INJECTION AND LESSONS FOR 2012

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Abstract

Injection of 144 bunches into the LHC became fully operational during the 2011 run and one nominal injection of 288 bunches was accomplished. Several mitigation solutions were put in place to minimise losses from the Transfer Line (TL) collimators and losses from kicking debunched beam during injection. Nevertheless, shot-by-shot and bunch-by-bunch trajectory variations, as well as long terms drifts, were observed and required a regular resteering of the TL implying a non negligible amount of time spent for injection setup. Likely sources of instability have been identified (i.e. MKE and MSE ripples) and possible cures to optimise 2012 operation are presented. Well defined references for TL steering will be defined in a more rigorous way in order to allow a more straightforward and faster injection setup. Encountered and potential issues of the injection system, in particular the injection kickers MKI, are discussed also in view of injections with a higher number of bunches.

2011 OPERATION

The performance of the LHC in 2011 was outstanding and much better than what was predicted during the last Chamonix workshop. Also the injection system [1] worked better than expectations [2] and the injection of batches of 144 bunches ($1.5{\cdot}10^{10}$ protons per bunch and emittance ε = 2 μm) became part of standard operation. Moreover, during Machine Development (MD) time, the injection of 288 bunches was accomplished for both beams with 30% margin between the injection losses and the dump thresholds. Work has still to be done to optimise the 25 ns beam in the injector chain, accumulation and beam lifetime in the LHC ring but, globally, the experiment was successful and promising in view of operation with the nominal intensity.

Mitigation Measures

Some mitigation measures were put in place and allowed to reduce the injection losses due to uncaptured beam (injection and abort gap cleaning) and showers from the transfer line collimators (TCDI shielding and aperture, SPS beam scraping) [3].

Studies showed the importance of a correct beam scraping in the SPS to reduce the losses at the TCDIs (by up to a factor of 10) without affecting the transverse emittance. The scraper has to cast a shadow on the transfer line collimators without cutting the beam core to avoid too high losses in the SPS and, as a consequence, machine activation [4].

In the middle of the 2011 run, after several beam dumps triggered by injection losses, the TCDI half gaps in TI2 were opened from 4.5 σ to 5 σ to be less sensitive to trajectory drifts. Before opening the TCDIs, it was checked that all the collimators were still centered with respect to the reference trajectory used for the Machine Protection (MP) validation tests at the beginning of the year (tests done with TCDI at 5 σ). A factor of 4 was gained in the injection losses coming from the TL (see Fig.1) but with some reduction in protection. Studies are ongoing to evaluate the impact of moving or adding collimators at the beginning of the TL to reduce the showers in the LHC injection region.

Further options are at present analyzed to have cleaner injections. BLM sunglasses should avoid unnecessary beam dumps due to showers from the outside and debunched beam. One possible solution is to replace some BLM monitors with less sensitive Little Ionization Chambers (LICs); this would potentially allow to increase the BLM thresholds by up to a factor of 60. No modification to the hardware, BIS system nor BLM firmware is required but certain thresholds would be constantly higher at 450 GeV. A list of monitors to be exchanged was defined and 7 LICs were installed during the 2011-2012 Christmas Technical Stop (TS). Thresholds will be kept unchanged at the LHC startup and will be increased according to operation and machine protection needs later during the run.

A better control of the transfer line stability would improve the injection process and reduce the downtime; details are presented in the following.

Transfer Line Stability

Injection played a dominant role in the LHC downtime during the 2011 run. Changes in the trajectories required a periodic re-steering of the TL: initially once, twice per week and every second day at the end of the year. Steering of the lines was complicated since a correct tradeoff between injection oscillations ($<$1.5 mm) and beam position at the TCDI had to be defined. Moreover, shot-by-shot variations were observed corresponding to a maximum trajectory excursion of 760-770 μm in the horizontal plane and 260 μm in the vertical plane for both beams [5]. A Model Independent Analysis (MIA) allowed to define the strongest Eigenmodes of the oscillations observed and to identify the most probable source of instability. The ripples measured at the power converter of the SPS extraction septum (MSE) might explain the oscillations in the horizontal

