BEAM COMMISSIONING OF THE SPS-TO-LHC TRANSFER LINE TI 2

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Abstract

The transfer line for the LHC Ring 1 was successfully commissioned with beam in the autumn of 2007. After extraction from the SPS accelerator and about 2.7 km of new transfer line, the beam arrived at the temporarily installed beam dump, about 50 m before the start of the LHC tunnel, without the need of any beam threading. This paper gives an overview of the hardware commissioning period and the actual beam tests carried out. It summarises the results of the beam test optics measurements and the performance of the installed hardware.

INTRODUCTION

The transfer lines between the CERN SPS and the LHC [1] are housed in new tunnels with a total length of 5.6 km (Fig. 1). The two lines comprise some 420 dipole magnets, 181 quadrupole magnets and 93 corrector magnets. The TI 8 transfer line carries beam from SPS Long Straight Section (LSS) 4 to the counter-clockwise LHC ring near Interaction Region (IR) 8. Installation of the full line up to a few metres before the LHC tunnel was completed in summer 2004. It was successfully commissioned in autumn 2004 [2], and tested again in May 2008 to be ready for LHC operation later this year.

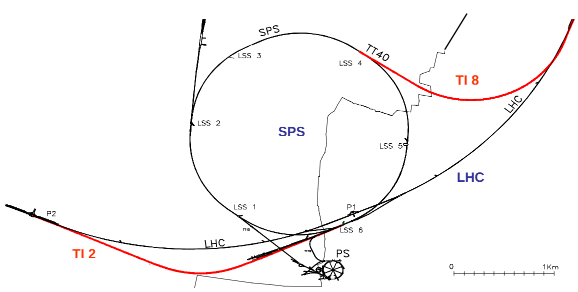

Figure 1: Layout of the LHC Transfer lines TI 2 and TI 8.

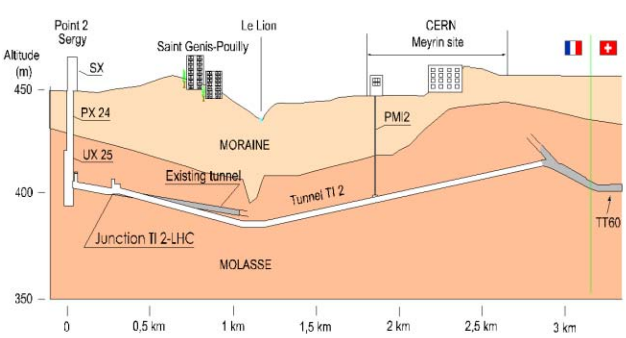

Figure 2: Vertical projection of the TI 2 transfer line.

TI 2 transports the beam from the SPS LSS6 to the clockwise LHC ring near IR 2. The new fast extraction from the SPS was commissioned in 2006 [3]. Although the depth of the extraction point of the SPS and the injection point in the LHC are very similar, a vertical dogleg was necessary to tunnel in the more stable 'molasse' rock material, see Fig. 2. This paper describes the hardware commissioning period, the conditions under which the beam tests took place and the results of the beam tests of this 2.7 km new transfer line.

HARDWARE COMMISSIONING

Hardware commissioning of the top part of the TI 2 line was already performed in the summer of 2005, shortly after installation of that part was finished. The main aim of this was to serve as test bed for the new LHC control system. One wrong polarity of a corrector magnet and three wrong maximum current values in the control system data base were found.

Most LHC magnets have been lowered down the PMI2 shaft (Fig. 2) and transported through the downstream part of the TI 2 tunnel into the LHC. For this reason, installation of the downstream part of the TI 2 line was only finished once all LHC magnets were in place.

The hardware commissioning of the complete line took place between July and September 2007. The polarities of the magnets were measured, the line was powered for 24 hours and tests were performed with the beam instrumentation and the control system. One of the main problems found was that many water connections of the water cooled cables supplying the main dipole chain were leaking and needed repair.

PREPARATION FOR THE BEAM TESTS

The first TI 2 beam test took place in October 2007. As at that time interconnection work on the LHC cryostats was still going on, the irradiation of equipment in the LHC tunnel had to be avoided. Simulations with the code FLUKA were made to estimate the dose rate behind the absorber block at the end of the TI 2 tunnel and in the adjacent LHC area [4]. It was concluded that a temporary iron beam absorber of two 160 x 80 x 80 cm iron blocks had to be installed about 50 m upstream of the normal absorber, where the wall between the TI 2 tunnel and the LHC tunnel was 3 m thick, see Fig. 3. This was complemented by a maze of three concrete walls to shield against stray radiation escaping the temporary dump. The calculated residual dose rates in the LHC tunnel after 1 hour of cool-down, assuming a total beam intensity of $5 \cdot 10^{13}$ protons, was smaller than 50 nSv/h.

