THE LHC SECTOR TEST

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Abstract
The proposal to inject beam into a sector of the partially completed LHC is presented. The test will provide an important milestone, force preparation of a number of key systems, and allow a number of critical measurements with beam. The motivation for the test is discussed, along with the proposed beam studies, the radiation issues and the potential impact on ongoing installation. The demands on the various accelerator systems implicated are presented along with the scheduling of the preparatory steps, the test itself and the recovery phase.

INTRODUCTION

An LHC sector test was approved in 2003. The aim is to inject beam into a sector of the partially completed LHC at least 6 months before full commissioning with beam. The LHC sector test will take in the last 200 metres of TI8 and 3.3 km of the LHC including one experiment insertion and a full arc [see figure 1]. As such it may be regarded as representative of the challenges to be faced in commissioning the whole machine.

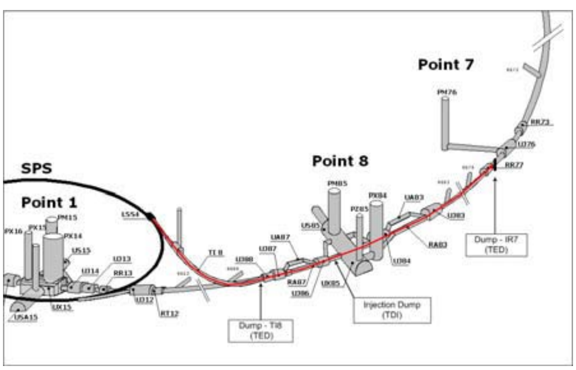

Figure 1: LHC infrastructure implicated in the sector test

It is clear that the test is potentially inconvenient, coming as it does during installation and hardware commissioning. The test will required around a week's preparation, during which the access system will be commissioned, a temporary vacuum pipe, a bunch current transformer and dump are installed in point 7 and a cold checkout and acceptance tests are performed. This is followed by 2 weeks test with beam with a 1 week recovery period during which a radiation survey is performed, access gates removed and the temporary installations, including the dump in IR7, are removed.

Although it does impact on installation, its effects are well constrained and manageable. The test will halt magnet transport through sector 7-8 for 28 days, and prevent access to part of 6-7 and part of 8-1 during the test (17 days).

There are clearly delimited demands on what is to be installed and operational, but it should be noted that the test is essentially baseline. There is very little additional installation and virtually all elements are in the final configuration.

MOTIVATION

A test with beam of part of an accelerator during the installation process is standard and the motivations in the case of the LHC have been well debated [1,2]. Such a test allows one to:

Verify system wide integration: full-blown system wide integration tests necessary for beam go one step beyond hardware commissioning. It allows one to field test beam related equipment such as: power converters, kickers, septa, dumps, pickups, synchronisation, timing, and to get them all working together. It stress tests the controls infrastructure and will fully validate integration and highlight oversights, and force the debugging of problems. There will be problems and the lessons learnt will undoubtedly speed full commissioning.

Check that the installed equipment works with beam: ensure that there are no problems with ongoing installation. Beam will confirm that the aperture in the cold machine is free and has the expected size. The beam samples all electromagnetic fields in the vacuum pipe and will allow polarity checks of the corrector elements and the beam position monitors, measurements of field errors, and determination of any large offsets between beam and magnet. Linear optics checks are also possible.

It will be the first exposure to beam of much of the hardware and will, potentially, allow verification of assumed quench limits and spatial resolution of beam losses.

Pre-commission essential acquisition and correction procedures: first tests of important beam diagnostic system will be possible. The beam provides the only way to verify the proper functioning of the diagnostics: timing, BPM resolution, BPM cabling, BPM offsets, BLM resolution. It will allow tests of the control and correction systems (including correctors, cabling, the control system, software, procedures etc.).

Last but not least it will provide an extremely **high profile milestone** forcing the preparedness of all components. These would include controls, timing, transfer from the injectors, instrumentation, interlocks, access, radiation protection etc. These systems are absolutely critical for the effective exploitation of the machine. They must be ready and tested when we come to commission the whole machine. The test can potentially highlight oversights, misconceptions and shortcomings.