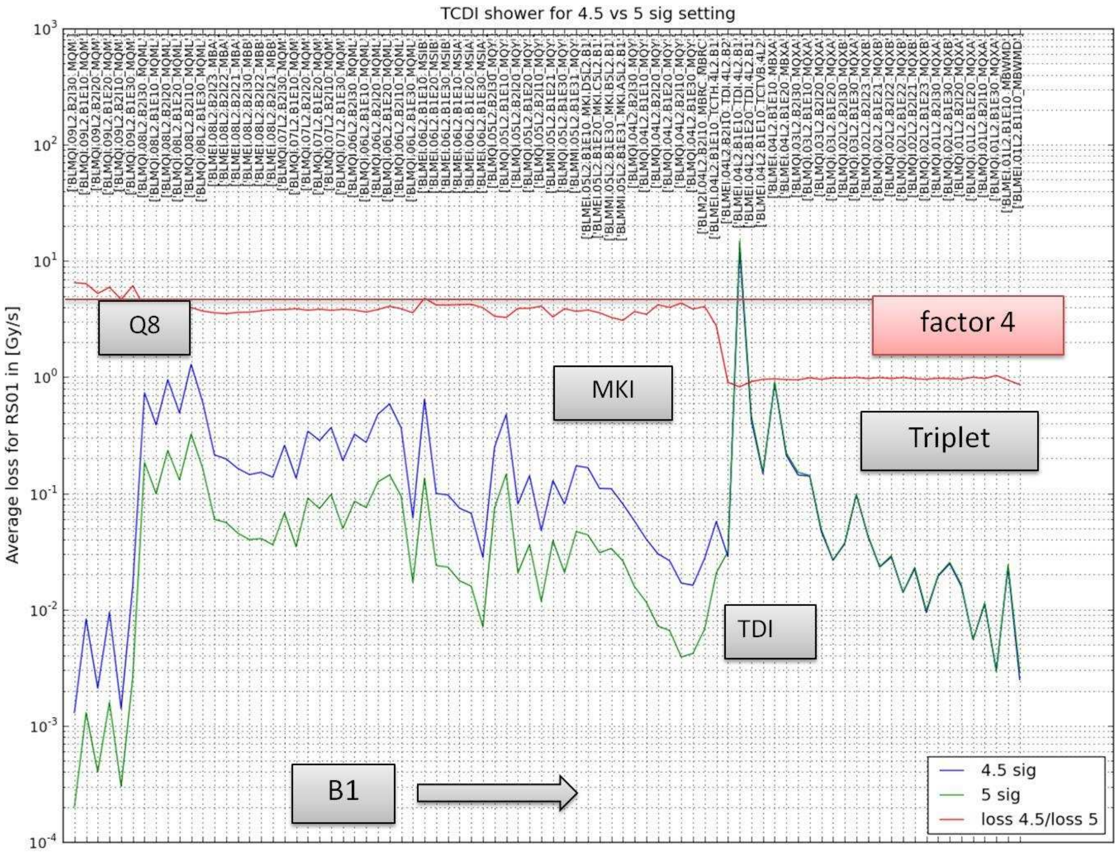

Figure 1: Loss shower from transfer line collimators (TCDI) for the cells 1 to 9 upstream of ALICE with the beam direction from left to right. The blue curve indicates the loss level with a TCDI opening of 4.5 σ and the green curve shows the reduced loss level after opening the TCDIs further to 5 σ [3].

plane for Beam 1. A second contribution from the SPS extraction kicker (MKE) has to be also taken into account for Beam 2.