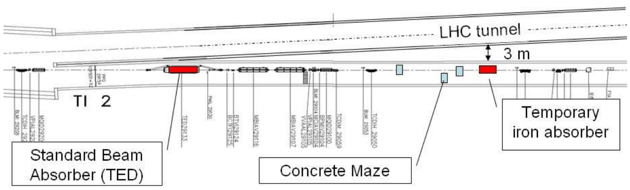

Figure 3: Temporary iron absorber and wall thickness between the two tunnels.

Other preparations included the tests of the LHC access system. For the TI 2 beam tests the access system around the LHC Point 2 was used for the first time in its nearly final configuration. Two octants and the Alice experiment in LHC point 2 needed to be searched and remained closed during the beam tests. Shielding was installed on top of the PMI2 access shaft.

BEAM TESTS

Intensity and Radiation

The first TI 2 beam test took place on 28 October 2007. A weekend was chosen to minimise the impact on the work in the LHC tunnel and the Alice experimental cavern. The tests started at 7:00. There were some initial delays due to a temperature interlock on one of the main vertical dipole magnet chains. This was solved by reducing the cycling rate of the magnets from the original one pulse per 8.4 s to on pulse per 12.6 s. This problem did not arise during the hardware commissioning, because these tests were performed at a slower repetition rate.

At 12:03 the first beam was sent down the line and went straight up to the end, without the need for any threading, like during the first test of TI 8 three years before [2]. The standard beam diagnostics at the end of the transfer line is situated just before the standard TED. For this reason this first beam tests could not profit from beam current measurements and beam screen images at the very end of the line. However, the beam position monitors along the complete transfer line, up to a few meters in front of the temporary dump, showed a signal with the first beam.

In the afternoon and over night a series of detailed measurement of the line were made. The beam was stopped at 5:00 the following morning. The beam intensity during the test at the top of the TI 2 line, as a function of time, is given in Fig. 4. The beam intensity per pulse was between $3{\cdot}10^9$ and $5{\cdot}10^9$ protons. The total intensity for the beam tests was $1.2{\cdot}10^{13}$ protons, which is well below the $5{\cdot}10^{13}$ protons assumed for the radiation calculations mentioned above. No remnant radiation in the LHC was measured after the beam tests.

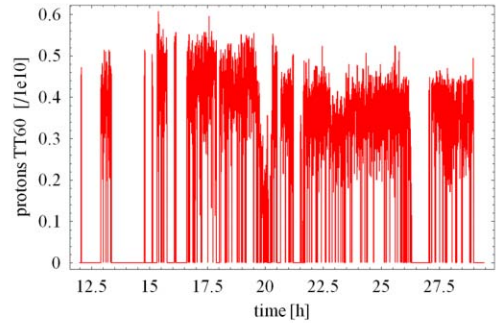

Figure 4: Measured beam intensity on the TT60 beam current transformer at the top of TI 2 line during the tests.

Trajectory and Optics

The trajectory was corrected to about 0.8 mm rms per plane, see Fig. 5. It shows some steering in the beginning of the line (called TT60) which is not yet fully understood. About a 0.15 % momentum offset between the line and the SPS was corrected. Two pairs of inverted corrector magnets were found by performing systematic 'kick – response' measurements.

The dispersion was measured in both planes by varying the energy of the beam. The measurements show a good agreement with the design parameters, with an error of about 10 cm at the end of the line in both planes, see Fig. 6. The 'kick – response' measurement and further off-line analysis allowed to check the phase advance between the different correctors and beam position monitors. Small quadrupole strength errors were derived from the data, with errors between 0.3 % and 0.8 %. This is a similar result as found for the TI 8 beam tests [2].

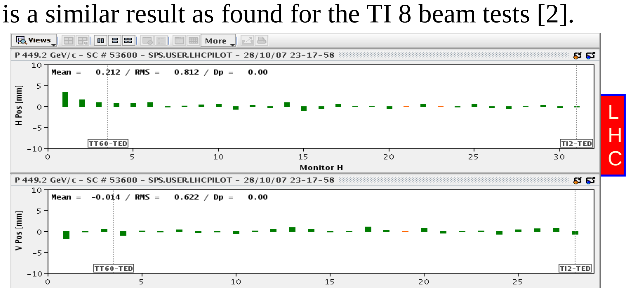

Figure 5: Horizontal and vertical trajectories after correction.

