# CHAPTER 20

# EARLY PLANS FOR COMMISSIONING AND OPERATION

Plans for commissioning of both hardware and with beam, are sure to evolve with time. The purpose of this chapter is to summarise the current thinking on these issues.

## 20.1 HARDWARE COMMISSIONING

The mandate of preparing the hardware commissioning was given to Hardware Commissioning Working Group, which started in May 2003 and is composed of staff from the equipment groups (project engineers and system owners). The group will act first as a working group during the study phase (programme, procedures, sequence) and will later evolve into a team deployed in the field when the actual commissioning in the tunnel starts.

### 20.1.1 General Plans for Commissioning a Sector

The commissioning of the hardware in the eight LHC sectors will be handled in two phases: the individual systems tests and the commissioning of each sector as a single system.

The individual system tests aim at qualifying the various systems for operation. The definition of the procedures, the conditions required for the tests to start, those needed during the tests and those signalling the end of the tests are defined by the system owners. The Hardware Commissioning Working Group then gathers these requirements, makes a refinement of the time required for the commissioning and issues a set of documents describing the commissioning. It then coordinates the tests and their sequencing and follows up the preparation work of the assemblers and the specialised teams.

The commissioning procedures and programme will vary depending on the contents of the sector, for example the presence of special machine systems like RF, warm magnets in the cleaning insertion, injection and the dump system.

The sectors are composed of several cold and warm sub sectors, which are mechanically separated and electrically and cryogenically independent. For the insulation vacuum the sub sectors are independent but coupled by the beam vacuum tubes. These features will impact on the order, the procedures and the usage of the resources during the two commissioning phases. The hardware commissioning of a sector is considered finished when all of the circuits have been powered to nominal current both independently and in unison in a pattern representative for operation. Acceptance tests and specific studies will also be carried-out for the first commissioned sector. The programme for these has not yet been determined but is expected to include performance measurements of the cryogenic control system, heat load measurements and quenching of a substantial part of the sector.

In the present plan, Sector 7-8 will be commissioned first. This sector contains 125 independent electrical circuits, 77 of which traverse the whole of the main arc sub sector; another 94 circuits for the orbit correctors are individually powered locally, two per short straight section. The complexity of these circuits varies greatly both in terms of number of components and the powering scheme: the biggest circuits in terms of components are the main dipole circuits (approximately 600 components), while the most difficult to commission will be the inner triplet circuit with its three nested power converters. Most of the magnets will have been individually tested; however one of the most complex components, the electrical feed boxes (in the arc, matching sections and inner triplet sub sectors), which vary from sector to sector, might be cooled and operated for the first time during the hardware commissioning.

While it is expected to carry out the hardware commissioning of the first sectors from ad-hoc control centres in the tunnel, the aim is to move the activity to the accelerator control room. By involving staff from the accelerator control room in the study and the execution of the hardware commissioning, a first link to commissioning with beam will be made. In addition, close collaboration with the LHCOP project will be maintained. The SPS stop (October 2004 to April 2006) takes place partly during the hardware commissioning (March 2005 to December 2006) and it is agreed that accelerator operators will be deployed for hardware commissioning with the double objective of training the future operators of the LHC and helping the hardware commissioning team.

### 20.1.2 RF Considerations

The planning of installation around point 4 is still under discussion and some extra time may become available for installation and tests of the RF system. The present schedule implies that installation in UX45 will take place in the last quarter of 2005 and the first of 2006, while installation in the tunnel will be during the second and third quarter of 2006. This means that RF tests without the cavities can take place in the last quarter of 2006 during the general cool-down of the cryogenic system. Full RF commissioning and conditioning of the cavities and couplers can only take place in the first quarter of 2007 and commissioning with beam will start in the April 2007. Conditioning will be time consuming (see below) and so very little time will be available to test and commission the complex loops and interlocks.

As a result, as many tests as possible must be carried out before installation. For this reason extensive full acceleration-chain tests will be done in the test facility building SM18 in 2004 and 2005, in order to test all items under full power and simulated transient conditions.

