SESSION 3 (INJECTION): DISCUSSION SUMMARY

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Abstract

This paper summarises the discussions that followed the presentations of the "Injection" session of the LHC Beam Operation Workshop, EVIAN2011.

INTRODUCTION

The third session of LHC Beam Commissioning Workshop was dedicated to issues relevant to Injection and included five talks:

1. **Transfer lines stability** by Lene Drosdal.
2. **Injection losses and protection** by Wolfgang Bartmann.
3. **Beam preparation in injectors and beam characteristics through the injector complex** by Karel Cornelis.
4. **Injection and Dump Systems** by Chiara Bracco.

For each presentation of the session, summaries of the discussion that followed the presentations are given.

TRANSFER LINE STABILITY

Performance of the transfer lines during the 2011 Run was reviewed, with particular focus on transfer line drift, shot-by-shot variations and bunch-by-bunch variations.

Regular re-steering was needed in 2011, as tight transfer line collimator settings strongly limited the degree of transfer line drift. It was noted that the frequency of re-steering increased over the proton run, with the required corrections often being of the same magnitude on the same corrector (RCIBH.20804). Slow baseline oscillation of the drift was considered and a dependence on the SPS super cycle suspected, but without conclusive proof.

For the shot-by-shot stability studies, both transfer lines showed that the horizontal plane was the greater stability issues, with the horizontal fluctuations being ~3 times larger for the vertical plane for both lines. Model Independent Analysis of the data for T12 identified one strong source responsible for the fluctuations and this was current variation of the SPS MSE. For TI8, the two fluctuation sources were identified, and these were MSE current variations and variations on the MKE which are still under investigation. It was noted that for the TI2 MSE the power converter ripple had been halved during the course of the run, and this reduced the fluctuation amplitude by ~1/3 (although this conclusion is taken with low statistics). However it was stated that a factor 2 improvement in both lines is still need to bring the horizontal fluctuations down to the same level as the vertical plane.

Large bunch-by-bunch variations were observed during 2011 on the TI8 line in the horizontal plane, and the horizontal Extraction Kicker (MKE) waveform is suspected, as the observed flattop ripple was a factor 4 above specification (i.e. at 4% of flattop voltage).

Given these observations and results, it was recognised that the MKE4 (TI8) flattop ripple is well outside specifications, but that this was not feasible to address until after the 2012 run. It is expected that transfer line steering will remain a complicated business in 2012, and that the regular 30 minutes to 2 hours of re-steering should be expected. Some reduction in the transfer line re-steering is expected due to MSE current stability improvements.

From the open discussion it was K. Cornelis mentioned that a 12-bunch batch was not representative of the 34 bunch batch transfer an that an appropriately constructed 6+6 bunch batch would better suite stability studies. B. Goddard agreed and suggested that with such a 6+6 bunch batch we could better identify where within the waveform ripple that a reduction would improve the bunch-by-bunch stability. J. Wenninger noted that in 2008 the MKE4 ripple was measured and was at the same 4% of total voltage, and so had not worsened. W. Hoffle questioned if these drifts and instabilities meant that the aperture limit was now in the transfer line, but is was reaffirmed that it is still in the ring and not in the transfer line. M. Lamont asked if there was any indication that the transfer line drift was a temperature effect, but this had been investigated and was not the case.

INJECTION LOSSES AND PROTECTION

A review of the overall injection performance was presented and then areas of improvement and open operational issues were discussed.

In the comparison between injection performance in 2010 and 2011, transfer line losses went from ~25% of dump threshold with 48 bunch injection in 2010 to ~31% for 288 bunches in 2011. This improvement was achieved by avoiding over-injection injection schemes, reducing transfer line showers, and mitigating uncaptured beam.

The reduction in transfer line showers was achieved in primarily by opening TCDIs from 4.5 to 5.0 sigma, which gave a factor 4 reduction in shower losses after the TDI. It was noted that further improvements ay be possible by moving or adding TCDIs, but the optics impact has not yet been assessed.

Studies of capture losses were performed by changing from matched RF voltages between SPS and LHC (3.5MV) to a mismatched RF voltage (SPS: 3.5MV and LHC: 6MV). This causes effective bunch length shrinkage due to the increased bucket amplitude, and improved capture losses were observed (but not really quantified). However this effective bunch length shrinkage requires increased longitudinal emittance blowup during the ramp to avoid instabilities and losses.