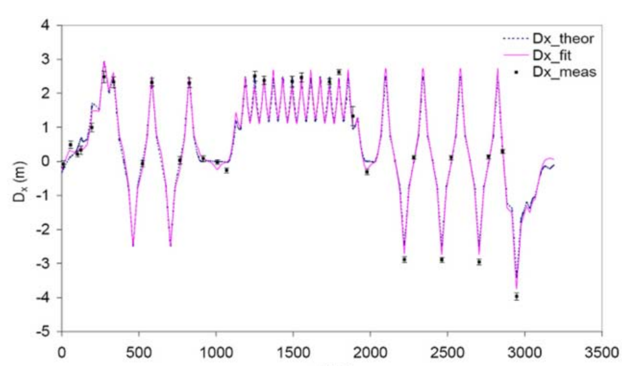

Figure 6: Comparison between measured and theoretical horizontal dispersion.

A series of beam size measurements during stable beam conditions have been used to determine the emittance, the energy spread and the Twiss parameters throughout the line, using a method of which the details are described in [6]. The images of nine BTVs equipped with OTR screens have been combined and averages are taken over the results from 15 pulses. The resulting fitted vertical beam sizes are shown in figure 7 and show a good agreement between expectation and measurement.

Apertures

The physical aperture of the line has been measured by applying oscillating bumps to the trajectory and studying the transmission of the line. This measurement was not very precise due to the missing beam current measurement at the end of the line, resulting in an estimated error of the measurements of up to a few σ. The theoretical aperture is about 9 σ, the measured apertures are about 8 σ, see Fig. 8 for the results in the horizontal plane. Due to some problem with the 'steering knobs' required to make the oscillating bumps at the beginning of the line, no measurements were made over the first 700 m of the transfer line.

It was also tried to measure the momentum aperture of the line, which was found to be very difficult. This was traced back to a bad chromaticity value of the SPS at the moment of extraction.

Collimator Operation

The collimators in the transfer line, intended to protect the LHC against mis-steered high intensity beam, were operated remotely for the first time. For some collimators noise on the position measurement was detected, induced by the pulsing of the transfer line magnets. The alignment with beam of the collimator in front of the temporary dump was done, but only little time was spent because the set-up was difficult without the beam current measurement at the end of the line.

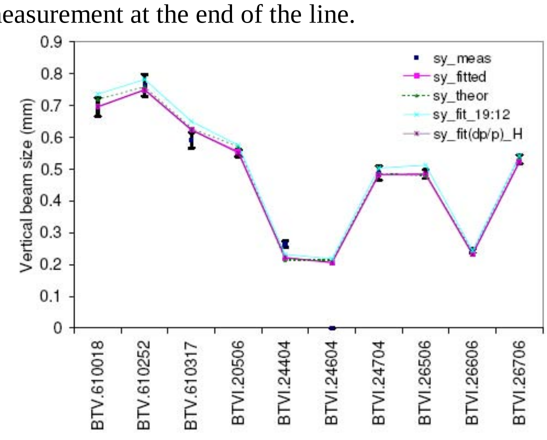

Figure 7: Fitted vertical beam sizes, from screen BTV images, compared with their theoretical values..

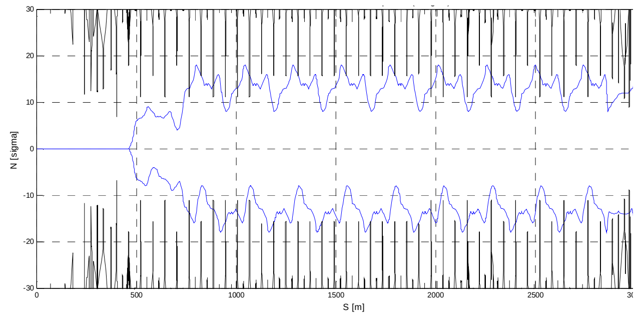

Figure 8: Measured (blue) and theoretical horizontal aperture throughout the TI 2 transfer line.

CONCLUSIONS

The LHC transfer line TI 2 has been successfully tested with beam in autumn 2007. A temporary absorber block was installed upstream of the standard beam absorber, to avoid any remnant radiation of equipment in the LHC tunnel. This resulted in limited diagnostics, as no beam current measurement and BTV screen were available at the temporary end of the line.

About 17 hours in total were spent on the beam measurements. No surprises in the optics were detected. A small difference in the effective quadrupole strengths, relative to their design value, of less than 1 %, was indicated by kick response measurements. This is similar to what was found during the TI 8 commissioning in 2004.

Many detailed measurements remain to be done in 2008 before LHC operation starts, including a detailed setting-up of the collimators, aperture measurements of the complete line, operation with multiple bunches and operation with higher beam intensities.

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