

LHC INJECTION AND TRANSFER LINES

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Abstract

The 2009 beam commissioning of the LHC injection and transfer lines will be reviewed. The measurements taken during 2009 will be discussed and compared with expectations. The presentation will cover the beam dynamics studies performed during the commissioning time. The overall performance of the systems will be summarised, with the emphasis on the problems encountered and the necessary improvements.

OUTCOMES FROM THE 2009 TRANSFER LINE OPTICS STUDIES

During the 2009 LHC beam commissioning, a series of transfer line measurements have been performed. These data taking campaigns and analysis were a logical continuation of the beam studies made in 2008 and described in [1-5]. Investigation on the beam trajectories, kick response and dispersion measurements have been carried out in parallel in order to arrive to a consistent model of the injection transfer lines.

Beam Instrumentation

Concerning the beam instrumentation, the main outcomes of the measurements were the following:

- The calibration of the BPM system was performed and the resulting correction is now included in all beam position readings. In this process, the kick response measurement data have been an essential cross-check tool as the finding from the data analysis agreed with the calibration results (work performed by Rhodri Jones and Kajetan Fuchsberger).
- Additional BPMs have been requested at the entrance of TI 2. Effectively from BPCK6105 to BPMIV20504, there is a region of about 200m lacking vertical beam position monitor and at a critical location in terms of aperture –chamber transition from SPS to TI standards. During aperture checks, it was deduced –no mean to directly measure it- that a π bump had been created at this location, reducing drastically the aperture. The bump was removed and the aperture indeed restored.
- During the 2008-2009 shutdown, all TI 8 BPMs have been upgraded into dual plane readings, allowing more robust dispersion measurements and facilitating their analysis. The same BPM improvements will be performed in TI 2 for the 2011 start-up.

Transfer line trajectory

Both the TI 2 and TI 8 trajectories were taken prior to corrections in the transfer lines –so called bare trajectory. The trajectory excursion was about 2 mm r.m.s. in both

planes, for both lines (Fig.1 for TI 8). Correction with 2 to 3 correctors allowed reducing it to about 1mm r.m.s. (Fig.2, for TI 8). These results were the outcome of careful trajectory studies, using bare trajectory and checking it with the model, before adding on correctors one by one and performing the same checks. It allowed finding errors in the affectation of the calibration curves to some of the SPS recuperated dipole magnets. In particular, TT60 MBE calibration curve was changed to the MBB one, leading to an immediate improvement of the vertical bare trajectory

Transfer line magnetic model

The extensive campaign of kick response measurements, analysed careful with the dispersion measurements, allowed performing major progress in the update of the transfer line magnetic model.

- The calibration curve of the main quadrupole magnets -MQI- was decreased by 6 per mil. The MQI are being measured by the CERN magnet group, TE/MSC, to confirm this beam measurements-based finding.
- Concerning the main bending magnets –MBI-, a sextupole component of about $-4.5e-4$ at a radius of 25mm has been confirmed by 2D calculation made by the magnet group colleagues. This sextupole component investigation was launched thanks to the idea of Stephane Fartoukh.
- Still for the MBI, a quadrupole component of about $1.35e-4$ at a radius of 25mm is believed to originate from a feed-down from the systematic horizontal offset performed on the MBI in order to accommodate for the large sagitta of these magnets [6-7].

The checks of this updated model were performed through kick response and dispersion measurements. The results show a clear improvement. The kick response measurements taken with the corresponding rematched optics (rectangular) is in very good agreement with the model (continuous line), Fig. 3 – 4, for the TI 8 vertical plane, before and after the optics rematching – Courtesy Kajetan Fuchsberger.

