clearly the options outlined here need to be studied in further detail. From a systems and beam based test perspective the full scheme is the most exacting and as a true reflection of the final configuration to be preferred. Clearly however temporal constraints may force consideration of one of the less complete options.

3.4 LHCb

The installation of LHCb is scheduled to start in November 2004. One key element of the experiment is a large dipole magnet which acts a spectrometer. The effect of this dipole on the beam will require compensation by 3 other dipole magnets installed in the interaction region. None of these magnets will be present for the sector test.

The installation of LHCb will last for around 18 months and during this time further injection tests in point 8 will not be possible. Technical system commissioning can continue during installation. The inner triplets if installed will not need to be removed for LHCb installation.

4 TECHNICAL COMMISSIONING

The commissioning of the technical systems required before beam can even be considered will the major part of the sector test, both in time and complexity. A detailed plan has yet to be drawn up and the list below is to give some flavour of what has to be done:

- Cryogenics: commissioning and debugging of the control system. System tests. Magnet temperature control. Screen cooling. Flow stability. Preliminary cool-down, final cool down. Warm up. Tuning of cryogenics distribution loops. Cryogenics heat loads. Cryo-plant dynamics. Quench recovery tests. Helium inventory management.
- Cold mass instrumentation: calibration of temperature sensors, voltage taps. Data acquisition.
- Vacuum: leak and pressure tests of the beam lines, Helium lines and external vacuum vessel. Subsectorisation. Full Helium pressure tests. Pump down. Alignment.
- Machine protection: system checks of quench protection, energy extraction, data acquisition, instrumentation, functional tests, recovery. Quench Propagation. Helium discharge.
- Powering: warm and cold DC low voltage tests, electrical insulation tests, power with short circuit, interlocks, energy extraction. Tracking studies.

It has been estimated that to get the sector into a state where the magnets may be powered at the 450 GeV level will take at least 3 months. This is regarded by some as very optimistic. High currents tests will only be able to take place after more thorough protection system and powering tests [1].

Clearly much of the system commissioning may be done in parallel, with inevitable interdependencies. Careful planning will obviously be required.

5 COLD CHECKOUT

At the end of the technical commissioning, with a bit of luck, the beam pipes will be pumped down, the magnets will be cold, the protection systems tested and one will be able to power the magnets safely. This will allow a program which might be called the very cold checkout to prepare for beam. This would include a full system shakedown by dry running the operational cycle, operational equipment tests of collimators, TDI, power converters, kickers and the associated control system . Fault recovery and quench recovery procedures can also be tested. Besides the technical systems many auxiliary requirements are to be met before one could consider taking beam. These are outlined below.

5.1 Transfer

Extraction from the SPS has to be commissioned. It is hoped to reach the TED in TT40 in 2003, this would be preferable allowing plenty of time for problem resolution. There is however possible interference with TI8 installation [2].

It is foreseen to commission TI8 in parallel with the sector test. Again potential interference, and implications for access and radiation protection.

There are problems with the production of prototype injection kickers for the LHC itself. These prototypes need to be tested before series production can start and there is a chance [3] that the kickers may not be ready for the sector test. It is therefore necessary to foresee an injection scheme without kickers. Clearly if there are available it would be very useful to test them and the associated timing.

5.2 Interlocks

Low intensity pilots will be used. These will not be able to quench a magnet themselves. Even so the power permit and power abort system will need to be in place to provide machine protection to avoid damage to the magnets, cables and current leads. The beam dump will clearly not be required but the beam permit system should be commissioned. Transfer line and SPS extraction interlocks and vetoes should be in place.

5.3 Power converters

As mentioned above extensive powering tests of the power converters and magnets will take place before beam is even contemplated. However, for tests with beam the full functionality of the digital controllers, the associated worldFIP field bus, gateways and network will need to be in place for appropriate high level control. High level functionality such as cycle, set and trim will be required, as well as interfaces to the alarm and interlock system.

For debugging and tracking studies appropriate data acquisition must be available.

