MACHINE CHECKOUT AND SETUP PERIODS

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Abstract

Before the first LHC beam operation and following the LHC hardware commissioning a cold checkout period is required to check the simultaneous functioning of the various LHC subsystems in their final configuration. Following this cold checkout period a set-up period with beam is required to verify the proper operation of all equipment, including the machine protection system, with beam. The tests required in both phases and the estimated overall time necessary to perform these tests are described. The same estimate is also made for the subsequent years of LHC operation.

INTRODUCTION

In the first year of LHC operation the machine checkout period [1] will follow the hardware commissioning phase [2]. During the hardware commissioning period of about 18 months all machine equipment will be tested and the maximum of system tests will be performed. However, many systems will need to be retested for several reasons:

- In some sectors tests were performed more than a year ago and will need to be partially repeated.
- The final configuration of certain systems might be different from the one during the hardware commissioning period, especially the interface to other systems.
- It might not have been possible to perform all system integration tests during the hardware commissioning period, either because the time available was limited or because other systems were not available at the moment of the tests.

During the cold checkout period some tests will be performed for the first time:

- Closure and cool down of the complete machine.
- Complete system integration tests, performed on a machine wide basis.
- Acceptance tests by the DSO – data for INB.

In subsequent years of LHC operation there will also be a machine checkout period, following the yearly shutdown. Tests will be very similar, with the difference that fewer system tests will be performed during normal shutdowns than following the hardware commissioning period. This should be compensated by the experience gained in operating the systems in the previous year(s).

The machine checkout should take place under the coordination and the responsibility of the Operations group. It is the final test to take place before injecting first beam. However, some equipment tests will need to be performed with beam during the first months of machine operation.

PHASES OF MACHINE CHECKOUT

It is possible to split the machine checkout period in three distinct phases.

Phase I: Cooldown and Closure

During phase I the following activities are foreseen:

- Guarantee the correct machine wide functioning of the infrastructure: water cooling, ventilation, power, controls network, UPS and AUG.
- Test of the functioning of the radiation protection infrastructure. This includes the verification of the proper response of the ionisation chambers distributed around the machine and their interface with other systems.
- Cooldown of the complete machine. For sectors in which the temperature has not gone up above 80 K the expected cooldown time should be less than 5 days. If the temperature of a sector has risen above 200 K, the expected cooldown time is about 10 days. Even more important is that for temperatures above 80 K the Electrical Quality Assurance tests (ELQA) will need to be redone. A period of up to three weeks needs to be envisaged for the ELQA tests. This then might have to be done in parallel with the hardware commissioning of the last sector, so manpower constraints can be an issue. One also has to keep in mind at what moment the full inventory of Helium will need to be available.
- The machine should be completely closed for the first time. This includes tests of the LHC Access Control System (LACS) and the LHC Access Safety System (LASS). The interface of the access system between adjacent sectors will be tested for the first time. Other tests are the interface with the radiation protection equipment and HR data base (biometrical data). The search procedures and the processes of going into and out of an controlled access will need to be practised. After this the machine should ideally remain in controlled access, without the need of a search before taking the first beam.

Ideally these tests should be done machine wide during phase I, but it will be prudent to start with the sectors which need to be available first in phase II, so if necessary work can continue in parallel between phases I and II.

Phase II: System and Equipment Tests per Sector

During phase II of the machine checkout period all power converters will need to be retested. This will be done two sectors at a time and this will likely set the pace for the other tests to be done in parallel in the other sectors. These tests are outlined in more detail below.

Interlocks will need to be retested before the power converters can be switched on at significant power. The following interlock systems are involved at this stage:

- The Quench Protection System (QPS) will need a visual check down in the tunnel (half a day per sector) followed by the automatic test procedure, which is the same as the future standard monthly test procedure for which about 8 hours are required (it fires the quench heaters without current in the magnets). The interface to the Beam Interlock System needs to be verified as well.
- The Powering Interlock Controller (PIC) takes the information from the QPS and normally passes it on to the Beam Interlock System. Automated test procedures will be in place for the PIC and will take, together with a visual control, about 8 hours per sector.
- The Warm Interlock Controller (WIC) has no automated test procedures foreseen, but some manual testing and a visual control is foreseen, also requiring about 8 hours per sector.

After this the **Power Converters** of the magnets can be tested, two sectors at a time. They all need to be operated at full power. Calibration will have been done during the hardware commissioning period and will not be repeated. A 12 hour run at full power is foreseen. About half a week per two sectors will be required and tests can proceed around the ring, following he interlock tests.

