EXPERIENCE WITH THE TI 8 AND TT40 TESTS

J. Uythoven, CERN, Geneva, Switzerland

Abstract

The LHC transfer line TI 8 was commissioned with beam in autumn 2004. In the same period the LSS4 extraction channel and TT40 line were commissioned with high intensity beams. This talk outlines the tests performed and their conclusions regarding measured beam parameters, optics, beam instrumentation, control system and machine protection system. The important lessons on machine protection and operational procedures learned from a beam loss incident are summarised. An extrapolation of the experience obtained during both tests towards LHC commissioning is made.

INTRODUCTION

The transfer line TI 8 was commissioned with beam in autumn 2004. The layout of the transfer line, which connects the SPS point 4 to the LHC point 8 and details of the equipment installed can be found in [1, 2, 3]. The extraction from the SPS had already been commissioned in autumn 2003 [3] with the beams being stopped at the TT40 dump block, about 200 m downstream from the extraction kickers. On 23 October 2004 extraction onto this TED was repeated, and after moving out the dump block the beam travelled right away 2.5 km to the TED at the end of the transfer line, without the need of any trajectory correction, see Fig. 1. The beam tests with low intensity beams took place over two weekends, 23 – 25 October and 6 – 8 November 2004, and many detailed optics and stability measurements were made.

During separate MD sessions the extraction was commissioned with high intensity beams up to the TT40 TED. This part of transfer line will be used for both the LHC and CNGS beams [4]. No high intensity beams were taken beyond this TED to limit the radiation impact. Several experiments were performed on temporary 'targets' installed just upstream of the TT40 TED. Beams were taken down to this TED on 8 September, 23 September, 25 October (high intensity beams resulting in a vacuum leak) and 8 November 2004 (high intensity test with success).

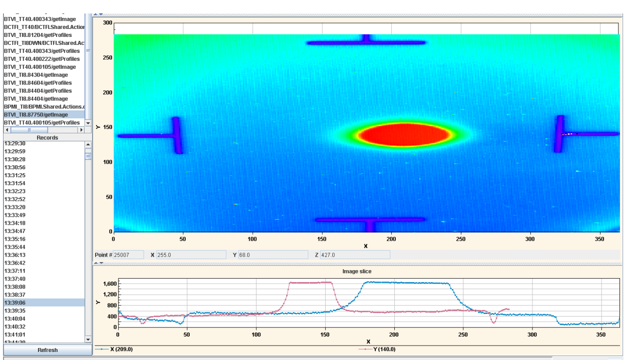

Figure 1: Screen image of the first beam which travelled down the TI 8 transfer line.

INTENSITIES AND INDUCED RADIATION

Table 1 summarises the integrated intensities for the different tests with beam. The intensities delivered on either the TT40 TED or the TI 8 TED are all well below the announced maximum intensity, for which dose calculations had been made. For the 23rd September it was decided to set-up the extraction safely, in case accidental extraction would take place.

For most of the TI 8 tests single pilot bunches were used, with an intensity around $5{\cdot}10^9$ protons, or single higher intensity bunches, around $3{\cdot}10^{10}$ protons, to improve the resolution of the beam diagnostics. The used intensities for the two weekends are shown in Fig. 2. It also shows that the highest intensities, for testing beam instrumentation with multiple bunches, were used towards the end of the second test period. This is explained by the unavailability of the injectors in the beginning of the second test weekend,

During the TI 8 tests the complete underground area of LHC point 8 was closed, including about 300 m in the LHC tunnel towards point 1 and about 600 m in the LHC tunnel towards point 7. Fig. 3 shows the additional shielding put in place behind the TI 8 beam dump together with the induced activity measured a few hours after the beams were stopped. The higher activity levels for the second test period, especially in the LHC tunnel opposite of the beam dump, result from the more intense beams used towards the end of the test period. An additional shielding was installed at this position in the LHC tunnel for several days which allowed passage without the need to carry a personal dosimeter. After both tests access was allowed to the LHCb cavern a few hours after the beams in TI 8 were stopped.

Table 1: Integrated proton intensities for the different tests.

Date	Test	Announced Σ I [p^+]	Produced Σ I [p^+]
8 Sept.	TT40	$3.0{\cdot}10^{15}$	$8.8{\cdot}10^{14}$
23 Sept	TT40	0	$6.7{\cdot}10^{13}$
23 - 25 Oct.	TI 8	$7.5{\cdot}10^{13}$	$3.4{\cdot}10^{13}$
25 Oct.	TT40	$5.0{\cdot}10^{15}$	$1.7{\cdot}10^{14}$
6 - 8 Nov.	TI 8	$7.5{\cdot}10^{13}$	$4.8{\cdot}10^{13}$
8 Nov.	TT40	$5.0{\cdot}10^{15}$	$1.0{\cdot}10^{15}$