Many more circuits will be available which are not necessary for the simple transfer of beam. More sophisticated tests with beam may required some of these other circuits e.g. multipole correctors. It will, however, be very useful to test and commission all circuits of the sector with or without beam [4].

5.4 Beam Instrumentation

The following beam instrumentation systems will need to be in place:

- Beam position monitors
- Beam loss monitors
- Beam current transformers (IBMS)
- Beam synchronous timing
- Screens

For these not only will the front-end hardware be required, but also front-end processors, gateways and networks to allow data acquisition by high level systems, plus, needless to say, the requisite application software.

5.5 Controls

Much of the technical commissioning and all of the beam based commissioning will be performed at the high level in dedicated control rooms. This has strong implications for the control system architecture which will have to integrate:

- front ends, e.g. power converters and beam instrumentation,
- field buses and gateways,
- networks,
- communication protocol or middleware,
- support for industrial control systems as used by cryogenics,
- support for PLCS as used by, for example, the vacuum system.

Other key supporting subsystems required will include: timing and synchronisation, alarms, post mortem, and logging. Cross system monitoring and data exchange must also be foreseen. For example between vacuum and cryogenics, between these and the PCR.

High level application software will be required. This will include:

- Measurement acquisition: e.g. trajectory, beam images from screens, BCT.
- Correction: e.g. trajectory, threading, injection steering.
- Trim: e.g. orbit bumps, phase advance, energy, multipole correctors.
- Setting generation: 450 GeV settings with and without inner triplets, baseline ramp.
- Hardware control: power converters, kickers, TDI, collimators.

6 WITH BEAM

6.1 Motivation

If the Higgs is at 115 GeV/c^2 then 20 fb^{-1} is need by the Tevatron for a discovery (CDF/D0 combination). At the LHC the standard model Higgs boson can be discovered at 5σ with around 10 fb^{-1} per experiment for $M_H \leq 150$ GeV and the whole mass range can be excluded at 95% confidence level after around one month of running at 10^{33}cm^{-2}s^{-1} [5]. This to make the point that the Tevatron has a tough target and that the LHC can quickly become competitive even with only moderate luminosity. This given that the experiments have in turn commissioned their detectors.

Ideally then one would like collisions as quickly as possible after the start of commissioning. Operations will depend crucially on not just the technical systems but also beam instrumentation, controls, accelerator understanding. The sector test, it might be argued, will provide the opportunity to get a running start on properly commissioning these systems. Therefore a thorough and hopefully reasonably prolonged beam based commissioning phase should be strongly encouraged.

Beam based tests also constitute an important part of system tests, and for example could reveal problems with mechanical aperture such as those missed during the RHIC sector test [6].

6.2 Transfer tests with beam

The transfer of beam to the LHC is not straight forward and there are demands on beam quality and stability. For SPS extraction it might be hoped during this phase to investigate pulse to pulse variations, matching, extraction steering, different bunch configurations and practice what will always be a demanding process.

In TI8 commissioning one would hope to commission the beam instrumentation and investigate such topics as batch to batch stability, longer term stability, effect of temperature drifts, steering, beam sizes, beam losses, interlock systems etc.

6.3 Sector test with beam

The main goal is of course proof of principle and it will clearly be psychologically important to get beam around the arc. To perform the basic task of steering beam around the arc one will need to:

- Commission kickers and related timing
- Commission beam instrumentation, namely, beam position monitors, beam loss monitors and beam synchronous timing
- Commission injection steering
- Match the energy of the sector and incoming beam
- Trajectory acquisition and correction.

Having established a single pass there are a wealth of other useful measurements that might be performed. These will allow further commissioning of beam instrumentation, exercising the control system and give valuable understanding of the dynamics of the LHC as a superconducting machine. These might include:

- Optics measurements and comparison with the model, via corrector kicks and difference trajectories. Dispersion, momentum aperture. Verification of pickup polarities.
- Coupling
- Acceptance, checks on mechanical aperture
- Effects of thermal cycling
- Multi-bunch injection
- Dynamic effects, persistent current decay, reproducibility and the effects of ramping and re-cycling
- Tests of the harmonic factory multipole model

7 CONCLUSIONS

The sector test will provide a major challenge and a major opportunity. All systems will be brought together for the first time and integration and full blown systems tests will clearly highlight any oversights and provide many opportunities to debug.