Using knowledge from LEP and SPS operation together with somewhat limited experience with the LHC cavities and couplers, the following conditioning times can be estimated:

- Cavity conditioning:
    - First conditioning in SM18, requiring 3 weeks per cavity.
    - After installation, before the beam arrives, some conditioning must be re-made, requiring 1 week per cavity. This may be done in parallel on some or all cavities if the total radiation generated does not exceed the safety limits for personnel in UX45.
    - During operation there is nothing special foreseen. However some helium processing may be unavoidable following cavity filling with nitrogen and would need about 1hour.
- Coupler conditioning
    - First conditioning in SR2 and SM18, requiring 7 weeks per coupler.
    - During operation, the polarisation will be on.

Operating the coupler with the polarisation on prevents multipactoring but the coupler slowly becomes contaminated and will eventually break down, catastrophically if left too long. After the coupler is used in this mode for periods of around a month, then a full re-conditioning may take about 1 week. Experience in the SPS with pulsed conditioning in beam-out times suggests that an operationally better approach may be to condition the couplers in between fills. However this remains to be proven. Conditioning will use a significant amount of time during the hardware test period before commissioning with beam.

## 20.2 BEAM TESTS BEFORE FULL MACHINE COMMISSIONING

As progress is made towards the completion of the LHC, a number of tests with beam are planned to validate the ongoing installation. The tests are; extraction into TT40 (the first part of TI8) in 2003, commissioning of the completed TI8 in 2004, a sector test with beam of LHC sector 7-8 in 2006 and finally commissioning of TI2 in 2007, culminating in the commissioning of the LHC itself in 2007. Two retractable beam stoppers (TEDs) will be installed, one at the SPS end and one at the LHC end of the TI8 and TI2 lines.

### 20.2.1 TT40

The TT40 extraction tests took place during two 24-hour periods in September and October 2003, with beam transported to the first TED of the TI8 line. Objectives included the verification of equipment functionality in the new extraction zone in LSS4 of the SPS (kickers, septa, beam instrumentation, magnetic elements and power converters) as well as a test of supporting systems such as interlocks and controls [1]. Low intensity beam was used throughout to verify the extraction channel and trajectory in the beginning of the line, to measure the acceptance of the extraction channel and check the reproducibility of the trajectory in the line. Double batch extraction as required for operation in the CNGS era was also demonstrated. Although relatively small in extent the test already posed an interesting integration exercise with issues such as radiation protection and access requiring careful attention.

### 20.2.2 TI8

The TI8 tests with beam are planned for two 48-hour periods in September and October 2004, with the aim to transport beam as far as the downstream TED in the transfer line. Limited cooling capacity in the line will prevent continuous pulsing during this period. The aims, similar to the TT40 test, are to verify equipment functionality and the proper integration of interlocks, surveillance, access and other systems. LHC pilot intensities ($5 \times 10^9$) are generally foreseen but higher intensities are considered in the dose estimations. The tests will include trajectory acquisition and correction, reproducibility, commissioning of the beam instrumentation, measurements of the optics in the line and matching between the line and the SPS.

The Radiation Protection Group has produced estimated dose rates [2]. These show that with intensities of $2.5 \times 10^{11}$ protons per pulse over 24 hours at 50% efficiency, remnant dose rates alongside the TED area would be around 120 μSv/h and around 3 μSv/h on the downstream face of the TED, after a 1-day cool down period. These figures show the need for extra shielding (iron/concrete) after the TED and the area around the TED to be declared a "Simple Controlled Radiation Area" after the tests. This would imply that people working in this zone after the test would be classified as radiation workers and carry film badges.

An access zone from the TED extending through UJ88 to UJ86 towards UX85 and US85, with a gate in the LHC tunnel towards point 1, will be required to prevent access downstream of the TED for the duration of the test and appropriate radiation monitoring will be installed. The impact on ongoing LHC installation still needs to be carefully evaluated.

### 20.2.3 LHC Injection Test in 2006

The LHC installation schedule (LHC-PM-MS-0005 rev 1.7) includes an injection test in April 2006. This is defined to be the injection of beam down TI8, into the LHC at the injection point right of IP8, traversal of IR8 and LHCb, through sector 7-8 to a temporary dump located near the position of Q6 right of point 7. The test will be made with the final machine configuration.

