INJECTION AND DUMP SYSTEM

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Abstract

Performance and failures of the LHC injection and extraction systems are presented. In particular, a comparison with the 2010 run, lessons learnt during operation with high intensity beams and foreseen upgrades are described. UFOs, vacuum and impedance problems related to the injection and extraction equipment are analysed together with possible improvements and solutions. New implemented features, diagnostics, critical issues of XPOC and IQC applications are addressed.

INTRODUCTION

Proton beams are injected, through the TI 2 and TI 8 transfer lines, into the LHC straight sections in point 2 (IR 2) and 8 (IR 8). The injection system [1], in each IR, consists of 5 horizontally deflecting septum magnets (MSI) and 4 vertically deflecting kickers (MKI). An absorber (TDI) is installed at a phase advance of 90° with respect to the MKI to intercept mis-kicked beams. Further protection is provided by two auxiliary collimators (TCLIA and TCLIB) located at 180° ± 20° from the TDI. At each injection, data from critical equipment in the LHC ring and in the Transfer Lines (TL) are collected and analysed by the Injection Quality Check application (IQC) [2]. The results of the analysis are displayed on a GUI and allow to qualify the injection and decide if any optimisation is needed. The IQC also provides software interlocks and can inhibit injection. A playback tool is also implemented for reviewing past events.

The LHC Beam Dumping System LBDS [3] is situated in IR 6 and consists, for each beam, of 15 extraction kickers (MKD), 15 septum magnets (MSD) and 8 dilution kickers (MKB) which paint the beam on an absorbing block (TDE). Two movable protection elements (TCSG, TCDQ) and 2 fixed masks (TCDS and TCDQM) are installed downstream the MKD to intercept the beam swept across the machine aperture in case of an asynchronous beam dump. After every beam dump, an automatic post mortem (PM) analysis is generated and a series of Internal (IPOC) and eXternal Post-Operational Checks (XPOC) is made to control the system and recover an “as good as new” state.

In this paper, performance of the LHC injection and extraction system during the 2011 run is presented.

LHC BEAM DUMPING SYSTEM 2010-2011OPERATION

A detailed analysis of the operation and failures of the LBDS system during the 2010 run can be found in [4]. No asynchronous beam dump occurred in 2011 (three happened in 2010, one with beam) but a considerable increase in the number of the internal triggers was recorded with respect to the previous year. In particular several beam dumps were induced by faults in the Beam Energy Tracking System (BETS) due to problems with the main power supplies which, for this reason, will be replaced during the 2011/2012 Christmas Stop.

The new Time Synchronisation Unit (TSU) firmware had to be downgraded back to the 2010 version, with consequent loss of redundancy, because of failures during the LBDS arming process and the increased frequency of spontaneous triggers. The new firmware was successfully tested in the lab over two months but insufficient time was dedicate to repeating these tests during the machine checkout.

A number of accesses was needed to exchange electronic components (PXI National Instrument digitiser fuses, GTO switches) which failed mainly during the magnet ramp down; this required 2-3 hours of downtime for each intervention.

TCDQ Induced Beam Dumps and Mechanical Jaw Offset

The number of beam dumps triggered by the TCDQ collimator increased with respect to last year (10 instead of 2). This collimator has to be correctly set up and centred around the beam to provide the required protection in case of an asynchronous beam dump. A redundant interlock system checks the absolute position of the TCDQ, the relative position to the nearby TCSG, the gap as a function of the energy and the beam position at this location. In 2012 a new interlock on the jaw positions as a function of the β* will be also implemented.

The biggest part of the dumps was caused by wrong operational requests, mainly during Machine Development (MD) and tests, which provoked a break in the interlock loop. In few cases the dump happened because of beam position instabilities (during ramp and flattop).

A problem of glitches in the energy gap limits, due to a noisy signal of the potentiometers, could be solved only relaxing the interlock thresholds. New potentiometer electronics will be integrated during the Christmas Stop and will provide a more precise and less noisy reading of the jaw positions.

Some issues were also encountered while running the TCDQ sequence to load settings and thresholds. They were generally solved by repeating the sequence task but, in some cases, it was necessary to dump the beam and restart the procedure from the beginning.