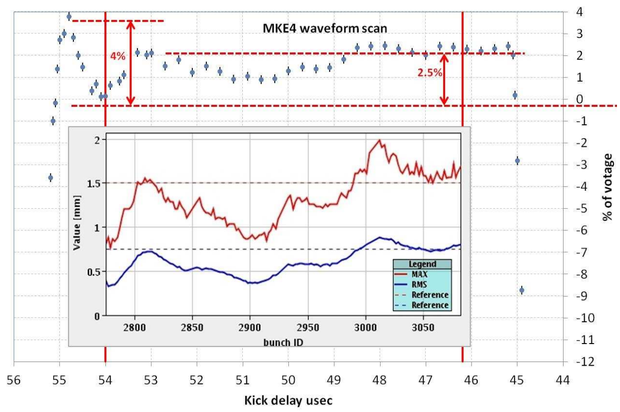

Figure 2: Comparison between scan of the SPS extraction kicker waveform in TI8 - MKE4 and IQC plot showing large variations for the bunch-by-bunch injection oscillations amplitude (Beam 3 horizontal) [5].

Large bunch-by-bunch amplitude modulation of the horizontal injection oscillations were observed for Beam 2 when injecting 144 bunches and seemed to indicate a bunch-by-bunch variation of the trajectory in TI8. A scan of the horizontal extraction kicker (MKE4) was performed and a ripple of up to 2.5% of the kick (maximum to minimum) was measured at flattop (specification: 1%), moreover, the waveform modulation was consistent with the bunch-by-bunch injection oscillation amplitude (see Fig.2).

About 60 hours, over 120 days of operation, will be spent at injection in 2012 if TL stability is not improved. Work is ongoing on the MSE power converters to reduce the ripples. In addition, the injected beam will be moved towards a flatter part of the waveform (in particular the 12 bunches used to steer the lines) to attenuate the bunch-by-bunch variation.

An adequate amount of the commissioning time will have to be used for a careful setup of the TL and to define new trajectories allowing an easier and faster steering (no more conflict between transverse losses and injection oscillations). New features and improved references have been implemented in the Injection Quality Checks (IQC) application (limits at the TL BPM and intensity dependent

BLM thresholds) and should further simplify the steering process. All this should reduce the downtime caused by the injection.

MKI FAILURES

The only quenches occurred during the 2011 run were a consequence of injection failures [6]. In one case, a flashover of the MKI-D in point 8 caused the over-kick of 36 injected bunches which grazed the TDI lower jaw and the TCLIB collimator and determined the quench of 11 magnets. The spark was the consequence of vacuum degradation in the kicker region during injection. As a followup of that event, the HW vacuum interlock at the MKI was reduced from 5×10^{-8} mbar to 2×10^{-8} mbar, a SW interlock was implemented to inhibit injection in case of pressure $>2\times10^{-9}$ mbar and a new interlock on the integrated pressure over time was added during the last Christmas TS. Anti-e-cloud solenoids in the injection region have to be switched on during nominal operation; special runs with solenoids off can be envisaged (i.e. scrubbing) provided that the interlock limits defined above are respected. The setup of the injection protection collimators was rechecked, in particular the TDI angular alignment, and the TCLIB half aperture was relaxed by 1.5 σ to reduce the load on the downstream magnet.

Two erratics happened at the MKI-C of Beam 1. The first erratic was correctly detected and the system reacted firing all the injection kickers. No beam passed across the MKI during the pulse but 144 bunches were extracted by the SPS when the MKI current was still zero and were dumped on to the upper TDI jaw. The second erratic happened, again at the MKI-C, during the resonant charging and was not detected by the system. The kicker pulsed for $\sim$9 μs and the circulating beam was swept over the aperture and grazed the TDI lower jaw. According to the XPOC analysis, 173 bunches were lost and not correctly dumped, 3 magnets quenched and the Silicon Drift Detector (SDD) of ALICE suffered permanent effects. Investigations showed

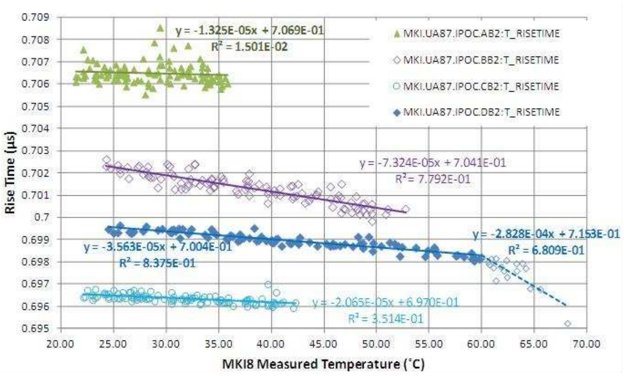

Figure 3: Rise time measurement as a function of the temperature of the MKIs in IR8 [6].

