LHC INJECTION AND DUMP PROTECTION

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Abstract

The machine protection against fast failures including injection or dump kickers relies on fixed and movable devices. Results will be shown from the low-intensity beam commissioning of the moveable injection protection devices in the SPS to LHC transfer lines and downstream of the LHC injection kickers, and of the LHC dump protection elements in IR6. This paper is almost exclusively focussing on the issues arising during the 2009 commissioning. The implications of these results and a commissioning status report with the planning for 2010 will be addressed.

INTRODUCTION

The SPS to LHC transfer lines TI2 and TI8 are equipped with 7 and 6 collimators (TCDI), respectively, protecting the LHC elements from particle loss due to injection oscillations or large betatron amplitudes. The injection dump (TDI) absorbs losses caused by injection kicker failure or overinjection with downstream collimators (TCLI) to incerease the TDI phase space coverage.

The moveable dump protection collimators TCDQ (single jaw) and TCSG (double jaw) in Point 6 protect the downstream LHC ring elements against particle showers originating from asynchronous beam dumps.

TCDI AND TDI SET-UP

The following steps are foreseen to commission the injection protection devices:

1. The beam loss signal at the respective position is calibrated by dumping a full bunch on the jaws and comparing the signal to the bunch intensity.
2. To align the jaws symmetrically around the beam, the jaws are separately scanned through the beam. The resulting loss signal gives the beam center and size at the respective position.
3. Due to machine protection reasons the transfer line collimators are set to 4.5 σ and the passive injection protection elements to 6.8 σ beam size [1]

In order to test the protection settings, orbit kicks are introduced in the transfer lines at certain phases to verify that the collimators provide full phase space coverage. The TDI protection is checked by injecting without firing the injection kicker or firing the kicker with a circulating bunch in the kicker gap (overinjection).

In the 2009 commissioning phase, all TCDI collimators have been centered, but only at 4 out of 13 the beam size was measured. Several problems arose:

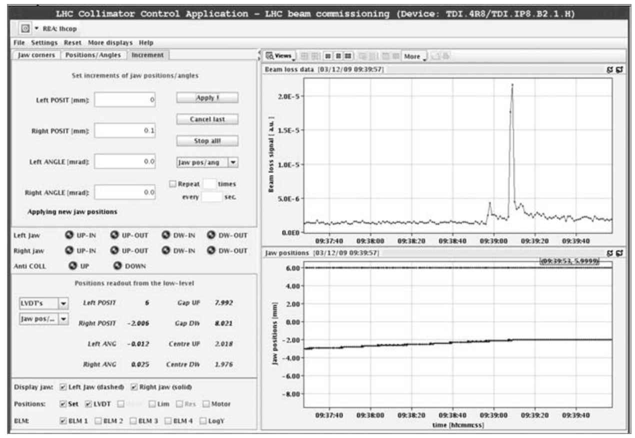

Figure 1: Misalignment of $\sim$ 2mm of the B2 injection dump (TDI).

- The normalization to the intensity is difficult because of a poor BCT resolution in the transfer line.
- The beam loss monitors with the fastest integration scale (40μs) saturate for low beam intensity.
- Particle showers from upstream collimators overlap and make beam size measurements more difficult due to saturation.

The TDI and TCLI were aligned without major problems. The beam edge was defined at 5.7σ by the collimation system. An asymetry of a few mm was found for B2, whereas the beam was well centered on adjacent BTV screens, (see Fig.1). A survey inspection states that the TDI tank is well in place. If the misalignment cannot be tracked down by further measurements, a tank opening is required to check the alignment of the jaws, however it is presently not foreseen.

The beam size was not measured at the TDI and TCLI, thus all elements were set to the theoretical σ values.

Injection of a pilot bunch with all protection devices in place results in ring losses close to the BLM interlock limit for the 40 μs integration time (see Fig.2 and Fig.3).

These loss levels are critical since the ratio of one nominal SPS batch to one pilot bunch is $6.4 \cdot 10^3$. Tail scans performed during the sector tests in the transfer lines show that the horizontal beam shape is rather exponential than gaussian and so the tails are significantly populated (see Fig.4).

Increasing the retraction of the horizontal TCDI collimators from 4.5 σ to 6 σ beam size gives a factor 2-3 loss reduction at injection. A far more efficient reduction of injection losses is reached by scraping the beam in the SPS.

Figure 2: Losses in the B1 injection area for a pilot bunch with $5 \cdot 10^9$ protons and transfer line collimators at nominal settings of 4.5 σ .

Figure 3: Losses in the B2 injection area for a pilot bunch with $5 \cdot 10^9$ protons and horizontal transfer line collimators at 6 σ (hor) and 4.5 σ (vert).