The motivation for performing this test was outlined at the LHC performance workshop held at Chamonix in 2003 [3], where it was strongly endorsed. However, many consequences and potential problems were also identified [4]. The issues raised included the impact of remnant radiation and INB approval, the need for access and interlock systems, the impact on LHCb, the impact on injectors, the impact on hardware commissioning and installation and the need to install and remove the beam dump. These and others have been carefully examined, shown to be manageable and outweighed by the many benefits [5].

The beam provides a powerful diagnostic tool and will allow checks of the physical aperture, giving a means of checking the field quality in situ. 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. It will also permit polarity checks of the corrector elements and the beam position monitors; key concerns in the installation procedure. First tests of important beam diagnostic systems would also be possible.

Furthermore the injection test will also provide an extremely high-profile milestone forcing large-scale integration of all components, including controls, timing, transfer from the injectors and instrumentation. The test will highlight any oversights, misconceptions and shortcomings. Operationally the exercise will be extremely valuable and the time and effort spent on the test will be more than compensated by a more efficient start-up of the completed machine. Any problems highlighted would have a whole year for resolution before the commissioning of the full machine.

*Tests with beam*

The aim is to mostly use the LHC pilot beam; that is, a single bunch of intensity between 5 and $10 \times 10^9$ protons. This is below the quench limit if losses are diluted over more than 5 m and 2 orders of magnitude below damage threshold. Folding in generous inefficiencies a programme of tests lasting seven days is planned, which, with around 50% operational efficiency gives a total elapsed time of 2 weeks for the test. A maximum of around 3000 shots is foreseen corresponding to a total intensity of $2 \times 10^{13}$ protons over the two-week period.

*Timing of the test*

At present the test is scheduled for April 2006. However, for start-up in 2006 both the SPS and PS will be recovering from the 2005 shutdown and it is estimated that 4 weeks will be required for cold checkout and re-commissioning. Also the SPS is presently subject to energy consumption restrictions and should not normally pulse before April. Thus the test will take place in the first two weeks of May 2006 unless provision is made to start the SPS earlier. This is compatible with the requirements of LHCb, who insist that a delay of more than 10 weeks beyond April 2006 would jeopardise the LHCb overall installation and commissioning as foreseen in the current schedule.

*Radiation issues*

It planned to use LHC pilot intensities ($5 \times 10^9$) with the strict proviso not to irradiate LHCb; their zone must remain a surveyed area with no restrictions after the test. The clear aim will be to minimise losses everywhere and use beam sparingly throughout the test. For the expected total intensity of $2 \times 10^{13}$ protons over the two-week period, simulations by the Radiation Protection Group [2] show that activation will be low. Appropriate radiation monitoring will be operational during the test and measures will be taken to minimise does rates and there will be a full survey after the event to check levels of activation. As with TI8 after the 2004 test, however, we must anticipate that particular zones, such as near the injection dump (TDI) and around the position of the temporary dump, may be declared a "Simple Controlled Area" and subsequent work in these areas will require wearing a film badge. It should be noted that the temporary dump itself would be removed after the test.

*Access considerations*

Gates in tunnel sectors 6-7 and 8-1 will be needed, along with interlocked, restricted access at PM76, PM85 and PZ85. Much of this infrastructure will be necessary in the final LHC configuration and can be made available for the test without too much extra cost [6].

## 20.3 CONSTRAINTS FOR THE FIRST YEAR OF OPERATIONS

Restrictions during the first year include the need to keep the event rate below or around 2 events per bunch crossing ($10^{33}$ cm$^{-2}$ s$^{-1}$ at 25 ns bunch spacing), a total maximum intensity of 50% of nominal because only 8 out 20 beam dump dilution modules will be installed and a bunch intensity limit of around 1/3 nominal with 25 ns bunch spacing to avoid electron cloud effects [8].

In addition, machine protection and collimation systems will favour initial operation with low beam power and low transverse beam density until multipole effects are controlled and a reproducible operational cycle has been established.