Parallel with the tests above, the following system tests can be performed in other sectors:

The **Control System** needs to be tested. The following aspects can be identified:

- Control System Communication Mechanisms: field busses should be operational machine wide. About 8 days will be required to test all elements.
- FrontEnds, BackEnds and General Services: they should have been made available during the hardware commissioning period and left running.
- Timing Generation and Distribution: 6 – 8 days of testing should be foreseen for the first year of operation.
- Access to Databases: at least one day needs to be foreseen.
- Application Software: this should have been tested continuously over the months / years preceding the machine checkout period. Many specific projects need testing (interlocks, real time feedback, logging, post-mortem, safe beam flag etc.). In general many days of *'Dry Runs'* will be required over a longer period, culminating in complete machine cycles ad described in phase III of the machine checkout period.

The **RF-System** is in principle tested during the hardware commissioning period, which for the RF system will take place just before the machine checkout period. This means that the cavities, the cryogenics and the low level control should be operational. However, there are a number of tests which would clearly accelerate the RF operations at a later stage and improve its performance. Any available time could be used for the following tests:

- Reliability of the RF system from the power and the cryogenics point of view.
- Software and diagnostics developments / improvements.
- New conditioning hardware for subsequent years.
- RF noise and ripple measurements.
- Customisation of klystrons, positioning of the resonance.
- Linearization of the klystron response.
- Effect of detuning and coupler position and the loop stability.
- Optimisation of the loops for higher intensities.
- Fine adjustment of the trip level for fast transients.
- Setting-up of the longitudinal damper.
- Preparation of feed-forward and one turn feedback.

The **Warm Magnets** will need a visual inspection and a verification of the cooling system. About one day per sector is required, adding up to 8 days in total.

The **Vacuum System** tests require a closed machine. The interlocks of the sector valves and the connection to the Beam Interlock System need to be verified. With two teams in parallel and three days per octant, about 12 days will be required for the tests foreseen. On top of this the vacuum of the transfer lines will need to be verified, for which two days will be required.

The **Collimators and Beam Absorbers** will need the verification of their motor control, positioning switches, temperature sensors and cooling system. The interface to some intelligent software for the positioning control and settings management remains to be defined but will definitely need some testing, together with its interface to the Beam Interlock System. It is expected that a couple of days will be required for the tests foreseen.

The **Pulsed Magnet Systems** (injection kickers MKI in points 2 and 8, beam dump kickers MKD and MKB in point 6 and the tune and aperture kickers in point 4) will need the verification of their local interlocks and some re-conditioning to be able to run at full power again. This will take a couple of days per system. The interface to other systems across the machine is expected to take much more time: interface with the RF for synchronisation, with the dipoles at either side of point 6 for the energy measurement, with the timing system and controls in general, with the machine protection system, the post mortem system, OASIS for the timing, the logging system and connection between MKI and MKD are required. Several weeks will be needed to verify the interface between these systems which will all need to be available simultaneously during the foreseen test period. One would also largely profit of tests performed during the reliability run of the beam dumping system, foreseen towards the end of the hardware commissioning period.

The **Beam Diagnostics and Instrumentation** can be divided in three groups. The large distributed systems consists of the BPMs and the BLMs. This hardware will need some re-checking after the full checks performed during hardware commissioning period, but most will be spent on software and logging related to these systems. Several *‘Dry Runs’* will be required, distributed over a period of some months, so starting well before the machine checkout period. For the interlocked systems (BLM, BPM, BCT point 4 and Longitudinal Density Monitor) the interface to the Beam Interlock System will need to be checked. For the diagnostic systems (Q and Q’ measurements, Schottky systems, synchrotron radiation monitors, OTR screens and wire scanners) no special requirements have been signalled.

Phase III: Complete Machine Cycles

After phases I and II all equipment and systems should have been (re-)tested, sector by sector, the individual interlocks tested, the machine completely cold and the machine searched and in controlled access. The aim of phase III is to go through the complete machine cycles without beam from the CCC. The accent will be on the control system and application software, interleaved with tests of the access system and the ‘green light’ by the DSO. Again, the control system tests should be built on the experience obtained over the years (TI 8 tests, hardware commissioning and sector test) and a large number of ‘*Dry Runs*’ performed over the previous months.

The complete machine cycle without beam will have to include the following steps:

- Initial machine cycle (45 minutes) to get the correct initial magnetic field conditions.
- Generate the functions for all power converters.
- Download all functions to the power converters, synchronised ramping of all power converters, including the energy ramping of the beam dumping system. Testing of the settings management system, trimming of the functions.
- Testing of the machine wide timing of the systems, pre-pulses, OASIS system (=remote scope), timing interface with RF, with the injection kickers, beam dump kickers, tune and aperture kickers and machine protection system.
- Testing of the application software and communication with all equipment, fixed displays, video, trajectory and orbit correction. Feedforward and feedback applications for trajectory, tune, chromaticity and the transverse and longitudinal feedback systems. Logging of all parameters during the cycle, vacuum displays, alarm screens and radiation monitoring.
- Verification of the interface with the Beam Interlock System, safe beam flag status generation (depending on beam energy) and post mortem after each beam dump.
- Clearly some kind of sequencer will be required to automate many of the tasks above (“LHCexec”).

