A STAGED APPROACH TO LHC COMMISSIONING

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Abstract

Effective commissioning of the LHC with beam will demand very good preparation; all concerned subsystems will need to be well-prepared and thoroughly tested before first beam. To clarify the demands on the systems involved the objectives of the commissioning phases are presented, along with a breakdown of the phases and the essential prerequisites for each. The nature of the interdependencies between the various systems is highlighted; in particular the need for a well-planned commissioning of the machine protection system.

INTRODUCTION

The LHC is a complex machine. Commissioning it fully with beam will be an exacting challenge. However, it is clearly of interest to provide useful physics as quickly as possible after it is ready to accept beam. This paper describes an overall strategy for commissioning with beam which places emphasis on careful preparation; staging the beam related goals of the commissioning and thus the demands on the commissioning and role of the various sub-systems; and a breakdown of the phases of the operational sequences with clearly delineated entry and exit conditions along with well-defined set of prerequisites for each.

PREPARATION

The importance of thorough preparation to effective beam commissioning can not be understated. Long experience from LEP, and elsewhere, reaffirmed by TI8, tells us that the testing of all systems as thoroughly as possible without beam in the machine checkout phase allows the resolution of a myriad of problems which would have otherwise dogged commissioning with beam. These problems have a two–fold effect: firstly the loss of time in problem resolution; secondly the disruption to the smooth flow of the commissioning process, and the knock-on effects to the machine state and reproducibility.

The months before LHC beam commissioning will necessarily see the end of hardware commissioning; a machine checkout; the re-commissioning of TI8 and the commissioning of TI2. The exit conditions from each of these phases needs to be well-defined. In particular the aims and planning for the machine checkout phase must be well established and rigorously pursued.

Hardware Commissioning

Hardware commissioning (HWC) is clearly a major phase involving the commissioning and testing of the accelerator hardware and of the LHC's technical infrastructure. Systems implicated include: beam vacuum [warm & cold]; QRL vacuum; insulation vacuum; cooling and ventilation; cryogenics plant; cryostat instrumentation; QRL instrumentation; electrical networks; powering interlocks; quench protection and energy extraction; the software interlock system; and the access system. HWC also includes including a systematic alignment by the survey group.

Beam related hardware will also have gone through appropriate commissioning including: magnet circuits [warm & cold]; power converters; kickers, septa; collimators, absorbers; beam dumps; RF systems; beam instrumentation; machine protection system and controls.

A breakdown of the detailed planning for the hardware commissioning is available [see, for example, 1]. Exit conditions for the hardware commissioning phase of the beam related hardware are being established.

At the end of the hardware commissioning phase we must anticipate the above systems moving into the global operational mode with appropriate facilities in the CERN Control Centre (CCC). These facilities should include: monitoring, logging, displays, post mortem, diagnostics; the appropriate control applications, definition and implementation of appropriate coupling between systems. Recovery procedures from CCC must be clearly defined.

Following initial hardware commissioning, some systems will enter an extended phase of hardware tests to be performed by the system experts. The RF system, for example, needs time for conditioning of the cavities along with detailed low-level tests. Such tests would continue in parallel with the main thrust of HWC. Again a well-defined hand over point to operations and the machine checkout should be established.

Machine Checkout

The machine checkout will be coordinated by the Operations group, with the support of equipment specialists, HWC team etc. and will be performed from the CCC. The objectives of this phase is to pull together the disparate components and subsystems of the accelerator and drive all relevant systems in a synchronized way through the complete operational sequence, anticipating the actual operation of the machine. This phase is estimated to take around 6 weeks [2]. The checkout can be performed partially in parallel with the hardware commissioning and one would anticipate complete powering sub-sectors and sub-systems being signed over to operations as available.

A detailed planning of this phase with rigorous acceptance criteria is essential. Opportunities for parallelism must be exploited to the maximum.

Injectors and Transfer lines

The SPS LHC cycle should have all requisite LHC beams available with the desired beam quality ready to be delivered when required [3]. TI8 & TI2 should have been commissioned and have delivered fully qualified LHC pilot beams to the final dump in the lines.

Magnets

In order to stand any chance of dealing with the vagaries of the huge magnet system, the strategy for dealing with the various characteristics of the magnets must have been clearly established before commissioning. For all circuits the following should be dealt with:

- DC Errors: geometric, beam screen, saturation;
- persistent/eddy currents: static model and powering history dependent model;
- cycling strategy including nested circuits;
- transfer functions;
- hysteresis behaviour for corrector circuits where appropriate;
- Strategy for the excitation of nested correctors.

All data, models, interfaces, components and implementation of strategies must be control system side, tested and accepted during the machine checkout phase.

COMMISSIONING WITH BEAM

A staged approach is clearly going to be useful to tackling the complexity of the LHC. It is envisaged to stage the commissioning of the machine with beam as follows:

- sector test [4,5] which would provide an invaluable milestone;
- 450 GeV commissioning run [6];
- Stage 1 - physics 43 x 43 moderate intensities;
- Stage 2 - move to 75 ns. with the aim of moving to intensities around 3 - 4 10^{10} particles per bunch;
- Stage 3 - move to 25 ns. with the aim of moving to intensities around 3 - 4 10^{10} particles per bunch. This will need to be followed by long shutdown for installation of phase 2 collimation and additional beam dump dilutors;
- nominal 25 ns running pushing towards design intensity and full squeeze.

This staged approach will allow phased commissioning of the sub-systems with increasing intensity. Key initial commissioning can be performed without having to face the dangers of high beam intensity and the full rigours of the final machine protection system.

Stage 1

The aim of stage 1 is to provide a reasonable initial target that will allow progressive approach to the complex problem of the commissioning the LHC with beam.