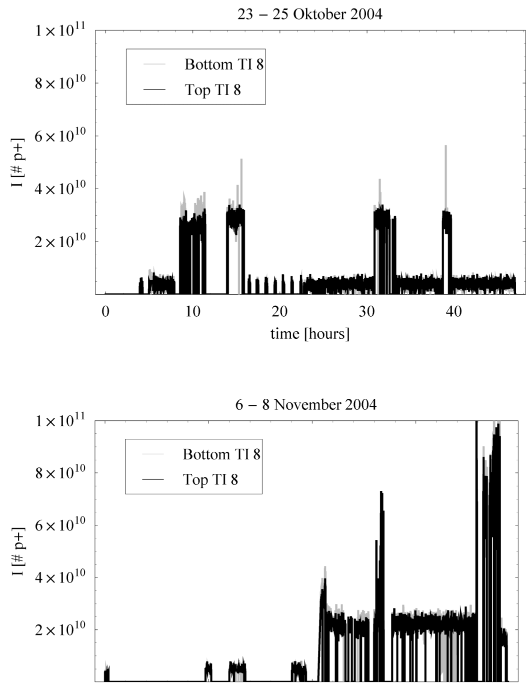

Figure 2: Intensities used for the TI 8 beam tests for the two test periods.

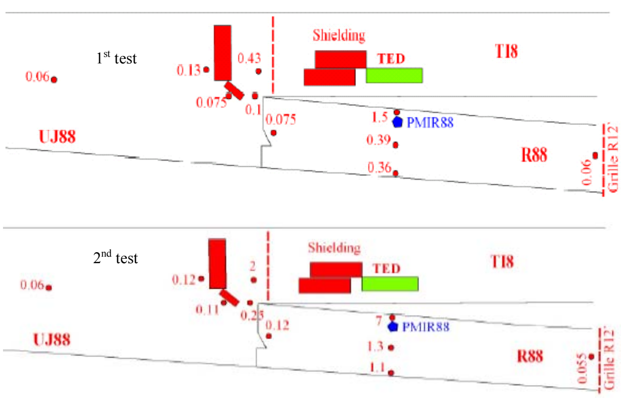

Figure 3: Additional shielding used during the TI 8 tests with the induced activity for the two test periods, given in µSv/h, measured straight after the end of the tests.

TI 8 BEAM TESTS

TI 8 optics measurements

The energy of the TI 8 line was set to 449.2 GeV, following the energy calibrations done with ions in 2003 [5, 6]. The measured energy acceptance, see Fig. 4, agrees very well with particle tracking results and confirms the theoretical acceptance.

The dispersion of TI 8 was measured during both test periods. The measurement during the first test weekend showed that 2 quadrupoles were set wrongly by about 20 % due to a wrong Imax setting in the database. This was corrected for the second test weekend; the results are shown in Fig. 5.

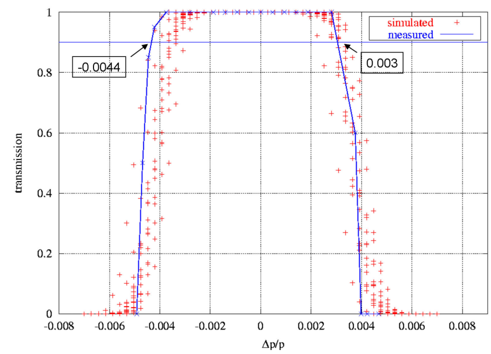

Figure 4: Measured transmission as a function of the relative energy off-set, compared with tracking simulations using a seed of 'realistic errors'.

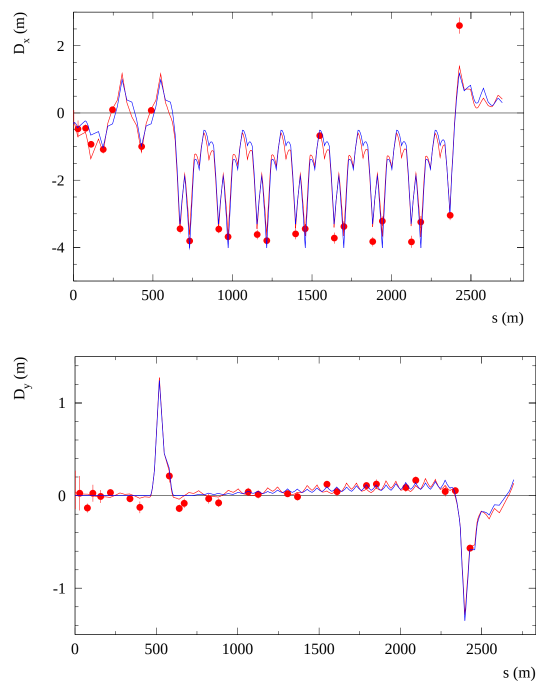

Figure 5: Dispersion measurements for both planes (dots) together with a fitted dispersion, compared with the theoretical function.