There are clearly many issues that need to followed up, among these are:

- The need for detailed planning of the commissioning schedule and system tests programs respecting the interplay of the many technical systems. Planning of the beam based measurement program, and the potential conflict of the PS extraction and TI8 commissioning with beam.
- The layout of IR8. Ideally the final configuration is too be preferred, but time and resource constraints need to be evaluated.
- Clear definition of what hardware, controls infrastructure and instrumentation needs to be in place and when.

The system commissioning will be a very large part of the sector test and problem resolution in this area must necessarily be a priority. However, the value of a beam based measurement program in commissioning instrumentation, controls and in gaining understanding of the machine must not be underestimated. Good progress here will go a long way towards a smooth commissioning of the completed machine and perhaps even future operations.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

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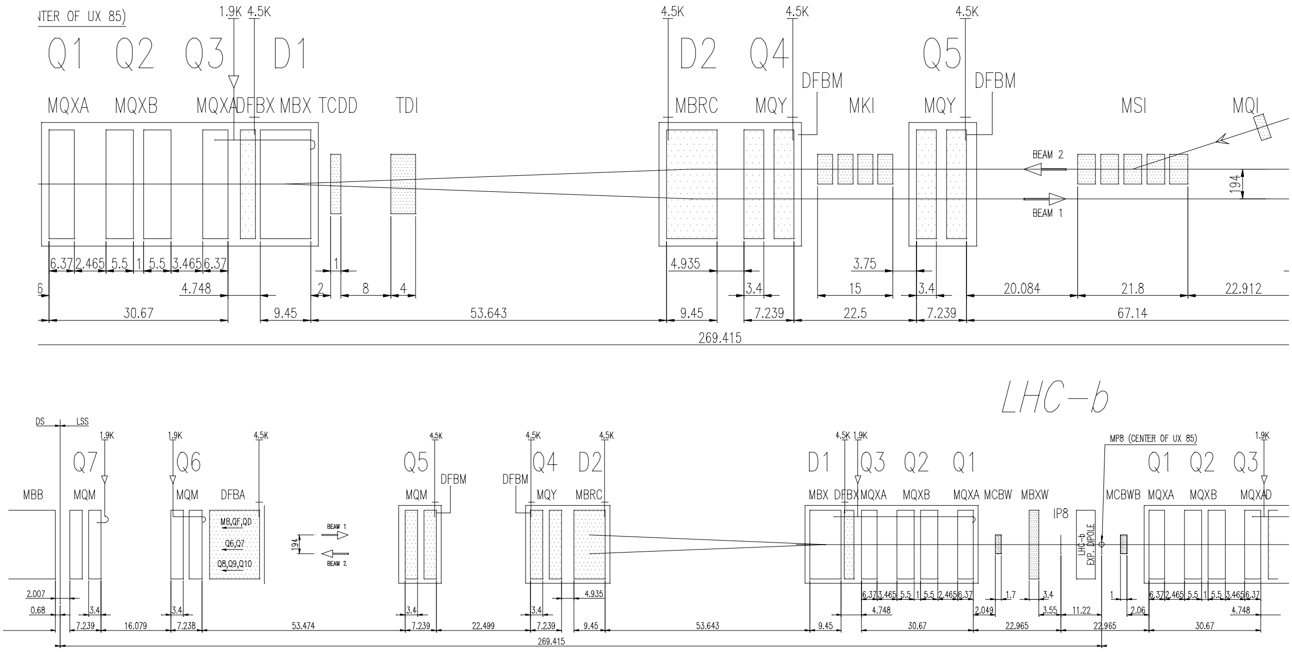

Figure 1: Final configuration of IR8