For the vacuum system, 3 phases are foreseen [9]. Firstly there will be a start-up phase below the electron cloud threshold of 3 to 4 x $10^{10}$ per bunch, followed by a conditioning of the cryo-elements with scrubbing runs and finally a post-conditioning phase. It may prove necessary to remain in phase 1 during the first year of operation.

From a radiation standpoint the lower intensities will favourably reduce the potential impact on equipment, particularly electronics and allow a first look at reliability issues under less severe conditions than those expected later.

For the cryogenics the lower intensity will mean lower heat load: from beam loss (given efficient collimation), from lower synchrotron radiation and lower image currents. The very difficult challenges for the LHC collimation system will be relaxed during commissioning by the lower total beam intensity, by keeping the $\beta^*$ at reasonable values and by not reducing the emittances below nominal. Lower intensity means that lower cleaning efficiencies can be accepted for a given beam lifetime while still respecting the quench limits.

It is not possible to reduce the heat load on the cryogenics system significantly by reducing the beam energy [10]. Reducing the energy can increase the quench level margin, but in order to gain an order of magnitude in the case of transient losses, a large reduction in energy is needed. There is only a small gain with respect to continuous losses and lower synchrotron radiation. The experiments are prepared to accept a

10% energy reduction for a limited period. This would gain something like a factor of two in the quench margin.

It is anticipated that the first months of LHC operation will be dedicated to commissioning the machine with a single beam before establishing colliding beams, with the goal of a low intensity pilot physics run before a 3-month shutdown requested by some experiments [7]. There would then be a longer physics run with the goal of establishing luminosities of up to $10^{33}$ $cm^{-2}$ $s^{-1}$ (Sec. 20.7). Bunch intensity for physics will be restricted to around $4 \times 10^{10}$ protons, in line with the constraints outlined above.

## 20.4 EARLY COMMISSIONING

### 20.4.1 Establish Circulating Beam

It is planned to begin with a special magnetic cycle in order to minimise the dynamic effects in the machine components. This cycle has a 'degauss blip' in order to minimise the decay of the multipole components in the dipoles during the injection plateau [12]. While this cycle cannot be used to accelerate the beam, it is expected to be of great advantage in the early commissioning of the machine. Studies have also shown that a similar level of stability can be gained with the normal cycle, by waiting around 30mins before injecting on the 450 GeV plateau.

A key factor in the commissioning will be to identify the simplest possible configuration that allows the beam to be injected, to use this to begin and then to increase the complexity in a controlled way. For the first turn in the LHC relatively few of the magnet power circuits will be needed. Clearly the main lattice circuits must be powered at their nominal values. Among the correction circuits the orbit correctors, trim quads, sextupole spool pieces and skew quadrupoles should suffice, with the skew sextupoles, octupole and decapole spool pieces switched off. Regarding the insertions, the crossing angle, spectrometer magnets, experiments' solenoids and separation bumps should be off. Simulations show that under these conditions the injected beam should, on average, traverse about 4 cells and so be seen by the beam position monitors. Threading can then be done, powering orbit correctors as needed. Once a complete turn has been made the trajectory must be closed on itself to form an orbit.

For multiple turns the chromaticity starts to become important. Decoherence of the beam from the huge chromaticity expected without correction make it difficult to measure the tune. Powering the $b_3$ spool pieces from magnetic measurement data and the lattice correctors to correct for the natural chromaticity should bring the chromaticity down to below 80 units.

A reasonable tune measurement should then be possible even without RF capture. However, feed down from the $b_3$ spool pieces, together with systematic $a_2$ in the dipoles and other contributions, lead to a significant coupling in the machine. The use of a special working point would help to minimise coupling, but the $a_2$ correctors should be powered, again based on magnetic measurement data.

It should be possible in this way to establish circulating beam making tens of turns before any RF is needed. However it is planned to capture the beam with the RF system very soon in the setting up; the commissioning of the RF will be then be interleaved with other ongoing activities.

### 20.4.2 Flat-bottom Tuning

Once circulating beam is established a campaign of measuring, checking and correcting a large number of parameters and settings can begin. The studies will include:

- Linear optics – model vs. measurements. Feed-down and alignment tolerances will lead to linear optics errors. Correct orbit, Q, Q', coupling, dispersion, $\beta^*$, $\beta$-beating.
- Compensation for the Experimental magnets – solenoids and dipoles.
- Aperture and collimator optimisation.
- Non-linear optics. There are some 256 corrector circuits from a2 to b6. For some of them, such as b5, the measurement and correction procedure is not yet known.
- RF studies.