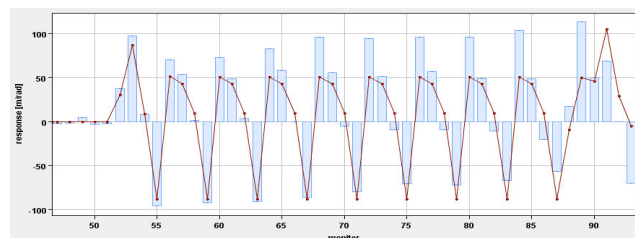


Figure 3: Kick response measurements before the optics rematching

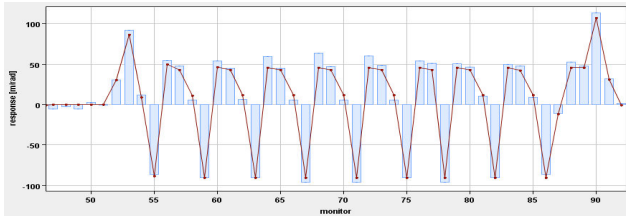


Figure 4: Kick response measurements after the optics rematching

The same excellent agreement is found for the dispersion measurements (Fig.5) and its derivative (Fig.6).

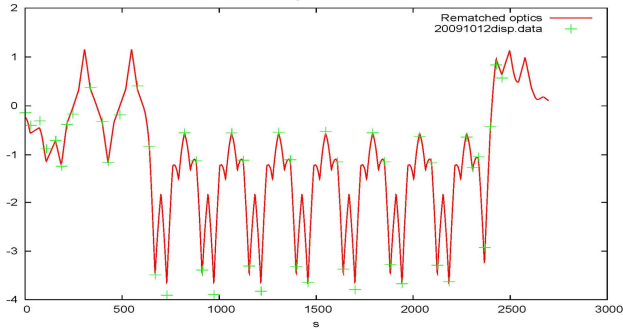


Figure 5: First order dispersion measurements (+) vs. model (continuous line), after the optics rematching.

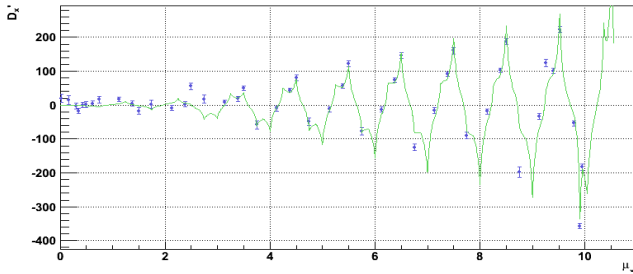


Figure 6: Second order dispersion measurements (+) vs. model (continuous line), after the optics rematching.

Aperture checks

An extensive campaign of aperture checks was performed. First, the momentum aperture of both lines was confirmed to be about +/- 0.4 %, in agreement with the model.

The physical aperture was explored in both lines, launching kicks of difference phases, at 30 degree intervals, using the on-line model and dedicated knobs (Fig.7, courtesy Brennan Goddard). At first, an aperture restriction was found between P8 MSI and Q5, which was solved after re-alignment of the vacuum chambers in this zone. In both planes, for both lines, the measured aperture is at least 10 times the nominal beam size (Fig.8 and Fig.9, courtesy Brennan Goddard). To be noted that some checks at certain phases are missing in the TI 2 transfer line in the horizontal plane, to be completed in 2010.

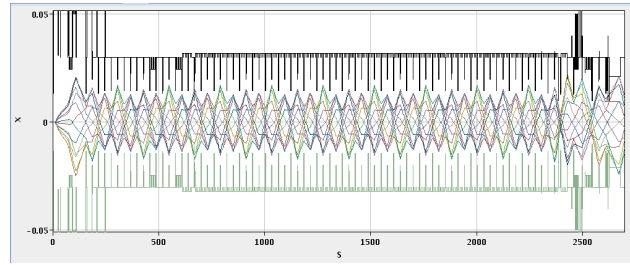


Figure 7: Aperture model from the SPS extraction to the LHC Injection channel.