It was stated that this optimisation between balance of capture loss and losses during the ramp, in terms of RF voltage mismatch has not been fully explored. Further, there is no hard limit at 6 MV, and the LHC RF total voltage could go up to 8MV if needed.

In order to reduce the number of dumps at injection from TCDI induced losses and unbunched beam showers, "sunglasses" solutions in terms of modifications in the BLM hardware and firmware for injection energy settings were discussed. These solutions would either suppress the signal or raise the dump threshold of certain BLMs during the injection phase. Of the agreed sunglasses solutions, the first is to replace certain ionization chambers with smaller versions, giving up to a factor 60 suppression of the signal. This is the minimal solution as there is no change in the firmware nor the interlock logic, and so is being implemented during the 2011-2012 shutdown for a select set of ring BLMs. In addition, with these new monitors, thresholds can be adjusted so that a factor 5 margin between thresholds and losses is achievable around the ring at injection energy.

Additional mitigation possibilities were briefly discussed, but only moving/adding TCDIs and BLM sunglasses mitigation offer the potential for significant reduction in losses at injection. However both mitigations have machine protection issues that must be followed.

It was also explicitly noted that increased beam scraping with present emittances does not improve losses.

In terms of operational issues several points were:

- Both injection and abort gap cleaning in 2011 were automatized and integrated into routine operation, but with injection cleaning requires on-the fly calculations and cannot rely on critical setting settings. However a fixed display for abort gap cleaning is still needed.
- TCLIA losses and asymmetry in TCTH losses are not yet fully understood (especially after an ALICE polarity flip).
- Re-steering of transfer lines and MKI kicker failures remain open issues.
- Additional localised shielding between the TDI and TCDD were simulated, and while it gives no significant improvement in injection losses, ALICE may pursue this as a possible beams to reduce backgrounds.

For the 2012 run, the focus is to be on reducing time spent at injection and to ensure that losses for 288-bunch injection is at ~30% of threshold. This requires improvement in trajectory stability, straightforward re-steering procedures, and fixed supercycles in the injectors when filling the LHC. It is also foreseen to upgrade the IQC monitoring to give tighter control over injection quality. Finally it was estimated that the set-up time for injection for the 2012 run is 4 shifts with beam.

From the open discussion, the first issue raised was that of button BPMs in the TCDI jaws, when B. Goddard asked if it was realistic and if so, on what time scale. It was stated that such an installation would not be available until after the long shutdown LS1. For the BLM sunglasses solutions, M. Pojer asked for details on type and location with regard to transfer line shower monitoring, and this led to a discussion on placement of diamond-sensor BLMs placed downstream of TCDIs and confirmation that they are used in multiple-hit counting mode.

For Operation issues J. Wenninger noted that SPS steering on the beam for the LHC is a common operation, and that in a similar way, collimator set-up, settings-copy, and steering procedures should be streamlined and potentially semi-automatized. Y. Papaphilippou noted that relation between capture losses and bunch length had not been fully explored, and that this may have a bearing on the best implementation of a BLM sunglasses solution. B Holzer then noted care is needed with implementation, as especially with higher BLM running sums there may be limitations from the electronics. R. Schmidt agreed and again stressed the need to ensure machine protection.

BEAM PREPARATION IN INJECTORS AND BEAM CHARACTERISTICS

Beam preparation and beam characteristics in the injector chain were presented with emphasis on drifting parameters, emittance and intensity, and considerations for filling, both for the LHC and the injectors.

Across the injector complex, variations in beam parameters that require regular attention are:

- Beam intensity variations between the Booster rings. (esp. ring 1 and ring 2)
- Booster to PS beam transfer
- Bunch splitting in the PS
- PS to SPS beam transfer
- SPS injection phase
- Longitudinal blow up in the SPS.

Of these, all but the bunch splitting is relatively straight forward, and all are part of routine operation. However it was stressed that these adjustments stop being routine operation if the beam requirements are moved outside the operational parameter window.

Particular reference was made in this case to the situation with emittance and intensity parameters. With less intensity stability in Ring 1 and 2 of the Booster, higher total beam intensities show a larger variation at 450GeV in the SPS and increased tail population in the beam profiles. In order to monitor and regulate these tails, there is an on-going request to BI for bunch-by bunch measurement with the wire scanners, and a continuous beam profile monitoring (Ionisation Beam Profile Monitor). It was also noted that for 25ns beam with an Intensity of $I < 1.15e11$, beams with Gaussian profiles and normalised emittances (in both planes) of 2.6 - 3.0 microns could be achieved.

