

STATUS AND PLANS FOR THE SPS TO LHC BEAM TRANSFER LINES TI 2 AND TI 8

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Abstract

Beam transfer from the CERN Super Proton Synchrotron (SPS) to the Large Hadron Collider (LHC) will be done through the two transfer lines TI 2 and TI 8, presently under construction, with a combined length of about 5.6 km. The final layout, optics design and correction scheme for these lines will be presented. The requirement of simultaneously matching their geometry and optics with that of the LHC will be treated, including the methodology for alignment of the elements along the line and a proposed solution in the final matching section. After the commissioning of the short transfer line TT40 just upstream of TI 8 in 2003, beam tests of the whole of TI 8 are scheduled for autumn 2004, with the aim to validate many of the new features and mechanisms involved in the future control and operation of these lines. The status of the installation will be described, comprising the progress with infrastructure, services and line elements. An outlook will be given for the work remaining until 2007.

INTRODUCTION

Two new transfer lines, called TI 2 and TI 8, with a combined length of about 5.6 km are presently being built at CERN to bring 450 GeV proton beams and heavy ions from the SPS to the LHC. A schematic view of the overall situation is given in Fig. 1. As an overview of the geometrical layout, the optics and the main parameters has already been given in [1] the discussion in the following chapter will be limited to more recently added features and modifications.

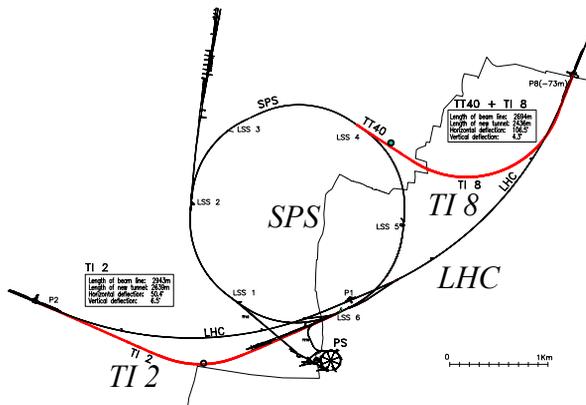


Figure 1: Schematic overall view of TI 2 and TI 8

RECENT DESIGN ISSUES

MAD-X use

Recently, MAD-X [2] has been adopted as tool for fur-

ther geometry and optics updates of the LHC transfer lines, offering several advantages such as the possibility of a fully integrated aperture model for ongoing studies related to clean injection and machine protection issues, and also the generation of the machine alignment (survey) data from a single sequence. The longer term goal is to derive the MAD-X description of the lines from the installation database as for the LHC main ring.

New SPS and LHC optics

Following an optics tuning in the SPS, the optics in TT40 and the beginning of TI 8 has been re-matched. The optics at the end of both lines has also been adjusted to match the latest LHC injection optics version 6.5.

Beam tilt issue

The tilt (roll) angle, which is created around the beam with respect to the reference frame by the combination of horizontal and vertical dipoles, has now been properly accounted for [3]. This effect had so far been neglected but accumulates over the whole of TI 8 to more than 50 mrad at the injection point (taking the tilt difference between the SPS and the LHC planes into account) and will, if not corrected, introduce mismatch. The resulting emittance dilution is only expected to be about 2 %, but entails also some repopulation of the beam halo. The potential consequences for the LHC collimation system, the requirements for the SPS scrapers and the question of whether additional skew quadrupoles should be installed are presently being studied for TI 8. Due to different geometries the effect is much less pronounced for TI 2.

To prevent betatron coupling between the planes and thus operational difficulties, like non-orthogonal trajectory measurement and correction, and also to help efficient and precise collimation in the lines (see below), all quadrupoles, correctors, beam position and profile monitors have been aligned with the locally accumulated beam tilt, which peaks at some 3.7° from the vertical at the end of TI 8.

Injection septa aperture and alignment issues

The latest error assumptions as well as final vacuum chamber dimensions have been analysed for the injection septum magnets MSI. To satisfy the aperture requirements for the circulating beams and the injected beam as well as the geometrical matching constraints, the septa will now be aligned in the LHC plane at some 13 mrad roll angle with respect to the initially assumed geometry. In TI 8 the resulting vertical trajectory angle difference of 160 μrad for the injected beam will be compensated for by an appropriate bump produced by the last vertical group of dipoles and 3 supplementary vertical correctors near the

septa. In TI 2 the effect is smaller and has been compensated by a bump over the last 1000 m with a maximum trajectory difference of about 20 mm. Here one small vertical steering magnet could be suppressed.

Re-optimised correction scheme

Considering the length and the relatively small apertures in TI 2 and TI 8 the performance, reliability and cost of the correction scheme have been optimised based on an in-depth study [4]. Subsequent considerations to ease a possible future upgrade of the position monitoring have led to a shift of every other vertical monitor and corrector by two cells, thus providing a more regular monitor coverage without increasing the amount of hardware presently needed [5], with the possibility to connect the monitors in the other plane if this should ever prove necessary. It has been checked that the new configuration also satisfies all previous performance criteria [6].

Transfer line collimators

To protect the LHC upstream of the cleaning insertions and the transfer line elements against consequences of equipment failures (like power supply trips just before the beam passes) or wrong settings it is proposed [7] to install a comprehensive system of 9 collimators per transfer line (one momentum collimator quite early in the line and one collimator in each plane at 0° and 90° phase advance to the injection septa; these will be complemented, for full LHC intensity, by collimators at 45° and 135°). All collimators should be adjustable and typically set to 5 σ to ensure good protection. The present design, in common with that of the LHC secondary collimators, foresees about 1 m long low-Z (carbon) jaws followed by fixed 50 cm long iron masks, with the main aim to dilute the beam sufficiently to prevent equipment damage. Appropriate locations have been identified, and final studies are ongoing.