Other studies at injection energy may include inner triplet alignment, commissioning of the separation scheme and squeeze pre-commissioning.

### 20.4.3 RF Capture

The RF system is very complex with nested loops to control the cavities and cope with the beam loading. The commissioning of the RF system will take place over an extended period of time with adjustments each time the bunch intensities and bunch patterns change. This activity will be interleaved with setting up the rest of the machine and a possible procedure is given in section 20.6.

### 20.4.4 Feedback Systems

Beam feedback systems will be very important in the LHC and several are envisaged, covering orbit, tune, energy, chromaticity and coupling. However, the machine should be setup in such a way as to minimise the errors left for the feedback systems to correct.

From the start, open loop correction using the multipole factory and feed-forward of trims to the next machine cycle will be required. The need here is to establish a reproducible magnetic cycle as early as possible. A powerful software system will also be needed to manage the trims and trim history.

The orbit feedback should be relatively easy to implement. Here the main question concerns the use of global correction algorithms and how these affect the need for local corrections around the collimation and beam dump regions. The energy feedback (using the horizontal orbit correctors) should also be commissioned early. Tune feedback will principally be needed once commissioning of the snapback and ramp begin. Chromaticity and coupling feedbacks are much more complex and will not figure in the early commissioning phase of the LHC.

## 20.5 COMMISSIONING THE NORMAL CYCLE

Some considerable time will have been spent at injection energy establishing circulating beam, commissioning beam instrumentation and other systems. However, to get beams to high energy it will be necessary to address the problems associated with the normal operational cycle. The following section examines the beam required in this phase, how tolerances may be relaxed and what simplifications can be made to ease operation, with the aim of getting colliding beams at close to full energy in a safe way.

### 20.5.1 The Baseline Cycle

The nominal LHC ramp has been established [11]. It is composed of a sequence of sections in the form of parabolic, exponential and linear, with a parabolic round off at high energy, designed to mitigate the effects of persistent currents and ramp-induced eddy currents. The power converters give the maximum ramp rate in the linear section. The ramp can be incorporated into a standard cycle as illustrated in Fig. 20.1. The power converters again determine the ramp down rate and the pre-injection plateau is introduced to help minimise the persistent current effects [12]. If the nominal cycle is interrupted for any reason, for example by a quench, a pre-cycle which takes the machine to 7 TeV equivalent for 30 minutes to re-establish the magnetic history is planned.

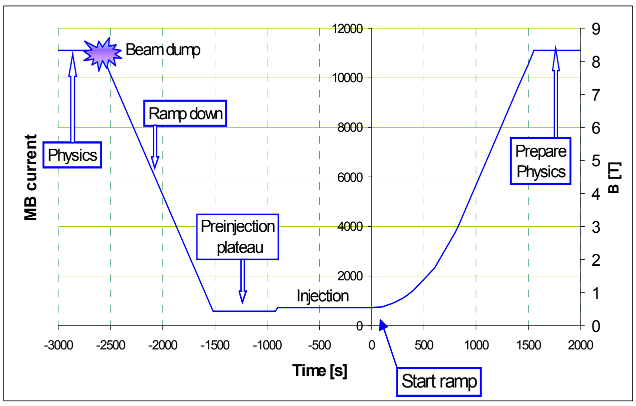


Figure 20.1: The baseline cycle for the LHC

The baseline cycle can be broken down into the main operational phases that make up the nominal cycle. A first version detailing these phases may be found in [13]. Clearly the complete cycle does not need to be commissioned in order to establish first collisions and the phases addressed herein are those which will allow the following to be performed:

1. First optimisation of the machine at 450 GeV; Beam 1, Beam 2, Beam 1 AND Beam 2.
2. Correction of snapback; single beam, ring 1.
3. Ramp; single beam, ring 1.
4. Stop in ramp. Commission beam dump, machine protection in ramp, ring 1.
5. Single beam to 7 TeV, ring 1 (± separation bump).
6. Ramp; single beam, ring 2.
7. Stop in ramp. Commission beam dump, machine protection in the ramp, ring 2.
8. Single beam to 7 TeV, ring 2 (± separation bump).
9. Two beams to 7 TeV and collide unsqueezed.
10. Increase intensity and collide.
11. Single beam partially through squeeze.

