LHC INJECTOR COMPLEX STATUS

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Abstract

We will present the status of the LHC proton and ion injector chain as of September 2014. We will briefly recap the main modifications done during LS1, in particular those which influence the LHC beam quality. Then we will review the first months of beam operation of the PS complex machines and the status and plans for commissioning of the SPS. We will in particular focus on the re-start of the injectors after LS1, and highlight the lessons learned and possible improvements for the re-start after LS2. Finally we will have a first look at the first months of the 2015 injector schedule.

INTRODUCTION

The re-start of the LHC proton and ion injectors was the first start-up after a long LHC shutdown (except for the long stop in 2005, when only Linac2, PSB and ISOLDE continued operation). The large amount of software and hardware interventions during LS1 required an extended check-out period and made the actual start-up phase an unprecedented challenge for the operations teams and equipment experts. We try a first analysis of the start-up and first months of operation, and attempt to derive the lessons learned in view of the re-commissioning of the complex after LS2. Figure 1 shows quarters 2 and 3 of the 2014 injector schedule (v 1.7) with the main time lines.

LINAC2

LS1 Work

No interventions were done during LS1 which would influence the Linac2 beam parameters. The work done during LS1 was standard maintenance work, aiming at ensuring reliable operation until the replacement of Linac2 by Linac4 during LS2.

Start-up and First Months of Operation

As the first machine of the injector chain to start up, Linac2 had to face a number of issues and teething problems with the general services (e.g. access system). On the machine side itself, the late delivery of some FESA classes caused delays. Once this was solved, the actual start-up went rapidly and without particular issues. Linac2 delivered beam to the PS Booster on 2nd June 2014. During the first months of running, operation has been stable and with nominal beam parameters.

PS BOOSTER

LS1 Work

Extensive maintenance work was done on the PS Booster, shared between maintenance and work related to the LIU upgrade. Much of the work has no direct influence on the beam quality. Apart from the standard maintenance work, a number of LIU upgrades were completed. The major intervention of which was the exchange of the beam dump. A newly designed beam dump was installed, appropriate for intensities expected with Linac4 and 2 GeV beam energy. The intervention involved dismantling and re-installation of parts of the measurement line. The intervention went according to plan, but the air cooling system and related interlock had some delays. Five additional Finemet cavity cells were installed in ring 4 (in addition to the already installed five cells), in order to continue testing the new technology. Some limited cabling work (and identification of obsolete cables) was done, as well as some related civil engineering work (new trenches). A new BIC (beam interlock controller) was installed for the extraction, and the handling equipment was consolidated in order for it to be fully operational during the coming shutdowns.

Among the numerous shutdown works the following will have (even if not immediately) impact on the beam performance: the implementation of the new digital low-level RF control, the upgrade of beam instrumentation (BLMs, orbit, BPMs and BCTs in the transfer lines), the renovation of the multipole power supplies and the alignment of the machine.

Start-up and First Months of Operation

First beam was injected into the PSB on 2 June 2014 and made a few turns in the machine immediately. Within one day low intensity was injected and accelerated in all rings. During the first weeks of operation, the machine was progressively debugged, a time consuming and tedious process. The heavily modified control system was behaving reasonably well, and remaining issues were attacked as they arose. The main issues that were encountered were related to hardware that had not sufficiently been commissioned, cabling errors, erratic alignment and late deployment of FESA classes that had to be changed due to the controls modifications. Good progress was made on the new digital LL-RF control, which was successfully commissioned during the first weeks. At the time of the workshop the PSB had set up the non-LHC physics beams for EAST Area, TOF, AD, ISOLDE and SFTPRO. The beam for multi-turn extraction in the PS had also been prepared in the PSB.