Improvement of beam quality by means of beam scraping in the SPS was evaluated, and it was shown that for optimum beam transfer the scraper must be in the shadow on the transfer line collimator. If this is the case then it was shown that even larger emittance beams could be efficiently transferred.

Further, increases in intensity are not always beneficial for performance as this increased intensity can put unnecessary stress on the SPS electrostatic extraction septum (ZS). This risk is in terms of ZS sparking which not only requires recovery time before continuing but also risks damage on a critical component. For bunch intensities above 1.45e11 (with 50ns bunch spacing) the ZS can spark frequently and the total voltage needs to be reduced to 110kV, which in turn prevents slow extraction on the SPS fixed target cycle. In order to address the risks associated with ZS sparking a new spark interlock has been implemented for LHC filling.

LHC filling strategies and experience from the 2011 were reviewed, and it was noted that the present SPS super-cycle satisfied the requirements from a number of clients. Specifically:

- The SPS fixed target cycle was always present and used to supply beam to a variety of North Area clients who have short running periods.
- There is a large number and variety of PS users, so that SPS super-cycle changes should be kept to a minimum to avoid constant reshuffling of the CPS cycles.
- A long SPS fixed target cycle is an efficient way to allocate space to PS users.

Given these constraints it was stated that any proposal for dedicated LHC filling has to be carefully assessed and the implications to the whole complex and user base considered.

For the 2012 run the following issues were identified:

- Switching between 12 and 36 bunches by using the spare cycle concept is being prepared.
- If ZS sparking with high beam intensities is a persistent issue, and the decision is to continue with the high intensities, the fixed target cycle can be removed from the LHC fill super cycle.
- If there is a dedicating LHC filling super-cycle, its duration could be shortened (e.g. by having only 1 or 2 CNGS cycles), but this has implications for PS users.
- During LHC filling, timing sequences should not be altered (i.e. no changing and no loading).
- For high intensity running ZS sparking may be an issue that can be mitigated by adjustment of the filling cycle sequence.

From the open discussion G. Arduini asked if, for extraction to the LHC with high intensities, the ZS voltage could be ramped down at the end of the fixed target cycle. This was not seen as feasible as B. Goddard as there would be issues with the control of the ion trap voltage. B Goddard commented that impedance shielding would also need to be improved. M. Pojer questioned if the drifts and variations in beam setup were significant on the 20-minute time scale (typical time scale for going from driving the LHC to injection settings to injecting high intensity beam). The speaker confirmed that on such a time scale settings needed re-checking or and adjusting. E. Chapochnikova noted that if beam parameters were observed to drift, there is beam blow up and adjustment is necessary. G. Arduini asked about an auto pilot mechanism for bunch splitting, but it was commented that the time scale for such an autopilot would be too long relative to the filling. Fourier analysis of beam from the ring in the Booster used for the previous splitting could be used as feed forward information, but this feed forward loop was also deemed too slow to be of use.

INJECTION AND DUMP SYSTEMS

The LBDS and injection system performance in 2011 was presented with focus on issues and concerns, which included the XPOC and IQC systems.

The LBDS in 2011 had no asynchronous beam dumps (compared to 3 in 2010), but a noticeable increase in internal dump triggers, due to timing and synchronisation issues. These internal trigger faults have been addressed in 2011 by new TSU firmware and replacement of hardware.

Ten beam dumps were induced by problems with TCQD settings and interlocks, but were not related to hardware failures. However, there we also problems with the TDCQ settings and sequences, which were often solved by re-running sequences or applying correct settings. Naturally it was stressed that care must be taken when updating settings associated with the LBDS or TCDQ.

For the injection system, a 2010 event where the MKI2 did not fire resulted in 32 bunches directly onto the TDI upper jaw, and this was used to benchmark losses and show that ALICE can withstand 288 bunches on to the TDI. A similar bench marking for LHCb does not yet exist.

In 2011 there were several incidents with the MKIs, in terms of MKI flashovers causing an over-kick of bunches and led to downstream magnet quenches. To prevent such flashovers, the vacuum interlock threshold has been tightened and e-cloud solenoids between the MKI and Q4/Q5 are switched ON.