Operationally the exercise would be extremely valuable and it can be argued that the time and effort spent on the test will be more than compensated by a more efficient start-up of the completed machine. Commissioning of the first sector will have to be done anyway: discovering the problems during a sector test will give us several months at least to resolve any problems, perform a critical analysis of the performance of the systems involved and implement improvements. A successful test would also validate the project to the wider world.

It might be argued that if any serious problems are uncovered then it would be too late to change anything. Related is the question: “What do you if you can’t get beam around after two weeks?” Clearly the sooner any problems, serious or otherwise, are revealed the better.

It is also argued that many things will change between the test and full commissioning and we will have to re-do the exercise anyway. The counter-argument is that most of the accelerator systems will necessarily be in the final configuration for the test. Every attempt should be made to avoid temporary solutions for the test.

Finally, it has been argued that we are going to be busy enough anyway installing and commissioning other sectors and the test will provide a distraction and a draw on valuable resources. It is undoubtedly true that the test will place demands on the teams involved and draw resources from the installation and hardware commissioning.

In balance the advantages of performing the test largely outweigh the short term costs.

PROPOSED TESTS WITH BEAM

The aim is to use pilot beam for the most part i.e. a single bunch with an intensity of 5 - 10 x 10^9 protons. To avoid unnecessary activation, the clear aim is to minimise losses, and use beam sparingly.

The planned total intensity will be at maximum 4 x 10^{13} protons delivered over 2 weeks. This is comparable with one nominal intensity LHC extraction from the SPS.

The essential outline of the planned tests is:

- commission the end of TI8, the kickers, septa and the injection region [3];
- commission trajectory acquisition and correction and thread beam through IR8, sector 7-8 to IR7;
- commission the Beam Loss Monitor system;
- perform linear optics measurements;
- perform aperture checks;
- check the effects of magnetic cycling;
- perform field quality checks;
- check the quench limits and BLM response;
- set up injection machine protection.

These tests will verify the proper functioning of the essential BDI systems, with checks of the BPM resolution, cabling, polarity and offsets, BLM response and resolution, and BTV resolution. The tests will verify with certitude that the aperture is as expected in the critical injection region and also in the arc and around IP8. In addition to the BDI, other hardware will be commissioned with beam, including the main magnets, injection system, orbit correctors, timing and machine protection.

The beam will sample all magnetic fields over 1/8 of the machine, which gives direct information about many aspects, including polarities, optics, key field errors to 1 unit, misalignments and corrector cabling. The test allows the deployment of control and correction procedures, via the beam threading, trajectory correction and bumps, and allows the magnetic model accuracy to be checked, providing data about the reproducibility of LHC cycle at injection and confirmation of the expected performance.

MAGNET QUENCHES WITH BEAM

Beam based machine protection will depend on the BLM system. Properly calibrated, they will allow safe and efficient operation and they will be a key element in avoiding quenches and damage. The aim during the sector test is to quench selected magnets with beam under controlled, well defined conditions to establish absolute quench limits; BLM threshold values; and to aid understanding of correlation between loss patterns, the quench level, and associated BLM signals [4].

These tests are an important first stage in understanding the above issues and it will help the efficient commissioning of the large, distributed BLM system with circulating beam.

BEAM INSTRUMENTATION FORESEEN FOR THE LHC SECTOR TEST

The key beam instrumentation for LHC operations, LHC commissioning and thus the LHC sector test are the distributed systems – the beam position monitors (BPMs) and beam loss monitors (BLMs). Implicated in sector test for these systems are consideration of the component production, component installation, tunnel electronics, acquisition electronics, acquisition transmission, calibration, and system tests [5].

Discrete systems also to be tested are a number of screens (BTV) and beam current transformers (BCT), one of which is a temporary installation for the test.

