

BEAM COMMISSIONING OF THE INJECTION PROTECTION SYSTEMS OF THE LHC

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Abstract

The movable LHC injection protection devices in the SPS-to-LHC transfer lines and downstream of the injection kicker in the LHC were commissioned with low-intensity beam. The different beam-based alignment measurements used to determine the beam centre and size are described, together with the results of measurements of the transverse beam distribution at large amplitude. The system was set up with beam to its nominal settings and the protection level against various failures was determined by measuring the transmission and transverse distribution into the LHC. Beam loss levels for regular operation were also extrapolated. The results are compared with the expected device settings and protection level, and the implications for LHC operation discussed.

INTRODUCTION

The LHC injection protection system in the transfer lines TI 2 and TI 8 consists of three movable collimators per plane (TCDI) to protect the LHC against missteered beam and large amplitude particles. A vertical dump in the injection region (TDI) absorbs the incoming beam in case of injection kicker failure or overinjection. Additional collimators (TCLI) complement the TDI protection against mis-kicked beam [1]. The protection settings are 4.5σ for the TCDI and 6.8σ for the TDI and TCLI collimators [2].

SET-UP OF INJECTION PROTECTION

TCDI Set-Up

As preparation of the set-up, the emittance in the TL was measured and the trajectory corrected. Interpolation from beam position monitors in YASP gave a rough estimate of the trajectory position at the TCDI. For the measurement of beam centre and size, both jaws are separately moved in half-sigma steps into the beam and the recorded beam loss monitor (BLM) signal is fitted with two single-sided error functions. The crossing defines the beam centre at the collimator while the error function fit gives a measure for the beam size assuming a gaussian beam shape. Figure 1 shows the scan of the vertical collimator TCDIV.29012 in the B1 transfer line (TI 2) with $5 \cdot 10^9$ protons. The data has been normalised to the intensity measurement of the SPS BCT (blue), however, this signal is tainted with too much noise and does not increase the accuracy of the scan measurement.

Since this set-up is very time consuming, as a first step

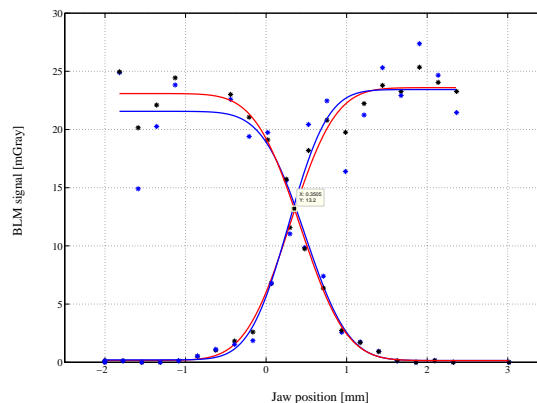


Figure 1: Scan of TCDIV.29012 in TI 2 with low intensity beam. The data in blue is normalised to the BCT intensity measurement. The measured centre is 0.35 mm and the 1σ beam size 0.63 mm.

only the beam centre was measured by moving the nominal collimator gap until reaching a minimum in the loss level. The collimators were set at 4.5σ nominal beam size about the measured centre.

TDI/TCLI Set-Up

The TDI and TCLI are set up with circulating beam. The primary collimators define the beam edge at 5.7σ which gives together with the nominal beam size an estimate at which distance the beam edge will be intercepted. Moving both jaws to the beam edge until a loss spike can be recorded allows to measure the beam position. The beam size is measured by a full beam scraping with one jaw (see Fig.2). Instead of measuring the beam size by a full beam scraping, the collimators can be retracted using the beam size given by the primary collimators around the measured beam centre.

VALIDATION OF PROTECTION LEVELS

Large Amplitude Particles

The performance of the injection protection system is strongly dependent on the transverse beam profile and the population of the beam tails in the transfer line. The transverse profile was measured by tail scans with the TCDI collimators. Figures 3 and 4 show the vertical and horizontal tail shape in TI 2 together with the jaw positions indicated by vertical lines. Earlier measurements show a significant

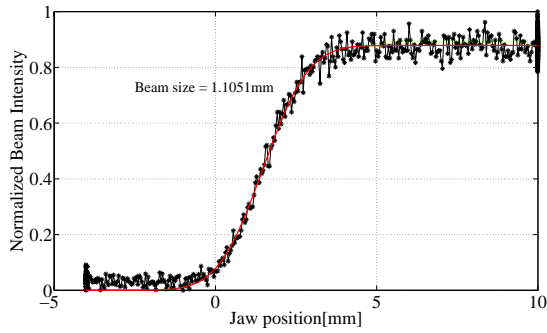


Figure 2: A full beam scraping with the B2 TDI to measure the beam size.