Many detailed optics measurements were made. The absolute values of the Twiss parameters, emittance and energy spread at the beginning of the line were determined by combining beam size measurements from different screens. An example of the resulting figure in phase space is given in Fig. 6. A relatively large spread was found between the results from different shots; work is ongoing to analyse the large amount of data available.

The beam stability was measured to be better than 100 µm. According to expectations the major contribution to this displacement comes from the ripple of the extraction septum power converter. This could be traced back by using Model Independent Analysis on the data of many trajectories. By displacing the timing of the extraction kicker magnets, an additional beam displacement could be identified.

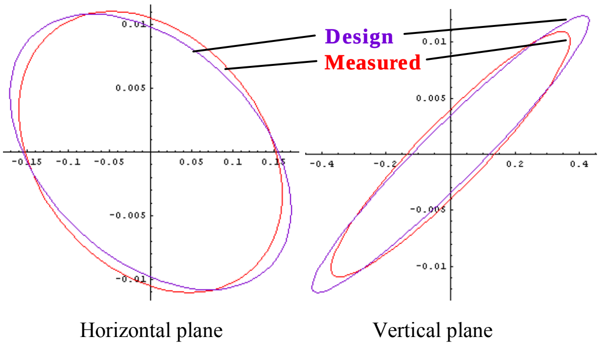

Figure 6: Beam profiles in horizontal and vertical phase space [mm, mrad] at the start of the TI 8 line.

The coupling between the two planes was found to be smaller than 2 % (amplitude coupling). The origin of this coupling was traced back to two suspect quadrupoles, but an alignment check of these elements did not confirm this.

The physical aperture of the line was checked by producing oscillating trajectories and measuring the transmission. The results were in good agreement with the aperture model of the transfer line.

A test of the collimator alignment procedure, by measuring the transmission, worked very well [7].

TI 8 tunnel temperatures

During the hardware commissioning period of TI 8 several temperatures were monitored during long periods of continuous cycling of the magnets (following the SPS cycle). The measurements, see Fig. 7, don't confirm the predicted significant temperature rise of the air in the tunnel after longer operational periods [8]. The measured maximum temperature rise of the air was about 3 degrees for both temperature probes. Only the temperature measured by the probe placed inside the concrete of the tunnel wall did not show an equilibrium. This is the only indication of a possible more significant temperature increase over very long running periods.

No strong correlation between the measured beam positions and the temperature of the magnets was found.

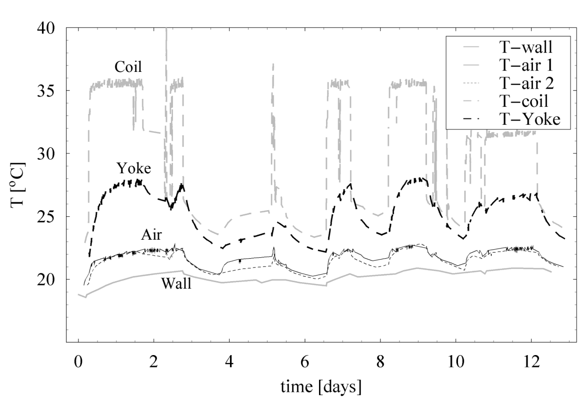

Figure 7: Measured temperatures in the TI 8 tunnel during the hardware commissioning period.

TI 8 Miscellaneous

The good functioning of the beam instrumentation and diagnostics allowed a correct assessment of the beam properties and largely contributed to the success of the TI 8 tests.

With the TI 8 tests the control system also passed an important milestone. Controlling the equipment and reading out the diagnostics worked well, using many applications and fixed displays which will also be used for the later LHC operation. The logging system and the retrieval applications played a crucial role in the beam test and showed a good performance.

The functionality of the Beam Interlock Controller was proven. In contrast to the 2003 extraction tests, no interlocks needed permanent masking during the tests.

Before the sector tests TI 8 will need re-commissioning, including the last 200 m of transfer line after the TED which is not yet installed. Ideally a number of MDs should be carried in 2006 which would allow to keep the TI 8 transfer line operational and even deepen the present understanding of its optics with more detailed measurements.

TT40 TESTS

Several tests took place with beams only up to the TT40 TED. The results of these tests are briefly described below.

The CNGS double batch extraction was commissioned successfully with 2 x 2100 bunches extracted 50 ms apart. It was confirmed that the transverse damper in the SPS can take care of the oscillations induced by the extraction kicker on the remaining bunches after the first extraction.

The LHC collimator robustness test showed that there was no damage on the collimator jaws after the impact of 4 x 72 nominal LHC bunches. This confirmed the go-ahead of the production of the LHC collimators.