During phase III the **Beam Interlock System** should be completely tested. This needs to be done towards the end of the machine checkout period, to avoid that the systems involved will be modified after the tests. All 150 ‘user boxes’, interfacing to 16 different users, will need to be tested individually, by each client provoking an interlock and verifying that the four beam dump request signals are received by the two Beam Dumping Systems. At least two periods of 8 hours will be required for these tests.

The machine access system will likely need a final verification by the equipment group (two times 12 hours) before the DSO can ‘rubber stamp’ the system and data for INB approval can be acquired. If the search of the machine would have been broken, a complete machine search is expected to require an additional two days with several teams working in parallel. The DSO test is likely to take one day.

In the final phase of testing, some rubber-stamping by a ‘Mr. Interlock’, following formal test procedures and acceptance criteria should be made obligatory to allow proceeding with the machine operation.

TIME REQUIRED

Taking into account the different tasks described above, phase I will require at least 1 week, phase II is likely to require at least 3 weeks and phase III will require about 2 weeks of testing. This adds up to a total of 6 weeks. This is valid for the first year of LHC operation, following the hardware commissioning period. For subsequent years, the tasks to be performed will be similar and about five weeks of machine checkout are estimated to be necessary: less system tests will have been performed during a normal shutdown period, but the experience obtained by operating the systems over the previous year(s) should compensate for this disadvantage.

A phase I of 1 week assumes that the cold part of the machine has not reached temperatures above 80 K. For higher temperatures, the cooldown has to start earlier (together with the ELQA tests) and work has to be done in parallel with the hardware commissioning period or other shutdown work.

EQUIPMENT TESTS WITH BEAM

After the formal machine checkout period, additional equipment tests will need to be performed with beam for a period of several weeks or months. The equipment which will certainly need commissioning with beam is:

- Beam Instrumentation and Diagnostics in general. Calibration of BPMs and BCTs with beam. Set-up of the tune and chromaticity measurements. Set-up of the tune and aperture kickers.
- RF: low level control systems (typically three weeks), phasing, feedback systems.
- Control system: logging beam data, post mortem, steering, feedback systems.
- Machine Protection System tests: check interlocks of the system with beam, safe beam flag dependability on beam intensity and energy.
- Beam Dumping System: needs to be set-up for the different beam energies, verification of post mortem, logging and analysis.
- Cryogenics performance once the beam load becomes significant.

CONCLUSIONS

After finishing the hardware commissioning period, at least six weeks will be necessary for machine checkout. Departing from the assumption that all equipment is operational on time (!), complete system tests remain to be done and the independencies of the different systems need to be verified. The machine checkout should take place under the responsibility of the Operations group, which allows them to verify all systems and gain on-hands experience. In the last two weeks of the cold checkout it is foreseen to take the machine through complete machine cycles without beam.

Some cooldown of sectors which have warmed up above 80 K will need to be done in parallel with the hardware commissioning period because of the longer cooldown period and additional ELQA tests required. A number of scheduled '*Dry Runs'* should also appear on the general planning to make global checks of software and machine protection. The first '*Dry Runs'* should also take place before the machine checkout period. Some equipment testing will only be possible with beam, and it is likely that some equipment will need several weeks or months to be fully commissioned with beam.

For subsequent years of LHC operation a similar period should be foreseen for machine checkout. This agrees well with the experience at CERN with the larger machines. For both the SPS and LEP about 2 weeks were used as pre-closure and 2 weeks as 'cold checkout'. These two weeks of cold checkout are similar to the 2 weeks of phase III for the machine checkout described above. The two weeks of pre-closure are then replaced by four weeks of machine checkout phases I and II; the longer period can be explained because the LHC will be more complex and the machine protection will have to be taken more seriously.

The re-commissioning of the two LHC transfer lines should not be forgotten. According to plan TI 8 will have been operated for the sector commissioning towards the end of 2006, but it will need recommissioning before first beam. The TI 2 transfer line will probably be ready for commissioning at about the same time as the last LHC sector since installation can only be completed once all LHC magnets have been transported through the TI 2 tunnel. Ideally commissioning of TI 2 should then take place in parallel with the hardware commissioning of the last sector. This will affect the hardware commissioning schedule, but minimise the risk in case of problems with this transfer line. The other option would be to commission the line in parallel with the beam 2 commissioning in the LHC, which increases the risk in case of problems.

Clearly, many tasks will have to be performed before, during and after the cold checkout period and careful planning and good coordination will be required.

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