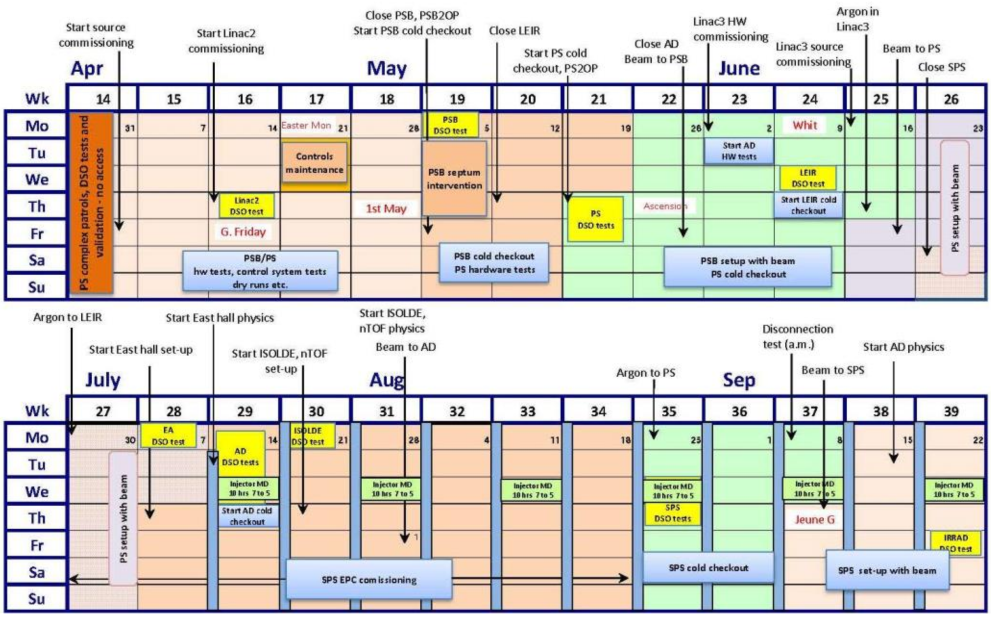

Figure 1: Quarters 2 and 3 of the 2014 injector schedule (v 1.7), indicating the key dates of the start-up.

On the LHC side, the single bunch LHCINDIV and LHCPROBE beams as well as the 25ns and 50ns physics beams had been set up. At this point, the PSB seemed to enter into a more stable phase, although even at present the full beam specifications from before LS1 had not been recovered.

PS

LS1 Work

A number of maintenance and upgrade items were included during LS1. Main items that will eventually impact on the beam performance were the alignment of the main magnets, upgrade of the diagnostics (new BCTs, new DAQ for the BCTs, calibration of the wire scanners, and new pick-up for ion tune measurement), recabling of the 10 MHz RF system, installation of a new, digital 1-turn delay feedback and the installation of a Finemet cavity as longitudinal damper. Furthermore seven magnets were refurbished (PFWs renovated). The ventilation system of the PS ring was renovated in order to minimise temperature fluctuations and to be conform to the legislation, the septa were changed with spares (preventive maintenance), the kicker controls for the CT extraction was renovated and the power supplies for the auxiliary magnets were renewed. On the side of the main power supply (POPS), some improvements to the capacitor banks and the control system have been implemented, which facilitates operation of the degraded modes. The interlock for the high-harmonics RF systems was improved and a dummy septum for the MTE extraction was installed (transparent for LHC beams).

Start-up and First Months of Operation

As in the PSB, beam was injected according to schedule and very rapidly. Rather quickly a 26 GeV beam for orbit measurements was available. On the instrumentation side, the basic tools were available, but there were some subtle issues to be identified.