A mechanical offset of the jaw was measured for both TCDQs while performing the beam based alignment. This offset was compensated by adding the following values to the beam position measured at the TCSG:

- Beam 1: -0.25 mm for all settings
- Beam 2: +0.5 mm for 3.5 TeV settings and +1 mm for 450 GeV settings

The offset at the Beam 2 TCDQ had to be re-measured as a consequence of a mis-correction applied in the tunnel during a Technical Stop; this time an offset of -0.6 mm was found for all settings.

LHC INJECTION SYSTEM 2010-2011 OPERATION

The only relevant event in 2010 was the dump of 32 bunches on the upper jaw of the TDI in point 2 as a consequence of the Abort Gap Keeper (AGK) preventing the MKI from firing [5]. The showers of secondary particles produced and hitting ALICE provided a benchmark to simulation results. The experiment confirmed to be ready for a full nominal batch of 288 bunches dumped on the TDI. Operation in 2011 was characterised by two main episodes which are presented in the following.

MKI Flashover

On April 18th, a breakdown in the second half of magnet D (the first magnet seeing the injected beam) of the Beam 2 MKIs occurred during the injection of two batches of 36 bunches. The second train was over-kick (110-125% nominal deflection) and almost all the protons grazed the TDI lower jaw and the TCLIB inducing the quench of 11 downstream magnets. The flashover was caused by an increase in the vacuum pressure at the MKIs. In order to avoid other similar events, the already existing vacuum hardware interlock limit was reduced from 5×10^{-8} mbar to 2×10^{-8} mbar. A new software interlock was also implemented to prevent injection in case of a pressure higher than 2×10^{-9} mbar. The possibility of implementing an interlock on the integrated pressure over time ($\int P\,dt$) is presently under study.

Nominal operation has to be performed with the anti-electron cloud solenoids, located between the injection kickers and the downstream quadrupole (MQ4), switched on to reduce pressure increase in this region. Special operation with solenoids off can be envisaged (i.e. scrubbing runs) provided the interlock limits defined above are respected.

As a follow-up of this incident the setup of the injection protection collimators was reviewed. The TCLIBs were opened from 6.8 σ to 8.3 σ to reduce the secondary showers on the downstream magnet (MQ6). The angular alignment of the TDI with respect to the beam was also re-checked. This collimator is made of two 4.2 m long jaws; a small tilt results in a big offset between the up and downstream jaw extremities (100 μrad = 420 μm $\sim$1 σ offset). A bad angular setup could reduce the active length of the collimator and increase the risk of grazing. The TDI jaw tilts measured in point 2 and point 8 are presented in Table 1.

Table 1: The angular offsets measured for the TDI jaws in point 2 (both ALICE polarities) and 8. A positive angle corresponds to a diverging jaw, with respect to the beam, for the left side and to a converging jaw for the right side.

	Left [μrad]	**Right [μrad]**
IP2 ALICE polarity +	-70	-750
IP2 ALICE polarity -	+86	-1035
IP8	-190	-110

MKI Erratics

On July 28th two erratics happened at the main switch of the MKI-C (MSC) in point 2. In the first case the interlock system detected correctly the erratic and triggered the firing of the remaining kickers within 2 μs. Hence the kicker-C pulsed for 6.5 μs and the 3 other kickers for 4.5 μs emptying the Pulse Forming Network (PFN) of energy (see Fig. 1). No circulating beam was passing through the MKIs at the moment of the pulse. The kicker current was still at zero when a batch of 144 bunches was extracted from the SPS and ended up on the upper TDI jaw. Several soft-starts were repeated after this event to check the status of the system but no failure was observed and a new machine fill was started.

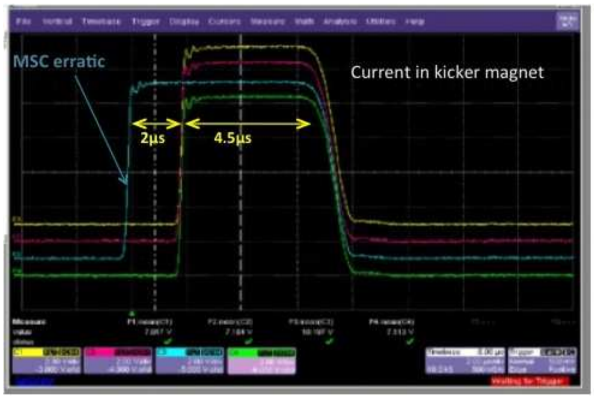

Figure 1: The current in the four injection kicker magnets following the first MSC erratic.