Required during the test are the key components of the Beam Synchronous Timing (BST) system and a large slice of the complete controls infrastructure which includes: Ethernet, slow and fast timing distribution, WIFI, VME infrastructure, and WorldFIP.

Although not strictly required, the test will also provide the opportunity to test the BLM to BIC connection and the Post Mortem system with beam.

The LHC Sector test provides an important mile-stone for beam instrumentation. It is the last chance to test with beam BPM and BLM ring systems before start-up. No show-stoppers for an LHC sector test with beam are foreseen, although a lot of equipment will only become available during spring 2006. It is now necessary to finalise procedures for test, installation and commissioning.

MAGNETS

The sector test will provide an appreciable scope (some 20 magnet families), comparable to the ring itself, and thus will provide a good test for magnet model [6].

The sector test will required transfer functions for the main magnet strings in 7-8 (MB, MQ); and for the insertion, matching section and dispersion suppressor quadrupoles which include MQY, MQM, MQX etc. These transfer functions can be provided by FiDeL - a Field Description for the LHC which is seen as a general framework for magnet setting generation. FiDeL will also provide the harmonic components for the main bends and quadrupoles, and other elements as necessary.

De-Gauss and nominal cycling prescriptions are described for the main bends, as well has cycling prescription for all other quadrupole and corrector circuits.

The work to be performed in 2006 is clear, and it is in line with the needs for the LHC commissioning and operation. The resources required are modest, but not negligible: the work to be done includes data reduction, model testing, data-fits, storage and tests, database work and the development of software tools.

CONTROLS REQUIREMENTS

The Sector Test is another progressive and important milestone for LHC controls and must be used for testing key functionality. It allows staged deployment and is absolutely critical to providing a satisfactory solution for eventual beam commissioning [7].

Among the systems implicated in the test for which controls plays a key role are the injection kickers, BLM, BPM, BTC, BTV, and beam interlocks. Required infrastructure includes VME, Ethernet, WorldFIP, and cabling. Frameworks and key components include configuration, FESA, and fast & slow timing. Some of these still demand development and testing.

Other important controls related implementations are interlocks & Safe Beam Parameters, application software, logging, Post Mortem, Alarms, Data exchange and Analog Acquisition. All of these will benefit from the serious field testing they will receive during the test.

SCHEDULE

An overview of the near test schedule is shown in table 1. A detailed breakdown is available at [8].

Task	Provisional Dates [days]		Comments
	Start	Stop	
IR7 vacuum & instrumentation	T_{start} – 20	T_{start} – 14	
Sector Checkout	T_{start} – 14	T_{start} – 4	Control from CCC
Install dump	T_{start} – 12	T_{start} – 10	Block 7-8
Access System	T_{start} - 7	T_{start} - 4	Installation of gates
Close sector	T_{start} - 4	T_{start} - 4	Access system tests, safety qualification
Beam to TI8 TED	T_{start} - 3	T_{start} – 1	
Tests with beam	T_{start}	T_{final}	Point 7,8 closed
Radiation Survey	T_{final} + 1	T_{final} + 1	
Gates Out	T_{final} + 2	T_{final} + 2	6-7,8-1 free
Dump Out	T_{final} + 7	T_{final} + 7	Ring free

Table 1: Overview of near test schedule

CONCLUSIONS

The LHC sector test is an important milestone for a number of critical subsystems. It provides an opportunity to thoroughly test full integration of a wide variety of accelerator systems, all of which will be needed for machine commissioning. It also allows important beam based checks of the ongoing installation.

It will give time to react to the problems thus revealed, resolution of which will be critical to effective full commissioning. Besides this important first checks can be performed with beam, and again lessons learnt will ease establishment of circulating beam and the huge amount of commissioning effort that is to follow.

Although it does impact on installation, its effects are well constrained and manageable. Careful planning is required to fully anticipate the requirements and effects of the test in order to minimise the disruption it will cause to other ongoing activities.

Performing the test is essentially win-win. If things go relatively smoothly, resolution of the inevitable, minor problems will speed up full beam commissioning. If we hit any major problems, we will at least have some time to react.

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