During the first phase of beam operation a number of issues needed to be followed up by the operations and equipment teams. The beam-based alignment needed to be repeated twice, due to an error in the FESA class which sends orbit data to YASP. A voltage probe of the newly installed Finemet cavity was detecting a signal at 40 MHz; some of the RF gaps were temporarily short-circuited to avoid possible damage to the RF components while investigating the source of the signal. The beam was never affected by the observed phenomena. This issue is presently under investigation. Also a magnetic field non-reproducibility at injection is being investigated. During the start-up phase a vacuum intervention on kicker 79 needed to be done, and the PFNs of the kickers for the MTE needed repair (still ongoing). Two wire scanners broke after a short while, and after having been replaced one of them broke again. This issue is presently under investigation. Apart from that some teething issues with the control system and some minor hardware issues were tackled as they arose.

At the time of the workshop the PS was delivering the following LHC-type beams: LHCINDIV, 25ns and 50ns physics beams (the RF gymnastics have been established and setting up of the double-batch injection had started). On the non-LHC physics side the following beams had been set up: EAST Area, AD, TOF, and SFTPRO. Setting up of the MTE beam had started, but was put on hold due to the kicker and wire scanner problems. Although all user beams were set up and delivered according to specifications and schedule, the PS was at this time still not back to the stable and efficient operation as before LS1.

SPS

LS1 Work

A number of maintenance and upgrade items were implemented during LS1. The alignment of the TT10 following the tunnel maintenance was beneficial and beam went through the transfer line at the first shot. Apart from that a major alignment campaign was done everywhere, especially in LSS1, 5 and 6. Some earth loops in the machine were removed, and graphite (aC) coated magnets installed in four complete half cells. A serigraphed kicker has been installed to reduce the heating with 25ns operation. On the RF side, a new power system for the second 800 MHz cavity, new cavity probes and a new low-level RF system (commissioning foreseen for 2015) have been put in place. The SPS damper has undergone a complete re-design of the electronics system and controls, new pick-ups have been installed and the power system has been consolidated. Presently it is being commissioned and progress is very promising. A vacuum tank for the new type of wire scanners has been installed in the machine, but for the moment the scanner is not yet installed. A synchrotron light monitor has been installed and other instrumentation items have been repaired. A complete survey of the ring for impedance sources has been performed. As part of the LIU upgrades, construction of the new building for the 200 MHz upgrade has started.

Start-up and Commissioning Status

First beam was injected into the SPS on 13 September. Beam was rapidly accelerated on a fixed-target cycle. Besides that 12 bunches of 25 ns LHC beam were accelerated. The issues encountered during the start-up were mainly standard issues. The machine seemed to be rather misaligned, with an RMS orbit of about 10 mm (normally around 2 mm). A beam based alignment performed for Q20 and Q26 optics yielded good results. At the time of the workshop, the commissioning was going reasonably smoothly.

LINAC3

LS1 Work

No shutdown work was done in Linac3 during LS1 which would influence the beam parameters.

Start-up and Commissioning Status

Linac3 started up with Ar for the fixed-target program. Pb ions for the LHC have not yet been produced to date. The start-up was hampered by some delayed hardware, but the linac is by now running up to specifications. In order to change to Pb ions, the source needs to be dismantled and parts be exchanged. This is not expected to be a major issue, as the general start-up issues have by now been solved.

LEIR

LS1 Work

No shutdown work was done in LEIR during LS1 which would influence the beam parameters.

Start-up and Commissioning Status

Due to an overrun of the hardware test period, the check-out of LEIR without beam could not be done and all the debugging took place during the setting up with beam. The unavoidable controls issues could rapidly been solved thanks to good support. Also other normal start-up issues could be tackled as they arose. Presently LEIR is running with Ar ions for the fixed target program. As for Linac3, it is expected that the change-over to Pb ions will be smooth since the general issues will have been solved by then. As a general comment, dedicated manpower is an issue (mainly part-time contributors).

CONTROLS

Dry Runs

A large number of controls upgrades and changes have been implemented during LS1, representing a concern for a smooth and rapid start-up. Figure 2 shows the percentage of front-end computers changed per machine.