that the erratics were caused by a HW problem, the faulty components were exchanged and a faster detection with lower voltage thresholds was implemented. No more erratics were recorded until the end of the run but similar accidents can happen, by design, few times per year. The injection protection collimators have to be correctly set up and the experiments have to be in a fully safe state to avoid damages.

A software interlock exists on the MKI temperature to forbid injection in case of excessive heating. The strength of the MKIs depends in fact on the ferrite temperature: the magnet inductance decreases when increasing the temperature above the ferrite Curie point. The ferrite inductance is evaluated by measuring either the MKI rise time or the delay during the soft-start. Results of rise time measurements performed on the four MKIs in point 8 are shown in Fig.3. A fast drop of the rise time can be observed for the MKI-D starting at about 60 °C. Based on these measurements, the interlock limit was set at 62 °C (originally at 55 °C) and it cannot be further increased. Temperature interlocks for individual magnets have been deployed from the 2011/2012 Christmas stop.

A long time-constant (10 hours) is associated with heating and cooling of the ferrite mass; this lag is due to the ferrite thermal capacity. Delays in operation have to be envisaged as some MKI cooling time has to be foreseen before injection, especially when moving to higher intensities.

OTHER INJECTION ISSUES

Other issues were observed during the 2011 operation. Unidentified Falling Objects (UFOs) were observed at the MKI and induced several beam dumps at the beginning of the run (details can be found in [7]).

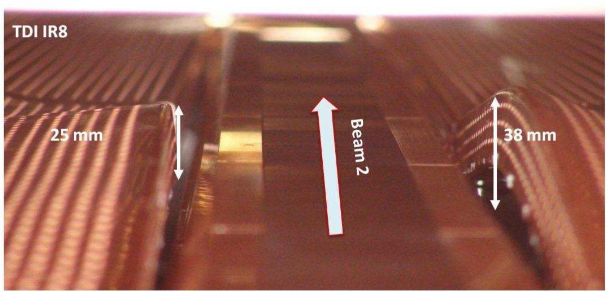

Figure 4: Deformation of the beam screen observed at the TDI in point 8.

Different problems were encountered at the TDI:

- Drift of the TDI LVDT: the interlock threshold had to be increased by 100 μm to avoid beam dumps.
- Vacuum pressure increase and heating at the TDI in points 2 and 8 during physics, when the jaws were set at $\pm$22 mm. This was particularly problematic for ALICE due to the high background. A new parking position with the jaws at $\pm$55 mm was defined and solved the vacuum issue but a temperature increase

is still present in this region. Impedance studies are ongoing to understand the origin of this effect [8].

- A deformation in the beam screen was found during the Christmas stop (see Fig.4). Investigation on the cause of the deformation and possible solutions is ongoing.

CONCLUSIONS

The injection system performance during the 2011 LHC run was better than expectations: injection of 144 bunches was fully operational and 288 bunches could be successfully injected, for both beams, during MD time.

Mitigation measures were put in place and allowed to reduce injection losses; several options are analyzed to further gain some margin with respect to the dump thresholds.

The transfer line stability caused a number of problems. The steering of the lines was not straightforward since the optimum tradeoff between minimum transverse losses and injection oscillations had to be defined. Moreover big shot-by-shot and bunch-by-bunch variations were observed together with long term trajectory drifts. Work is ongoing to minimise the instability sources and improve the references in the lines in order to reduce injection induced downtime.

Two major failures involved the injection system (MKI flashover and erratic) and caused the only magnet quenches occurred in 2011 and some damage of ALICE SDD. The MKI faulty components were replaced, diagnostic improved and interlock logic enforced. Future failures have still to be envisaged but serious damages should be avoided if the injection protection collimators are correctly set up and the experiments in a fully safe state.

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