### 20.5.2 Bootstrapping the Cycle

*Beam considerations*

For commissioning the ramp and beyond a setup beam consisting of a single bunch with an intensity of around 5 to $10 \times 10^9$ will be needed. This intensity is below the quench limit at 450 GeV but is, however, above the damage threshold at 7 TeV.

Low emittance of $\varepsilon_n \approx 1.0$ μm.rad gives a beam size of around 0.6 mm at $\beta = 180$ m at 450 GeV, compared to a value of 1.1 mm with nominal emittance. This reduction is useful in two ways; firstly the mechanical aperture in terms of $\sigma$ increases and the margin for orbit and optics corrections can be relaxed; secondly the dynamic aperture constraints are relaxed and smaller particle amplitudes mean less sampling of the non-linear fields at high amplitudes. The longitudinal emittance should be between 0.5 eV.s and 0.7 eV.s.

The nominal LHC beam parameters have very tight tolerances [14,15], which can be relaxed with the setup beam described. This beam would also be needed later for re-commissioning and debugging.

*Reproducibility issues*

Establishing reproducible conditions will be essential to LHC operations and at the commissioning stage it is planned to avoid starting the ramp after a variable length of time at injection. Thus there are two choices at injection; either wait each time for the persistent currents to decay fully, or move quickly and avoid the full decay and snap-back by ramping after a short, fixed time interval. Initially it will be easier for the injectors to follow the former option; when reliable filling is possible the latter option should be possible.

To compensate for the effects of snapback, a number of tools are available; the use of a predictive model, cold magnet measurements, on-line measurements from reference magnets and beam-based feedback. Strict procedures will need to be in place in order to establish a reproducible magnetic history.

*Ramp*

In order to accelerate the beam it will be necessary to use low intensities and even then care is needed since the pilot bunch can cause damage at high energy. It will be necessary to use the simplest possible machine and stop at pre-programmed places in the ramp to measure and correct parameters.

The ramp will be driven by current, voltage and frequency as functions of time, pre-loaded to the power converters and RF, with the start of ramp triggered by a timing event. Before the start of the ramp the TDI and injection collimators are retracted, while the cleaning insertion collimators are left where they are.

Real-time corrections from operator-controlled knobs, feed-forward from reference magnets and beam-based feedback are all planned, but these tools are unlikely to be in place initially.

The main challenge will be anticipating the depth of the snapback and attempting to deal with the associated swing of beam parameters. With the larger tolerances, input from the offline multipole factory, tune and orbit measurements and some rudimentary corrections, it should be possible to get some beam through the snapback.

After snapback and the first 100 GeV it is expected that problems associated with dynamic effects will be considerably reduced. The ramp dependent eddy currents are expected to be reproducible, small and thus to be taken care of in corrector functions.

In the ramp, orbit corrections, tune measurement and operator control of various parameters will be necessary. It is expected that the collimators can remain at fixed positions.

*Beam dump*

The beam dump system should be commissioned as soon as possible to allow safe extraction of the beam from the machine. It will be necessary to commission the beam dump at a number of intermediate energies. The pilot beam is fairly innocuous at low energies but will need a fully functioning beam dump before pushing too far in energy.

Although the beam dump could be commissioned with a ramping beam, the present plan is to perform a programmed stop of the ramp at intermediate energies. This would give the opportunity to perform measurement checks and to commission the beam loss monitors cleanly before dumping.

A number of systems and parameters are important for the correct functioning of the beam dump and have to be checked. These are;

- Energy tracking calibration (MKD, MSD, MKB).
- Orbit/aperture.
- Extraction trajectory.
- Instrumentation.
- Kicker timings/retriggering.
- Post mortem.