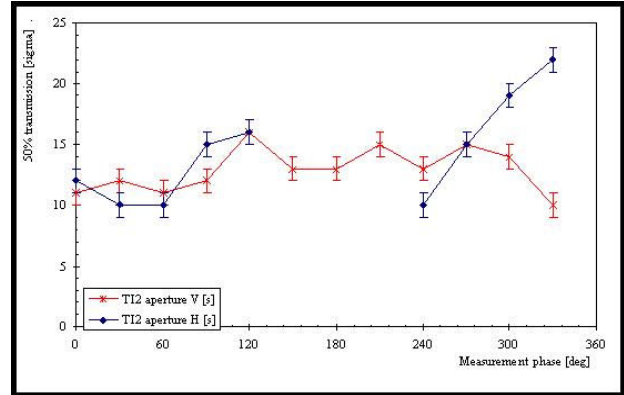


Figure 8: TI 2 aperture measurements results for different phases. Continuous line is vertical plane, interrupted line is horizontal plane.

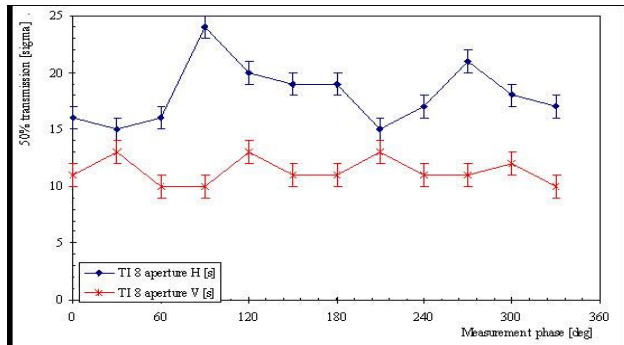


Figure 9: TI 8 aperture measurements results for different phases. Top line is horizontal plane, bottom is vertical.

OUTCOMES FROM THE 2009 INJECTION REGION STUDIES

Much injection checks and setting up work were performed through the LHC commissioning. The list includes injection steering, injection region aperture checks, kick response and dispersion measurements, MKI waveform measurements, TDI and TCLIA/B setting up around the orbit, LHCb beam condition monitor, set-up of TDIs to golden orbit, checks of losses on the TDI and IR8 for MKI off /overinjecting, tests of injection and matching

with crossing and separation bumps on, injection kicker timing in, injection of multiple bunches.

Concerning the TI 2 and TI 8 steering, the YASP steering application has been much improved by Jörg Wenninger. It now takes by default TI 2 + S23 and TI 8 + S78 selections of the steering display, as illustrated in Fig. 10, courtesy Jörg Wenninger. It will display the trajectory in the transfer line and the ring first turn to which the ring closed orbit has been deduced (thereafter, FT-CO), providing a direct measurement of the injection oscillation.

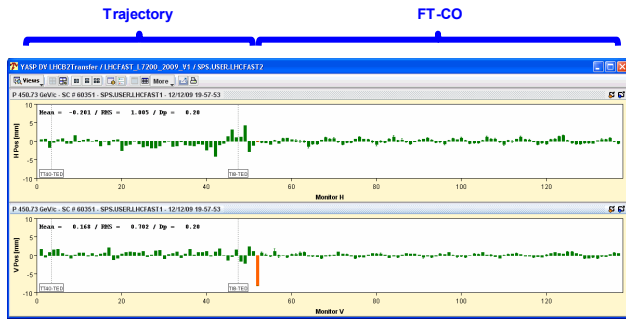


Figure 10: Steering application display showing the trajectory in the transfer line and the “first turn-closed orbit” in the LHC adjacent sector

The improvement made allows as well using the injection autopilot which performs automatic correction of the injection oscillations. This feature is manually activated and the present algorithm performs a fit of the betatron oscillation to the ring “FT-CO”, taking into account the dp/p error in the horizontal plane, then interpolate the fit to a virtual start point (position and angle) and finally if the position and angle are out of tolerance, a trajectory correction will be applied, using 2 correctors at the end of the line. 2010 experience with the beam operation will allow assessing the efficiency of this algorithm and if needed, change the algorithm to a global MICADO. In particular, when then transfer line collimator will be set-up, the trajectory at their location will have to be monitored carefully and should not be changed through automated steering, after the collimator setting-up.