STATUS

SPS LSS4 Extraction and TT40

The new fast extraction in the long straight section 4 of the SPS has been commissioned in autumn 2003 [8] as part of the upgrade programme of the SPS as injector for the LHC. Beam was sent over some 100 m onto a dump in the transfer line TT40, from which point it will eventually continue through TI 8 towards the LHC or the CNGS facility [9].

TI 8 installation

Installation of the general services infrastructure in the TI 8 tunnel (electricity, water cooling, ventilation, safety systems) was recently terminated. Between February and May 2004, some 370 magnets ranging in weight from 0.3 to 13 tonnes each were installed, using specially designed handling devices able to manoeuvre in the 3 m diameter tunnels. A photo from the installation period is shown in Fig. 2, showing the red main dipoles and the blue main

quadrupoles which have been, like the correctors and the vacuum system, manufactured and supplied by the Budker Institute for Nuclear Physics in Novosibirsk in the framework of the contribution of the Russian Federation to the LHC. The injection septa, to be installed later, have been built by the Institute for High Energy Physics at Protvino. The remaining beam line installation and other associated work will be completed in July.



Figure 2: TI 8 during magnet installation

TI 2 installation

Installation of the general services infrastructure in TI 2 is nearly completed.

PLANS

TI 8 commissioning and beam tests

After the end of the installation, two months are foreseen to thoroughly test the TI 8 beam line equipment, its powering system and new control system and interlock components. After a subsequent cold check-out phase of two weeks, two 48-hour periods are scheduled in October and November 2004 for beam commissioning. The primary objective is to transport a low intensity ($5 \cdot 10^{10}$ p) single bunch beam to the 22-tonne dump right at the end of TI 8, a few metres from the junction with the LHC tunnel, thus verifying the functionality and performance of the line hardware systems, and the associated software for equipment control and beam steering.

A mandatory prerequisite for this test is the well functioning of the access and interlocks systems. To avoid unnecessary irradiation of the LHC tunnel with regard to the ongoing installation (the affected area will of course be locked off during the tests) additional iron and concrete shielding will be placed behind the dump.

Once beam has been successfully steered to the end of the line, further studies are planned, such as the verification of the aperture and the optical characteristics, or the stability of the line with time. Extraction of some multi-bunch trains is also foreseen to test additional beam instrumentation and control system functionalities.

As the SPS will not be operated in 2005, this beam test offers a unique opportunity to verify a multitude of new components (readout electronics, application software, data logging for post-mortem analysis, new interlock controllers) on a large scale well before the LHC sector test.

LHC sector test

After the 2004 tests, the next use of TI 8 will be during the LHC sector test. The aim is, during two weeks in spring 2006, to send beam from the SPS, through TT40, down TI 8, and then to inject it into the anti-clockwise ring of the LHC right of IP8. From there the beam will continue through the LHCb experiment, through the arc 8-7 to a temporary dump right of IP7.

TI 2 installation

Installation of the TI 2 line is intimately linked to the general installation of the LHC machine, as all main LHC components will be lowered through the PMI2 shaft and then transported through TI 2 into the LHC. A longitudinal cut of the line is given in Fig. 3, showing, directly upstream of the PMI2 shaft, a 200 m long storage area for the LHC transport vehicles. This whole downstream part must be left exempt of beam line elements for space reasons, until the LHC components have passed through. The 300 m just adjacent to the SPS are inaccessible during machine operation for radiation reasons.

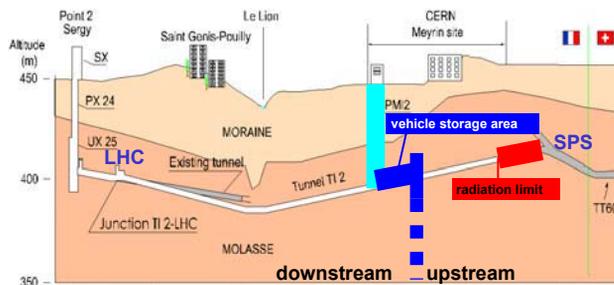


Figure 3: Schematic longitudinal profile of TI 2

Installation of the line elements in the presently accessible area upstream of PMI2 is about to start, to be followed by the part inside the radiation limit in the coming shutdown, as of November 2004. Installation in the upstream part must be finished before installation of the CNGS transfer line TT41 starts in July 2005, for reasons of manpower and common use of logistics and handling equipment. This part comprises 76 magnets (without correctors), 30 % of the TI 2 material.

The remaining part of the TI 2 beam line, extending over about 1.8 km, can only be installed as of summer 2006. Commissioning of TI 2 is foreseen in February and March 2007 [10]. Prior to this, the extraction system in SPS LSS6 needs to be modified [11], with commissioning planned for early 2006. More details on the line installation planning and its constraints are given in [12].

SUMMARY

Good progress has been made in the construction of the LHC transfer lines. The new extraction towards the anti-clockwise LHC ring has been commissioned with beam in late 2003, including the first 100 m of the transfer line. Installation of TI 8 is well underway to meet the beam test deadline in October 2004. This test will, for the first time, bring beam to the doorstep of the LHC. It constitutes not only an important milestone for the LHC project but also a crucial, large-scale test bed for many new systems and ingredients well before the LHC sector test. TI 2 installation is also on schedule, with beam line installation in the upstream part about to start.

ACKNOWLEDGEMENTS

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