*Two beam operation*

In the interest of having the simplest possible configuration for the first collisions, it is planned to use one bunch per beam, crossing in ATLAS and CMS. This will require commissioning the separation bumps in points 1 and 5. A cautious approach would be to ramp a single beam with the separation bumps on to check orbit control and closure.

It is envisaged colliding one point at a time. Beams will be put into collisions by extrapolation of the position at the interaction point from the beam position monitors near the first of the triplet quadrupoles, followed by a luminosity scan. At the low luminosity ($2.0 \times 10^{26}$ $cm^{-2}s^{-1}$) expected, integration times will be long but as the exercise is performed with un-squeezed beams with $\beta^*$ of 18 m, the bigger beam sizes should help in establishing the collision point. Finally, the RF will need phase adjustments and other checks before collisions.

*Squeeze*

Commissioning of the squeeze will take place with a single beam, one interaction region at a time. The primary and secondary collimators (and TCDQ) will have to follow the squeeze, with relaxed settings in the commissioning stage. Operationally the challenges will be the tune, chromaticity and orbit control, potentially exacerbated by beta beating. Optics and aperture checks will be necessary at each stage.

*Conclusions*

Commissioning with a low intensity, low emittance and single bunch should allow relaxed tolerances on the critical beam parameters. The machine configuration will be kept as simple as possible.

It will be necessary to anticipate snapback and have the ability to incorporate predictions into the machine settings. This should help to bring tune, chromaticity and orbit within reasonable bounds. Measurement and correction facilities will of course be necessary but fast, real-time feedback should not be obligatory.

It will be necessary to stop in the ramp to commission the beam dump, perform measurement checks and commission beam instrumentation.

This strategy should allow the two beams to be brought safely into collisions for the first time.

## 20.6 RF COMMISSIONING WITH BEAM

A possible procedure for preliminary commissioning of the RF is given below. Clearly it must be interleaved with the setting up of many other machine elements.

### 20.6.1 Special Cycle

It is proposed to use the special magnetic cycle designed to minimise dynamic effects for a substantial part of the RF commissioning. This would allow the use of an 'inject and dump' mode where each SPS cycle could be used to inject beam. This will bring advantages in terms of ease of setting up and will therefore minimise the time needed. The total time estimated for RF work on this cycle will be of order 3 weeks. Tab. 20.1 summarises the different beams envisaged and the uses made of them.

Table 20.1 : RF commissioning on the special magnetic cycle

| Beam | Purpose |
|---|---|
| Single pilot bunch<br>$5\ 10^{9}$ , 0.4 eV.s | Find the bunch, set up the phase and synchronisation loops.<br>Set up observation equipment and bunch reference numbers.<br>Set up the beam dump timing and adjust B-field and phase offsets. |
| Single PS batch from SPS<br>Few $10^{10}$ per bunch, 0.4 eV.s | Readjust loops with beam, verify and adjust transients in loops. |
| 2,3,4 PS batches from SPS<br>Few $10^{10}$ per bunch, 0.4 eV.s | Check everything (transients change). |
| Repeated injections from SPS | Set up injection damping of each batch.<br>Confirm batch position. Confirm effective energy jitter. |
| Increase intensity to nominal | Observation and adjustment. |

### 20.6.2 Nominal Accelerating Cycle

With the RF now in a solid state with respect to operation with beam induced transients, the problems generated by persistent currents can be addressed. The total time for these procedures is estimated to be of the order of 2 weeks. Tab. 20.2 summarises the different beams envisaged and the uses made of them.

Table 20.2 : RF commissioning on the nominal cycle

| Beam | Purpose |
|---|---|
| Single pilot bunch<br>$5\ 10^{9}$ , 0.4 eV.s | Make multiple injections onto flat bottom with no acceleration.<br>Dump just before the B-field rises.<br>Control B-field correction procedures to obtain $dB/B < 10^{-4}$. |
| Single pilot bunch<br>$5\ 10^{9}$ , 0.4 eV.s | Make multiple injections onto the flat bottom and accelerate.<br>Beam dump progressively moved up in energy.<br>Control acceleration through snap-back, measure capture losses. |
| Single PS batch from SPS<br>Few $10^{10}$ per bunch, 0.4 eV.s | Verify acceleration of a batch. |

From this point onwards the number of injected batches and the intensity will be slowly increased. It has also been suggested (Sec. 20.7) that a good commissioning beam for physics would contain 43 (or 86) bunches spaced at ~ 2 µs. This would induce very small transients in the loops even if the bunches were at nominal intensity and so would also be a good initial beam for the RF.