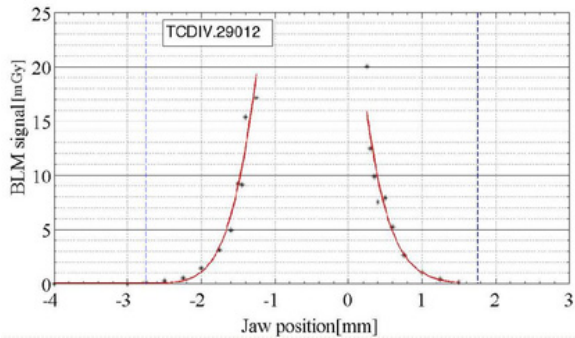


Figure 3: Scan of the vertical beam tail in TI 2 with a TCDI collimator. The vertical lines indicate the jaw position at protection settings.

non-gaussian shape of the beam tails in the horizontal plane which are intercepted by the collimators.

During first injections of low intensity beam, interception of these large amplitude particles at downstream TCDI collimators caused particle losses in the LHC only a factor 10 - 2 below the loss threshold for dumping the beam. Assuming the beam profile independent from the intensity, injection of a nominal SPS batch with a factor $6 \cdot 10^4$ higher number of particles would be a factor $1 - 6 \cdot 10^3$ above the threshold. The injection on 24 March 2010 of nominal

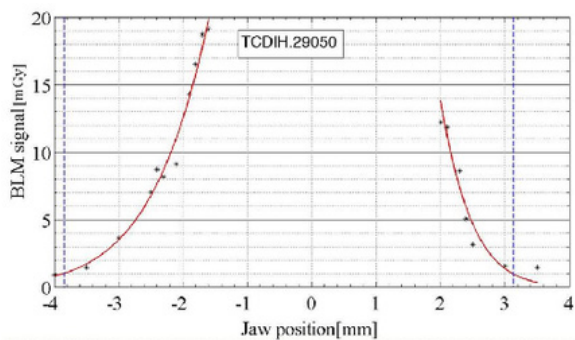


Figure 4: Scan of the horizontal beam tail in TI 2 with a TCDI collimator. The vertical lines indicate the jaw position at protection settings.

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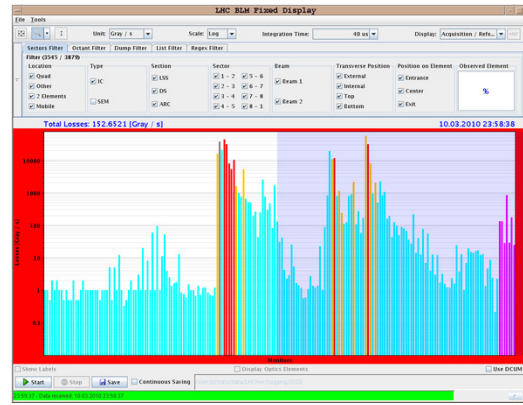


Figure 5: Losses in the injection region for B1 TDI grazing with MKI delay.

bunch intensity of $1 \cdot 10^{11}$ is much cleaner which is due to the beam quality delivered by the injectors.

MKI Failure

In case the injection kicker (MKI) is not firing, the injected bunch is absorbed by the upper jaw of the TDI. This case was studied in detail by changing the MKI kick delay and thereby letting the injected beam graze on the TDI. Figure 5 shows the losses in the injection area for B1 with an MKI delay of 80300 ns compared to nominal 88475 ns. Most of the beam is scraped on the TDI with losses on the TDI, TCT, TCLI and in arc 23. The second possible case for beam interception at the TDI is overinjecting a bunch onto a circulating pilot bunch which is needed for injected intensities above $1 \cdot 10^{10}$ protons per bunch.

For B2, the circulating bunch kicked onto the upper jaw of the TDI causes distinct losses on the BLM protecting the downstream element MQXA (see Fig. 6) which is not observed for beam grazing on the TDI nor injection without kicking the circulating bunch. These measurements indicate that radiation not from the inside but from the tunnel causes this signal. As a short term solution the BLM thresholds for these elements have been increased. Simulations including the detailed geometry of the injection region are starting to understand this loss pattern.