Kick response measurements were performed as well by Kajetan Fuchsberger, this time taking also into account the response into the LHC ring. The comparison between the measurements and the model (continuous line with dots) shows an excellent agreement (Fig. 11 and Fig. 12, courtesy of Kajetan Fuchsberger).

Figure 11: Horizontal response from horizontal kick at the TI 8 start. Beam from the left.

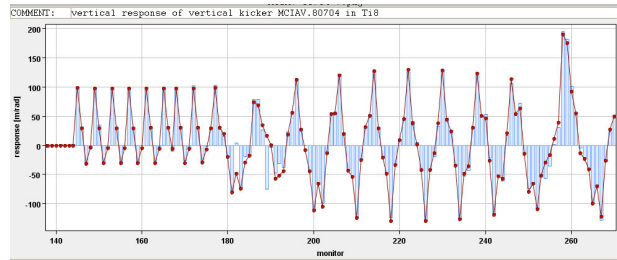


Figure 12: Vertical response from vertical kick at the TI 8 start. Beam from the left.

The LHC injection kicker (MKI) waveform was measured for both injection systems – Mike Barnes. The result is shown in Fig. 12 (courtesy Mike Barnes) and indicates a 2% overshoot at the start of the flat top with respect to the specification. This has been corrected for both systems.

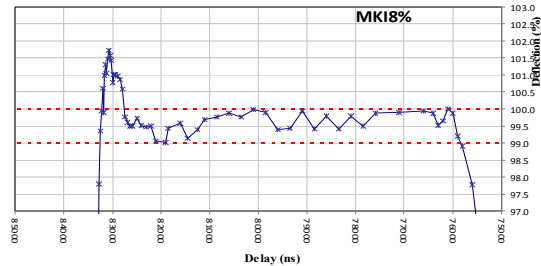
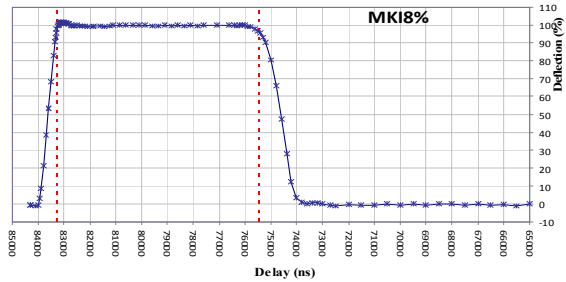


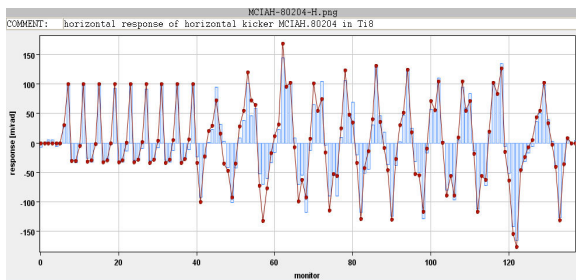
Figure 13: P8 MKI waveform and zoom on the overshoot at the start of the flat top.

The MKIs were carefully timed in for both beams, up to 4 bunch injection. In this process, the injected beam oscillations were carefully monitored and optimised.

Other studies, such as the protection setting-up of the injection and beam dump systems, are presented in these proceedings, by Jan Uythoven and Wolfgang Bartmann.

OUTLOOK

The transfer line and injection systems were thoroughly checked during 2009. Dedicated beam time allocated to the studies of the injection systems before the LHC restart were essential to update the transfer line model and build confidence into it. The robustness of the model has been established, the TI 2 and TI 8 beam line optics rematched and used in regular operation. Extensive



studies, including aperture checks, MKI waveform measurements, setting-up of protection systems have been performed and it is now of high importance that sufficient beam time is allocated to continue the setting-up of the

injection systems and prepare for higher intensities and energy.