Less then two hours later, a new erratic occurred on the same MSC. This time the failure happened during the resonant charging. The erratic was not detected and the MKI-C pulsed for about 9 μs (17% of nominal injection kick, see Fig. 2). The extraction from the SPS was inhibited but the circulating beam was swept over the aperture and grazed the TDI lower jaw. The XPOC analysis showed that 173 bunches (2.15×10^{13} protons) were lost in the machine and not dumped. Three magnets quenched and ALICE suffered permanent effects in the silicon detector.

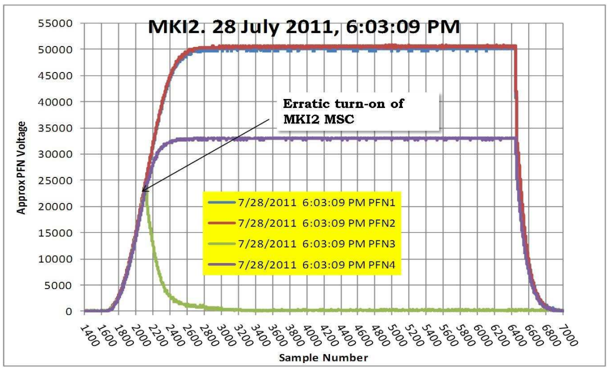

Figure 2: The current in the four injection kicker magnets following the second MSC erratic is presented.

The cause of the erratics was identified as the MSC thyratron itself which was replaced together with other damaged components. Diagnostics were improved and a faster detection system with a lower voltage threshold was implemented.

No similar events occurred after this intervention in 2011. However, erratics can occur up to several times per year. Moreover, the associated loss rate could be up to a factor 4 higher than observed in July (higher bunch intensity and number of bunches in conjunction with worse impact parameter at the TDI). These failures do not constitute a hazard for the machine itself, provided that the injection protection collimators are correctly set up, but can be risky for the experiments if not completely switched off during injection.

MKI Temperature Interlock

In order to insure the correct functioning of the MKI the ferrite temperature is indirectly monitored. The magnet inductance decreases when increasing the temperature above the ferrite Curie point of 130 °C (106 °C were measured, in the clean room, at the ground plates of the kicker); this results in a decrease in the ferrite permeability and, as a consequence, in the magnet strength. For this reason, a software interlock exists on the MKI temperature to forbid injection in case of excessive heating.

A direct measurement of the ferrite inductance could be obtained by quantifying the beam deviation from the nominal deflection. Indirect measurements can be performed during the soft-start. In particular one can measure either the MKI rise time or the delay; both decrease linearly with reducing magnet inductance (see simulation results in Fig. 3). At present the rise time method is used; new diagnostic will be installed, during the 2011/2012 Christmas Stop, allowing for more sensitive delay measurements.

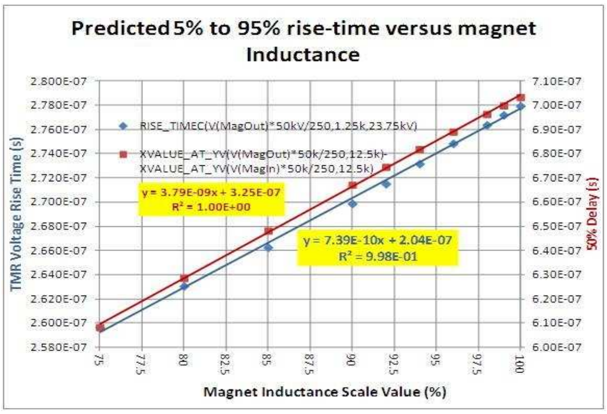

Figure 3: MKI Rise time and delay are plotted as a function of the ferrite magnet inductance (simulations results). These two quantities can be measured during the soft start and provide an indirect measurement of the kicker strength.

Results of rise time measurements performed on the four MKIs in point 8 are shown in Fig. 4. All the kickers present a slow linear reduction in rise time with the temperature; this effect seems to be mainly due to a capacitance reduction. A clear faster drop can be observed for the MKI-D starting at about 60 °C, indicating a change in the ferrite inductance. 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 will be deployed from the 2011/2012 Christmas stop.