Injection Oscillations

Three TCDI collimators per plane are in place to intercept wrongly steered beam in the transfer lines. To validate their protection settings, trajectory oscillations with different phases are excited. The transmission and the transverse distribution into LHC are measured as a function of the oscillations amplitude. These measurements are time consuming and could not be completed yet. First injection tests with intensities above $1 \cdot 10^{10}$ triggered dumps due to crosstalk between TCDI losses and LHC BLMs upstream of the injection septum. The downstream TL collimators are in the same tunnel as the cold magnets upstream of the injection region and thus, showers from beam interaction

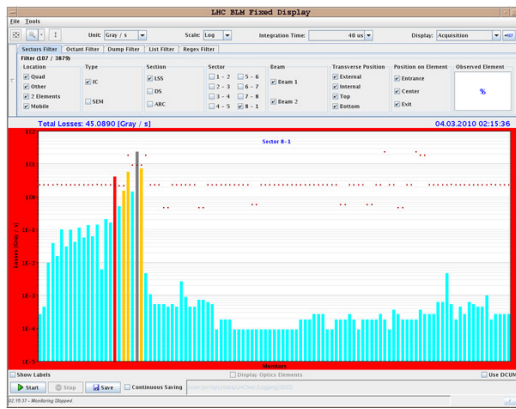


Figure 6: Overinjection losses with Q3 BLM signal over threshold.

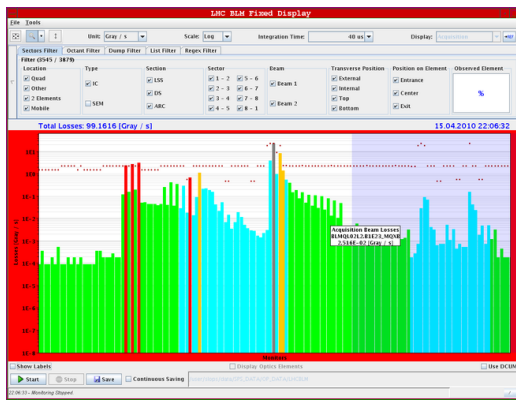


Figure 7: B1 injection of $4 \cdot 10^{10}$ protons. The losses caused by the TI 2 TCDI collimators were over threshold on Q8 and Q6.

with the TCDI are recorded by the external LHC BLMs while the internal ones are shielded by the cryostat. Figure 7 shows the losses measured in the LHC for a B1 injection of $4 \cdot 10^{10}$ protons. For B1, the downstream TCDI centres were carefully remeasured and injections of high intensity bunches with 4.5σ protection settings were carried out successfully. In order to allow B2 injections above $1 \cdot 10^{10}$ protons per bunch, the TCDI had to be opened from 4.5 to 5.5σ . Only the horizontal plane was affected which could be caused by a power converter ripple from the SPS extraction septum and by the differently populated beam tails in the horizontal and vertical plane [3]. After a quick solution to diminish the power converter ripple was in place, the stability of both TL trajectories was measured and reproduced for TI 2 while for TI 8 a clear improvement of the stability was found. Profiting from the stable TI 8 trajectory also B2 injections with nominal bunch intensities could be demonstrated.

IMPLICATIONS FOR OPERATION

Overinjection: One of the main findings for LHC operation from injection tests was the need to revise BLM

thresholds in the injection region. Overinjection caused systematically losses on the TDI over threshold for both beams, and the presently not understood losses on D1 and Q3 for B2. If the bunch intensity for the obligatory circulating bunch - in case of high intensity injection - is decreased below $5 \cdot 10^9$, the intensity measurement of the FBCT is lost and injection is inhibited. A trade-off between maximum allowable overinjection losses and a stable FBCT signal for low intensity beams has to be found. Presently, the concerned monitors were either equipped with additional capacitors and resistors to delay the signal or their thresholds were increased [4, 5]. Investigations on the unexplained loss peaks are ongoing.

High-Intensity Injection: Injection of higher intensity beams will be limited by losses on cold elements from TCDI collimators. As a long term solution, not triggering on these losses during injection might be necessary. Another prerequisite for injecting a full SPS batch of nominal bunch intensities is a fully operational SPS scraper for the LHC beam type in order to cut off large amplitude particles.

CONCLUSION

The TCDI collimators were centered and set to the nominal beam size protection settings. The TDI and TCLI were set up with respect to the primary collimators which proved to be a fast and reliable set-up procedure. The protection settings were validated for MKI failure and large amplitude particles. The machine protection tests to validate the TCDI settings in case of missteered beam need to be completed. Highly populated beam tails in the horizontal plane for certain beam types, conservative setting of thresholds and trajectory instability were identified as issues. Short-term solutions were brought in place to allow the injection of single high-intensity bunches while studies are ongoing to enable injection of a full SPS batch. Finally, injection of single high-intensity bunches together with overinjection for both beams could be performed.

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