The impact of 12 – 72 nominal bunches on a sandwich of different metals was studied. Holes were created in some of the plates, mostly according to expectation [9]. Detailed analysis remains to be done.

A sample CNGS target rod was also tested with beam intensities up 4 x 72 nominal LHC bunches. Beam induced vibrations and their damping times were studied. The damping times are below the 50 ms interval between two extractions. The measured temperatures on the rod agree with simulations.

TT40 incident

During the first high intensity TT40 beam test on 25 October a grazing beam of 4 x 72 nominal intensity LHC bunches created a vacuum leak in the QTRF 4002 vacuum chamber. The incident was caused by temperature sensors in the extraction septum magnet which picked up the beam signal. This signal was, via crosstalk, induced in the various interlock chains. As a first action the interlocks were disabled at the PLC which generated the interlocks. Because of the crosstalk within the PLC, interlocks were still created when the beam was bumped towards the septum, just before extraction took place. High intensity extraction continued under the assumption that the interlock system would protect the transfer line. However, this was not the case. Detailed analysis showed that the survey of the septum current, about 3 ms after the interlock generation, was still OK, but that the extraction actually took place about 8 ms after the interlock generation and at this moment the septum current has decayed by about 5 %. The trajectory calculation with this error in the septum current shows the critical aperture being the vacuum chamber of the QTRF 4002 quadrupole. FLUKA simulations for these beam conditions resulted in maximum temperatures close to the melting point of the stainless steel vacuum chamber (1400 °C) [9].

The high intensity tests were successfully repeated two weeks later. The preparation and the testing procedures were improved. The interlock system was also adapted: in case of a septum interlock, the septum PLC would send a signal directly to the Beam Interlock Controller which inhibits the extraction. Only after a delay of 10 ms the interlock signal would be sent to the septum power converter.

ORGANISATION

The tests confirmed the importance of thorough preparation, in a positive sense for the TI 8 tests and in a negative sense for the first TT40 test, where insufficient preparation contributed greatly to the incident. Equipment testing should start as soon as possible. Interlocks and software should be tested by early and many 'dry runs'. During all tests as many signals as possible should be logged. This gives information about what happened during the tests and simultaneously commissions the logging system. One needs the logging system at the beginning of the tests and not at the end. The need of having equipment tests under the responsibility of the Operations group, following the tests by the equipment groups and using the control room software, was proven.

The outcome also showed the necessity of formal acceptance tests of safety and other key elements, following predefined and stepwise commissioning procedures. These tests should be separated from the other tests and not take place in parallel. The result of these tests will then formally determine if the foreseen beam tests can take place or not. During the beam tests one person should be responsible for the go / no-go in critical situations. This person should be different from the person 'driving' the tests.

CONCLUSIONS

The TI 8 beam tests have confirmed the correct design and operation of the transfer line and one can expect a good working transfer line, ready for the sector test and LHC running, delivering a beam according to specifications. It was a positive surprise that the tunnel temperature did not increase by more than a few degrees even after several days of running.

The vacuum leak created by the beam during the first high intensity extraction tests in TT40 underlined once again the risk of the operation with high intensity beam. Improved procedures and design changes of the extraction septum interlock system were required and implemented. Further interlock modifications are outstanding. The functionality of the BIC system was confirmed. Both tests confirmed the importance of thorough preparation before beam commissioning.

ACKNOWLEDGEMENTS

The contributions of all colleagues involved in the design of the beam line and the equipment, in the equipment construction, installation, beam tests and data analysis are gratefully acknowledged.

REFERENCES

[1] http://proj-lti.web.cern.ch/proj-lti/.
[2] A. Spinks, "TI 8 Installation and Hardware Commissioning", Proceedings of the LHC Project Workshop, Chamonix XIII, 19 – 23 January 2004, p. 75.
[3] J. Uythoven, "TT40 Experience and TI 8 Beam Tests", Proceedings of the LHC Project Workshop, Chamonix XIII, 19 – 23 January 2004, p. 77.
[4] http://proj-cngs.web.cern.ch/proj-cngs/.
[5] J. Wenninger, "SPS Momentum Calibration and Stability in 2003", CERN-AB-Note-2003-091-OP
[6] G. Arduini et al, "Energy Calibration of the SPS at 450 GeV/c with Proton and Lead Ion Beams", CERN-AB-Note-2003-014-OP.
[7] V.Kain, "Safe Injection into the LHC", Second LHC Project Workshop, Chamonix XIV, 2005.
[8] C. Martel,"Air Handling of the LHC Tunnel and its Underground Areas", LHC-UA-ES-001 rev. 2.0, EDMS no. 344211, 3-10-2003.
[9] V.Kain, "Damage Levels: Comparison of Experiment and Simulation", Second LHC Project Workshop, Chamonix XIV, 2005.