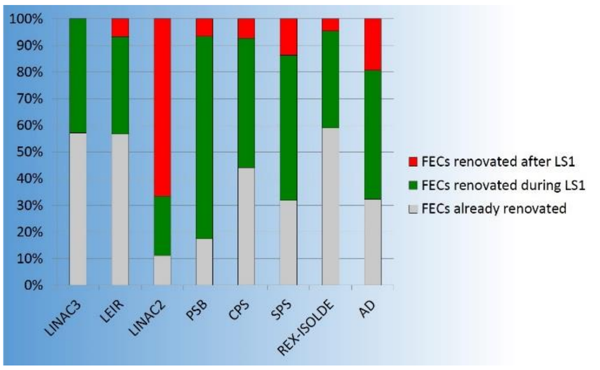

Figure 2: Percentage of FECs changed in the different machines during LS1.

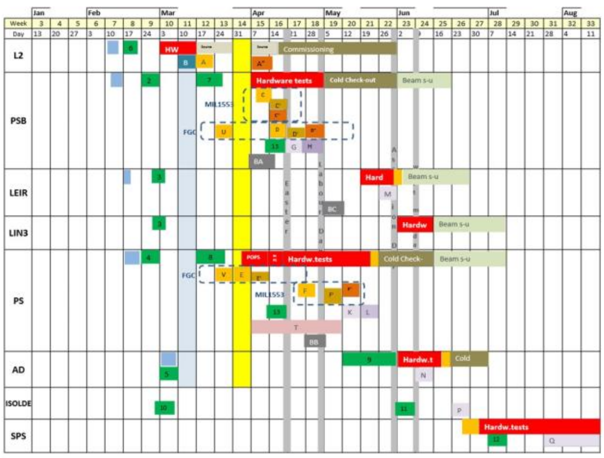

Figure 3: Planning of controls dry runs per machine.

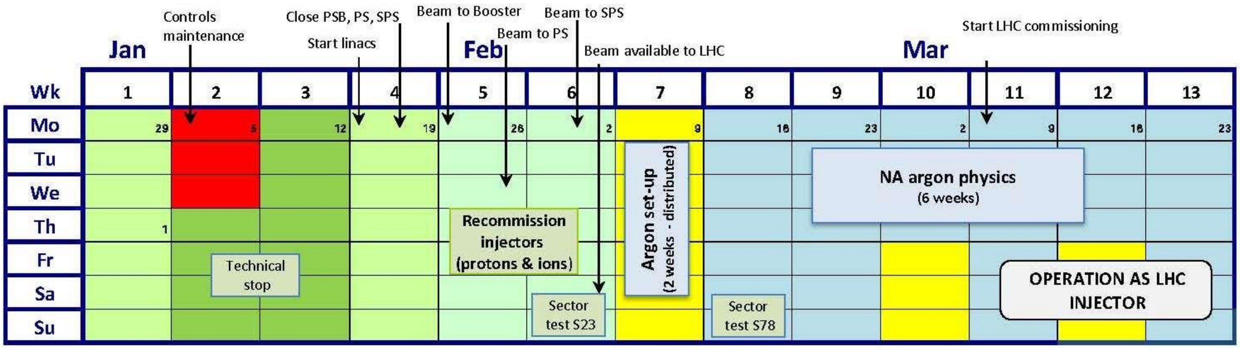

Figure 4: Quarter 1 of the draft 2015 injector schedule, indicating the main time lines.

In order to mitigate this risk, the CO group have organised dry runs in all machines. There were debriefing meetings, where the issues identified were followed up, and renewed tests were scheduled where necessary. The complete process was documented in EDMS. This procedure has proven to be very efficient to capture and fix issues before the actual start-up of the machines. The unavoidable remaining items where then tackled by the specialists, who were present in the control room during the first period to work with the OP teams. Figure 3 shows the planning of the dry runs per machine [1].