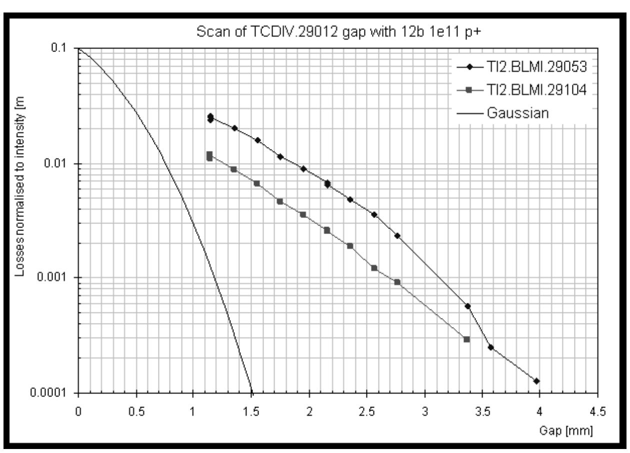

Figure 4: Tail scan in TI2 with 12 bunches of $1 \cdot 10^{11}$ protons showing extensive exponential tails.

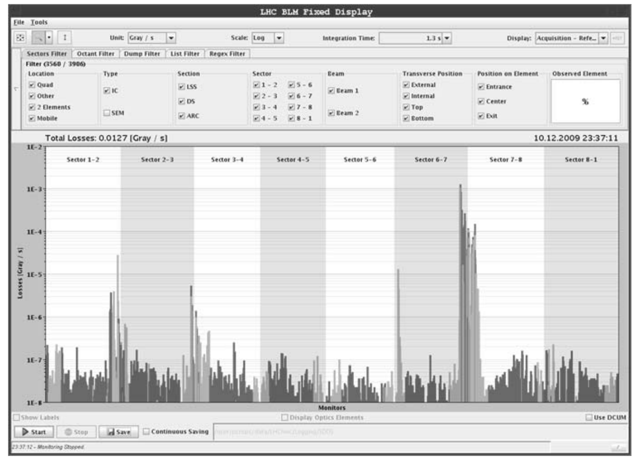

Figure 5: Losses in the LHC after B1 injection for a bunch intensity of $2 \cdot 10^{10}$ protons with SPS scraping and horizontal TCDI collimators at 6 instead of 4.5 σ .

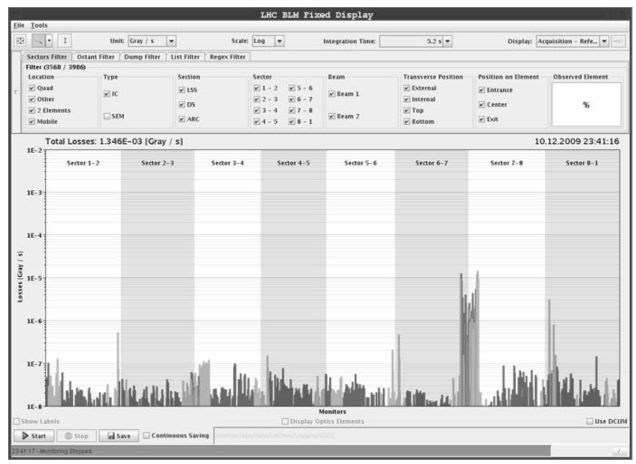

Figure 6: Losses in the LHC after B2 injection for a bunch intensity of $2 \cdot 10^{10}$ protons with SPS scraping and horizontal TCDI collimators at 6 instead of 4.5 σ .

Results for an injection of $2 \cdot 10^{10}$ protons with SPS scraping and 6 σ horizontal and 4.5 σ vertical TCDI settings are shown in Fig.5 and Fig.6. The injection is very clean for B2, while the B1 injection still needs to be improved.

These results indicate that scraping is necessary for injecting intensities up to nominal into LHC.

TCDQ/TCSG SET-UP

The commissioning steps for the TCDQ system comprise:

1. Orbit correction in Point 6.
2. Checking the software interlock on the beam position with respect to the TCDQ position.
3. Alignment of the collimator jaws.
4. Checking the TCDQ protection settings with asynchronous dump.

Figure 7: Losses on the dump protection devices TCDQ and TCSG for B1 (top) and B2 (bottom).

5. Calibration of the beam loss signal at the TCDQ.

6. Aperture measurments in the circulating and extraction channels.

7. Checking beam dilution on the dump block.

The measurement of the beam center at TCDQ/TCSG shows several problems:

- A movement sense inversion was solved by a mechanical inversion in the tank.
- The setting resolution of 0.1 mm is rather coarse and could be be improved.
- A position reading problem for the TCDQ was mechanically fixed to reduce the friction of the spring on the LVDT.
- There are regular problems with the transducer so a potentiometer is being considered to be used as position reading system.

The beam size was not measured at the TCDQ and TCSG and therefore a retraction to the theoretical beam σ was done. To check the system an asynchronous dump was performed for 4 bunches. The RF cavities had been switched off to let the beam debunch and thereby fill the abort gap. Fig.7 shows the losses for B1 and B2 on the TCDQ system. The losses are concentrated on the dump protection devices with 0.1% on the collimators which is in good agreement with expectations.