Additional MKI erratics were observed in the form of:

- 1 of the 4 kicker magnets of the MKI having a non standard kick duration
- Erratic turn on of one magnet during charging, which gave a kick of 17% of nominal to ~170 bunches.

These erratics were traced to hardware problems, the components exchanged, and faster detection electronics with lower thresholds added. For the erratic that caused a partial kick of ~170 bunches, magnets were quenched, but there was no safety concern for the machine. However, for ALICE the spray of beam caused concern, as 9 out of 17 sub-detector systems were affected and the ALICE Silicon Drift Detector suffered some degree of semi permanent damage. As intensity and number of bunches is expected to increase, this MKI erratic is still a source of concern for ALICE.

For the MKIs, the increase in bunches and intensity also caused issues with MKI heating. Increase in magnet temperature during injection causes a decrease in its inductance (due to reduced ferrite permeability), which in turn reduces the magnet strength, rise time and delay. In order limit the changes of the MKI magnet due to heating, a SIS interlock is used, and the threshold has been raised to its maximum value of 62 degrees C. For temperatures above this injection is not possible, and in 2011, with increased intensities and bunch numbers and with fast turn around times this interlock was encountered a number of times. In 2011, the only solution for the MKI temperature interlock was to wait until the MKI temperature cooled below threshold.

Several other operational issues were also briefly discussed, which included operational errors, UFOs at injection, localised vacuum pressure bumps due to TDI parking positions of 20mm rather than 55mm (new parking setting).

The XPOC system in 2011 had a number of issues with BLM thresholds, missing data and wrong filling patterns, but the XPOC interface was upgraded to allow EIC resets of the XPOC for Context and BLM loss related issues, but maintains the LBDS expert sign-off for all other blocking situations. For the IQC, new monitoring and playback features were highlighted that make the evaluation of injections easier.

In terms of concerns, the case of a 144-bunch injection that was not seen by the IQC was highlighted, as it shows a real risk of serious over-injection. This fault was traced to a server communication problem, but such an error should be eliminated.

For the 2012 run it was concluded that dedicated time with and without beam is again needed for set up and for testing of new components. Further, for smooth operation, it was reaffirmed that setup and operational procedures should be adhered to. However, at the time of the presentation, no time estimation of the 2012 setup time was given.

During the open discussion D. Jacquet commented that the risk of over injection has been removed, as there are now injection sequencer checks between database and BQM measurements. R. Schmidt asked if this check should go into a hardware interlock, and both B Goddard and V. Kain responded that the there are several layer of checking. Further, the abort gap keeper makes a decision on injection at the last possible moment, so it was not foreseen to add this additional check to a hardware interlock. W. Venturini Delsolaro asked if the MKI temperature could be better controlled by better cooling, and it was stated that there is no cooling on the MKI and nothing foreseen for the 2012 run. However, J. Uythoven commented that they were looking reducing induction heating.

SUMMARY NOTES

In the wrap up of the session, the Chair made the following concluding remarks:

- For regular operation there should be a documented list of nominal beam parameters for the injector chain, and this should be adhered to.
- For LHC filling during regular operation, the SPS super cycle composition should be fixed, and not be changed from fill to fill. For this, decisions are required on:
  - The number of CNGS cycles - if only 1 or 2 the time spent at LHC flat bottom is reduced (hence reduced emittance blow up), but there is increased of ZS sparking at high intensity.
  - Whether to remove the SPS Fixed Target cycle for LHC filling if ZS sparking is an issue.
- Agree on injection strategy for filling:
  - Inject Pilot
  - Steering of Transfer Lines with 12 bunches if needed
  - SPS checks on 4 x 36 bunches
  - LHC filling with no changes in PSB or PS
- For 2012 there are to be no sequence changes in the SPS injectors when switching from 12 to 36 bunches
- Time should be given early on in the 2012 run for Transfer Line stability studies, in order to reduce the time for beam steering of the lines
- Improvement of tools required in 2012
  - IQC: upgrade of software to include steering envelopes for operation and trajectories at the collimators.
  - Transverse diagnostics in the injector chain.
- Beam loss mitigation campaigns: shielding, BLM sunglasses, and adding/moving TCDIs.
- Dedicated beam time for both injection and beam dump setup, both with and without beam.
- Clear procedures and safety instructions should be defined and respected during operation.