LESSONS LEARNED FROM THE START-UP AFTER LS1

Schedule

In order for the check-out and start-up to proceed smoothly, it is important to allocate sufficient time for hardware test and check-out, but also that the different parties respect the time lines. Any overrun of shutdown work or hardware test will propagate down to the next phase, and eventually into the beam setting up. It is also worth noticing that non-respect of the time lines can lead to safety issues, for example the need to give access to machines which are already powered. Good coordination is the key to success. A coherent follow-up of the whole process (shutdown – hardware test – cold check-out – beam setting up) is essential.

Quality of the Hardware Tests

Some issues encountered during the start-up of the different machines suggest a more rigorous hardware test. While certain issues become only apparent when injecting beam, one would hope to capture other issues like missing or inverted cabling already before. Check-lists would be helpful. Certain safety relevant equipment may need to be signed off after having been tested.

Delayed Delivery

Delayed delivery of FESA classes was reported throughout the accelerator complex. This is obviously a consequence of work overload in the equipment groups and of the restructuring of the controls organisation. While there is no obvious solution to this underlying reason, it is recommended to make the timely delivery of FESA classes part of the check-lists.

Issues with Equipment

Certain problems may only become apparent when beam is injected into the machines. In order to tackle these in the most efficient and timely manner, the presence and proactive approach of equipment experts in the control room is the key to success.

Pre-shutdown Reference

Equipment that is modified or replaced should be documented before the intervention, in order to ensure correct re-installation.

Lessons for the Start-up after LS2

LS1 was very much dedicated to LHC work, and despite the impressive list of work done in the injectors this represents only a small fraction of upgrades planned in the frame of the LIU project. The focus of LS2 will be the upgrade of the LHC injectors, and we will face quantitatively more and qualitatively new problems. An example is the connection of Linac4 to the PSB which comes along with a completely new injection scheme. This means that the standard maintenance has to be perfectly transparent, such that the OP and equipment teams can be fully dedicated to the new equipment and no time is lost to do avoidable debugging. Scheduling-wise sufficient time must be allocated for check-out and commissioning. A thorough planning has been presented at the RLIUP workshop [2]. As mentioned above, hardware tests must be rigorous and comprehensive, and dry runs per equipment group shall be organised.

2015 START-UP

A draft schedule for the re-start of the LHC injectors in 2015 is available (Fig. 4).

The actual end-year stop will comprise weeks 51 and 52 of 2014, and weeks 1-3 in 2015. Afterwards the machines have to start up rapidly with both protons and ions. As can be seen from the schedule, the key dates are to start the linacs in week 4, send beam to the PSB and PS in week 5, and to inject into the SPS in week 6. Therefore any interventions during the 2014/15 technical stop need to be compatible with a rapid start-up (e.g. no venting of sensitive equipment). The requests will be collected and approved beforehand.

The fixed-target ion run is scheduled for weeks 8-14. It is worth noticing that the requirements for the vacuum are particularly demanding for ion operation.

Re-start of the LHC is presently foreseen as from week 11. By then all LHC-type beams must be available in the injector chain in a stable and reliable way and within specifications.

SUMMARY

The start-up of the LHC injectors in 2014 was the first start-up after a long shutdown, except for 2005 when the PSB and ISOLDE continued operation. In summary the injectors were able to deliver the beams on request and within specifications. Points of improvement have been identified and listed in the preceding sections. From this experience lessons can be drawn for the re-start after coming long stops, and improved procedures be put in place.

ACKNOWLEDGMENTS

We would like to thank the operations and machine supervisor teams as well as the equipment and support groups who have in a common effort contributed to the successful re-start of the injector complex after LS1. We wish also to thank the teams responsible for the shutdown work for their collaboration in ensuring the transition from the shutdown into the check-out and start-up phase.

REFERENCES

[1] https://edms.cern.ch/document/1340573/1

[2] Review of LHC and Injector Upgrade Plans Workshop (RLIUP), Archamps, France, 2013, CERN–2014–006