It should not be forgotten that the LHC is basically two machines and everything will have to be repeated for the second beam. In practice this might be interleaved with the first beam setting-up.

## 20.7 PHYSICS

The constraints outlined in Sec. 20.3 are expected to limit the maximum instantaneous luminosity to about $10^{33}$ $cm^{-2}$ $s^{-1}$ during the first year of LHC operations. Furthermore the requirement from the experiments to have an event pileup less than 2 limits the luminosity in all modes except 25 ns operation.

### 20.7.1 Operation with Zero Crossing Angle

It is proposed to begin high energy running without a crossing angle and the associated complexity of parasitic beam-beam interactions. This will allow the beams to cross the inner triplets and matching insertions on-axis. With this configuration, a large amount of beam-based studies can be made and the squeeze to smaller $\beta^*$ can be made in much cleaner conditions.

The geometry of the interaction regions limits the number of bunches per beam in this mode to under 100. For ease of operation of the injectors, it is proposed to take single (or double) bunches from the PS into the SPS, thereby providing 43 (or 86) bunches in the LHC in a filling scheme closely related to the one needed for operation with high numbers of bunches [16]. In order to provide collisions in LHCb it will be necessary to displace some bunches in one beam by 75ns. These displaced bunches will cause events offset by 11.25 m in the other detectors.

Bringing beams like this into collision would set a clear baseline for luminosity in a simple configuration. Expected performance for parasitic physics with the given parameters at 7 TeV is as follows:

| Bunches per beam | Crossing Angle | Bunch Intensity | $\beta^*$ [m] | Max. Luminosity |
|---|---|---|---|---|
| 43 | 0 | $0.5\ 10^{11}$ | 1 | $2\times10^{31}$ $cm^{-2}$ $s^{-1}$ |

After having established reasonable performance levels under these conditions, one can bring on the crossing angles, redo the squeeze and re-establish physics conditions.

### 20.7.2 Operation with 75 ns Bunch Spacing

When running with 75 ns bunch spacing there are fewer parasitic beam-beam encounters than in the 25 ns mode. This allows relaxing the crossing angle. Furthermore, if the $\beta^*$ is held greater than 0.75 m, any field errors in the triplet are less critical. It is therefore proposed to run with 75 ns spacing, with relaxed parameters, in order to commission multi-bunch operation. No bunch intensity limitations due to electron cloud are expected. Early physics runs could be foreseen at 7 TeV with the following parameters:

| Bunches per beam | Crossing Angle [μrad] | Bunch Intensity | $\beta^*$ [m] | Max. Luminosity |
|---|---|---|---|---|
| 936 | 250 | $0.5\ 10^{11}$ | 1 | $5\times10^{32}$ $cm^{-2}$ $s^{-1}$ |

### 20.7.3 Operation with 25 ns Bunch Spacing

Electron cloud effects will limit the bunch intensity in this mode until beam scrubbing has been performed. Otherwise, assuming that the 75 ns operation has allowed reaching all other nominal parameters, the following physics conditions can be expected at 7 TeV:

| Bunches per beam | Crossing Angle [μrad] | Bunch Intensity | $\beta^*$ [m] | Max. Luminosity |
|---|---|---|---|---|
| 2808 | 285 | $0.4\ 10^{11}$ | 0.55 | $1.2\times10^{33}$ $cm^{-2}$ $s^{-1}$ |

For completeness, the nominal performance at 7 TeV and parameters, with bunch intensities that can only be achieved when the electron cloud has been mastered are:

| Bunches per beam | Crossing Angle [μrad] | Bunch Intensity | $\beta^*$ [m] | Max. Luminosity |
|---|---|---|---|---|
| 2808 | 285 | $1.15\ 10^{11}$ | 0.55 | $1\times10^{34}$ $cm^{-2}$ $s^{-1}$ |

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