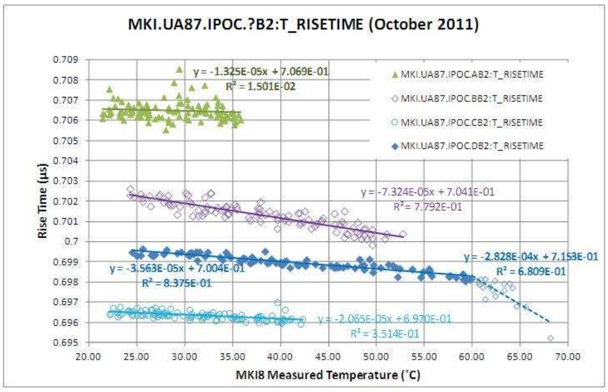

Figure 4: The rise time is measured as a function of the temperature of the 4 MKIs in IR8.

There is a long time-constant (∼10 hours) 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) at the MKI inducing several beam dumps at the beginning of the run [6].
- Problems with the kicker delay requiring dedicated adjustments when moving to the ion run.
- AGK window not correctly set up and consequent dump of the injected beam on the TDI upper jaw (32 bunches for Beam 1 and 72 for Beam 2)
- Vacuum pressure increase and heating at the TDI in points 2 and 8 during physics, when the jaws were set at ±22 mm. This was particularly problematic for ALICE due to the high background. A new parking position with the jaws at ±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 [7].
- Control problems for the TDI in point 2: settings different from measured positions and noisy LVDTs measuring a gap opening outside the limits. The interlock threshold had to be increased by 100 μm to avoid beam dumps.
- Wrong association between injection protection collimator settings and beam process during MD time.

XPOC AND IQC

The main problems with faulty XPOCs were related to missing data from various Beam Instrumentation (BI) equipment (BLM, BCT, BSRA). A new logic of BI data collection, directly into the PM system, will be applied and should solve this issue. A new BIS interface card had to be installed in the middle of 2011 to eliminate a delay in the BLM data acquisition which prevented operation in inject-and-dump mode.

At the beginning of the year several faults were triggered by wrong filling patterns and MKB waveforms. The first problem was mitigated with a new XPOC release, while the integration of filters allowed to reduce the noise on the waveforms. Stronger filters will be installed during the Christmas break to further attenuate the noise.

The XPOC acknowledgment logic proved to be safe and will not be changed for future operation. Faults in Context and BLM modules will be reset by the Engineer-in-Charge while all the other modules can be reset by the LBDS experts.

Missing data from MKI and BCT in the TL affected also the IQC analysis. Moreover, at two occasions the injection of 144 bunches was not recorded, both by the IQC and the injection sequencer, due to server communication problems.

Future upgrades are foreseen for the IQC and are mainly devoted to improve the interaction with the operators and simplify the beam steering in the TL. Clearer limits will be defined at the BPM in the lines and unambiguous warning loss levels will be specified, at the critical BLMs, depending on the number of bunches injected (i.e. losses at the MSI $\geq$ 5% when injecting 12 bunches: steering needed).

The software interlock that forbids the injection of more than 12 bunches in case of injection oscillation above limits was still maskable in 2011. The option of removing this mask is evaluated.

CONCLUSIONS

The performance of the LHC beam dump and injection system during 2011 run has been presented in detail with particular attention to the problems encountered, solutions applied and upgrades foreseen. Both systems, after some consolidations during the Christmas stop, will be ready for 2012 operation. An adequate amount of time, without and with beam, will have to be dedicated to properly test the new components (electronics, hardware, software, firmware, etc.) and setup the systems (collimators, references for steering, etc.).

The temperature and vacuum interlocks plus the use of the e-cloud solenoids should reduce the number of injection failures but some downtime has to be expected for cooling and reconditioning of the MKIs. Future injection failures have still to be envisaged but no major problems are expected, provided that the injection protection collimators are correctly set up and the experimental detectors are switched off during injection.

The improvement of the XPOC and IQC data collection plus the integration of clear references in the IQC will allow to improve the interaction with the operation, speed up and optimise the beam steering in the transfer lines and reduced the downtime.

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