There is a clear desire to establish colliding beams as quickly as possible. This must be done safely and without compromising further progress. This moderate initial goal will reduce the demands on a number of key systems, the dependencies between them and remove the need for full beam based commissioning of each. It will allow the development of efficient commissioning path and a way of safely boot strapping the machine i.e. commissioning the equipment, the beam instrumentation and the machine protection system to the levels required to meet the above objectives.

The objective of this first stage is to take two moderate intensity multi-bunch beams to high energy and collide them. More specifically we would aim to take 43 on 43 bunches with 3 to 4 x 10^{10} protons per bunch into collisions at 7 TeV. This beam simplifies things because: there are no parasitic encounters and hence no crossing angle required; no long range beam; there is larger aperture in the insertions; instrumentation has to deal with widely spaced bunches; it is a relatively easy beam for RF [7]; it is relatively easy for vacuum [8]; has lower energy densities: and places reduced demands on beam dump system, collimation and machine protection.

The luminosity will be only moderate with around 10^{30} $cm^{-2}s^{-1}$ at a β*=18 m. and 2 x 10^{31} $cm^{-2}s^{-1}$ at β*=1 m. However, it will mark an important milestone and it should be possible to move rapidly on to a higher number of bunches via 156 x 156 and a 75 ns. bunch spacing. A pilot physics run is foreseen at this stage during which luminosity delivery to the experiments is interleafed with further machine development.

Initial commissioning will be done with low intensities. It is planned to start with the pilot beam (single bunch, 5 to 10 x 10^9 protons) possibly with reduced emittance. The next move will be to towards an intermediate single bunch (3 to 4 x 10^{10} protons) which gives better measurement resolution. The number of bunches can then be increased gradually via 4 bunches per beam pushing towards 43 bunches of 3 to 4 x 10^{10} protons per bunch.

The overall breakdown of the phases required to meet the stage 1 goals is shown in table 1. At each phase there will be:

- systems (RF, collimators, power converters, beam dump etc.) commissioning with beam;
- instrumentation commissioning with beam;
- various checks with beam: for example, BPM polarity, corrector polarity, BPM response;
- machine protection commissioning and tests with beam;
- beam measurements: beam parameter adjustment, energy, linear optics checks, aperture etc.

The main exit conditions of each phase are listed in table 1. Some of the phases have to be repeated for both rings.

Beam Instrumentation

Beam instrumentation is covered in some detail elsewhere [9] but it should be emphasised that immediately availability and subsequent commissioning of the key systems should take place as soon as possible. For the first turn we will need acquisition from screens, BPMs, fast BCT, and slow BLMs. Once circulating beams are established at 450 GeV, BPMs, DC BCT & lifetime, and BLMs are required.

Transverse diagnostics (tune - both FFT and PLL, chromaticity) become especially critical when the commissioning of the snapback and ramp start.

Phase	Main goals
Transfer and Injection	Pilot on axis through to TDI
First turn	Pilot threaded – single turn
Circulating beam	Multiple turns, RF capture.
450 GeV: initial commissioning	Q, Q', coupling. Polarities and apertures checked; basic optics checks.
450 GeV: consolidation	Well adjusted beam parameters, key instrumentation operational, machine protection as required for ramp.
450 GeV: two beam operation	Two beams, well adjusted beam parameters.
Snapback: single beam	Single beam, good transmission through snapback, requisite measurements.
Ramp: single beam	Single beam to top energy, beam dump commissioned in ramp, PC tracking checked
Single beam to physics energy	Stable beam at top energy, measurements, beam parameter adjustment.
Two beams to physics energy	Separation bumps on. Commission ramp with two beams
Physics: un-squeezed	establish collisions
Partial squeeze: single beam	single beam in steps through squeeze, parameter control
Physics: partial squeeze	Two beam through squeeze - collide

Table 1: Beam commissioning – Stage 1 – phases.

Machine Protection

Commissioning the machine protection system (MPS) with beam will be a piecewise process: for example, hardware and instrumentation, such as the beam dump and BLM, have to be commissioned with beam before connection to the Beam Interlock Controller (BIC). However, it is clear that a certain level of protection must be provided before the starting certain phases. Once we start to ramp, for example, the MPS must provide the requisite level of protection to cover the damage potential of a pilot/intermediate single at higher energy. This will include partial commissioning of the collimation system.

It must be stressed, therefore, that we need a well defined plan for the commissioning and integration of the Machine Protection System without and with beam including full specification & formal acceptance procedures.

FIRST COLLISIONS

The essential proviso here is that the elapsed time from first beam to first collisions will obviously depend on machine availability for beam. The commissioning process could be seriously compromised by the reliability of key systems e.g. controls, machine protection. One of the main roles of machine checkout phase is catch and resolve such problems before beam.

Given: a sector test; thorough preparation; and the moderate goal of Stage 1 of beam commissioning which postpones the need to fully commission some systems, it is estimated that a total beam time of 5-6 weeks minimum will be required to establish first collisions at 7 TeV. With operational efficiency of around 60% (optimistic) the total elapsed time will be around 2 to 3 months. Experience during HWC and the machine checkout will give us the first indications of the reliability of the LHC machine as a whole. A detailed breakdown of the time required for Stage 1 may be found at [10]

CONCLUSIONS

Commissioning the LHC will involve negotiating a multi-dimensional problem space. Meticulous preparation is mandatory. The hand over from hardware commissioning to machine checkout must be well-defined and the machine checkout planned and executed with care.

A staged approach to commissioning with beam is adopted with the first goal being the collision of 43 on 43 intermediate intensity bunches at 7 TeV. A breakdown of the phases required to get to this goal has been outlined. A detailed breakdown of the individual phases is in the process of elucidation [6].

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