The sweep shape on the BTVDD shows the expected dilution on the dump block (see Fig.8).

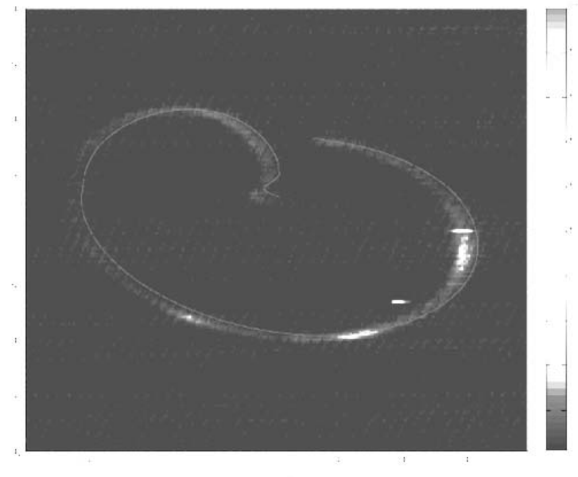

Figure 8: Sweep shape on the BTVDD during an asynchronous dump test with 4 bunches. The scale for the position in x and y is +/-200mm.

COMMISSIONING STATUS

The status of the beam commissioning in 2009 is shown in Table 1 and 2. All steps need to be repeated for the 2010 commissioning except for the measurement of the physical aperture in Point 6. S and O stand for re-commissioning after a shutdown or a change in the optics.

Table 1: Commissioning status of the injection protection.

Injection Protection	**2009**	**Repetition**
Calibration of BLMs	NOT DONE	S
TCDI centering	OK	S,O
TCDI beam size	NOT DONE	O
Check phase space coverage	NOT DONE	S,O
Check local MSI protection	NOT DONE	S,O
TDI/TCLI centering	OK	S,O
TDI/TCLI beam size	NOT DONE	O
Check MKI failure	OK	S,O

Table 2: Commissioning status of the dump protection.

Dump Protection	**2009**	**Repetition**
Correct orbit in Point 6	OK	S,O
Beam position SW interlock	OK	S,O
Set up TCDQ/TCS jaws	OK	S,O
Check of TCDQ protection	OK	S,O
Calibration of beam loss	NOT DONE	S
Aperture in P6	OK	S,O

PROBLEM SUMMARY

This paragraph gives a list of the problems that ocurred during 2009 commissioning with their possible solutions.

TCDI Set-up

Injection of pilot bunches with the TCDI collimators at their nominal protection retractions gives losses close to the interlock limit of the LHC BLMs for the fastest integration scale. Table 3 shows the ratio for measured losses at intensities of $5 \cdot 10^9$ and $1.6 \cdot 10^{10}$ protons while the ratios for nominal injected intensity (288 bunches with $1.15 \cdot 10^{11}$ protons each) were extrapolated. The extrapolated ratios show that in case of nominal intensities injected and without SPS scraping we expect losses three orders of magnitude higher than the interlock threshold.

Table 3: Ratio of BLM interlock threshold to losses.

TCDI setting	**BLM: threshold/losses B1/B2**		
	$5 \cdot 10^9$	$1.6 \cdot 10^{10}$	Nominal
4.5 σ hor/vert	10/20		$1 \cdot 10^{-3}/2 \cdot 10^{-3}$
6.0 σ hor/4.5 σ vert	30/60		$3 \cdot 10^{-3}/6 \cdot 10^{-3}$
6.0 σ hor/4.5 σ vert+ SPS scraping		$10^3/10^5$	$10^{-1}/10$

TDI Asymmetry

A 2 mm offset of the TDI in Point 8 needs to be understood, maybe a tank opening is required.

TCDQ

The TCDQ has a reading problem, probably the LVDT will be changed to a potentiometer. There is a misalignment of 7 mm for the B1 TCDQ which is being checked and seems to be understood. This needs rechecking.

Overinjection

Overinjecting B2 causes losses at one of the triplet quadrupoles in Point 8 (MQXA) which needs to be understood.

CONCLUSION

The issues which arose during the 2009 commissioning have been described. High loss levels in the LHC ring at injection, unexplained loss positions at overinjection and misalignments show that the systems are not ready for increased energy and intensity. The injection protection needs to be fully operational for a maximum intensity of $1 \cdot 10^{12}$ protons per injection. The TCDQ system should be tested for different β^* squeeze steps and needs to be operational for declaring stable beams. Both systems, injection and dump protection, need adequate setting-up time in 2010 to fulfill their requirements for higher energies and intensities.

REFERENCES

[1] V. Kain, B. Goddard, R. Schmidt and J. Wenninger, ”Protection Level during Extraction, Transfer and Injection into the LHC”, CERN-LHC-Project-Report-851, Aug 2005.