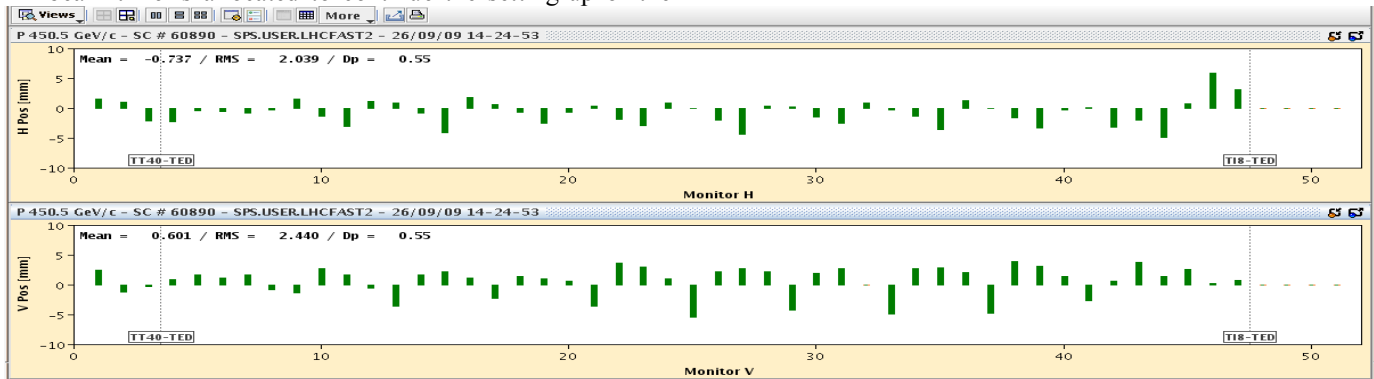


Figure 1: TT 40 and TI 8 bare Trajectory.

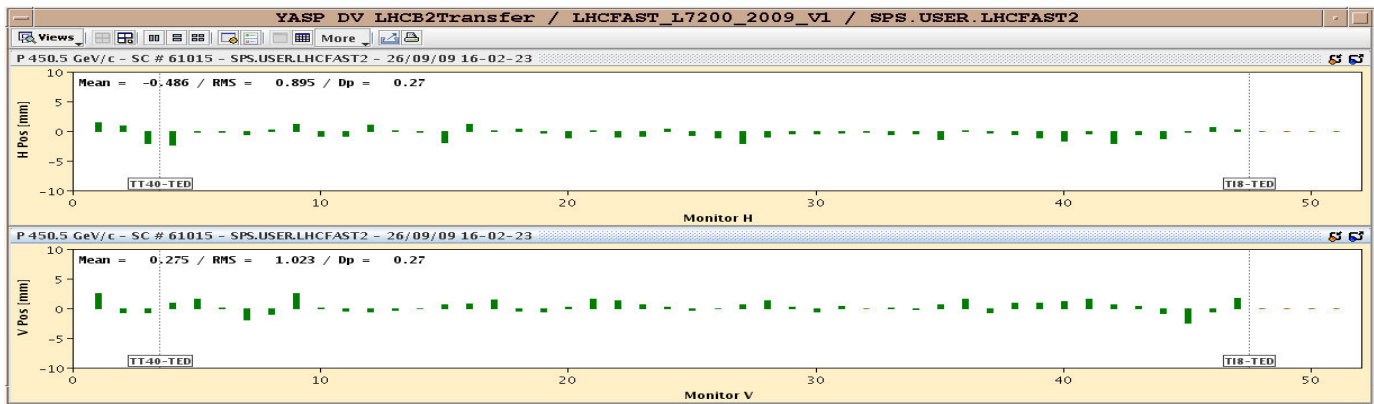


Figure 2: TT 40 and TI 8 corrected trajectory.

ACKNOWLEDGEMENT

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