BEAM AND CONTROLS REQUIREMENTS FOR TI 2 AND TI 8

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Abstract

The transfer of intense high-energy proton beams over large distances through relatively tight apertures, the need to preserve the small emittance and the safety requirements of the superconducting LHC put high demands on beam control and stability. After a brief overview of TI 2 and TI 8 as well beam physics requirements as controls related aspects are addressed.

1 OVERVIEW OF TI 2 AND TI 8

Two new transfer lines with a combined length of 5.6 km, TI 2 and TI 8, are being built to transport 450 GeV/c protons from SPS to LHC. An overview of these lines is given in [1]; however, a few remarks are in order here.

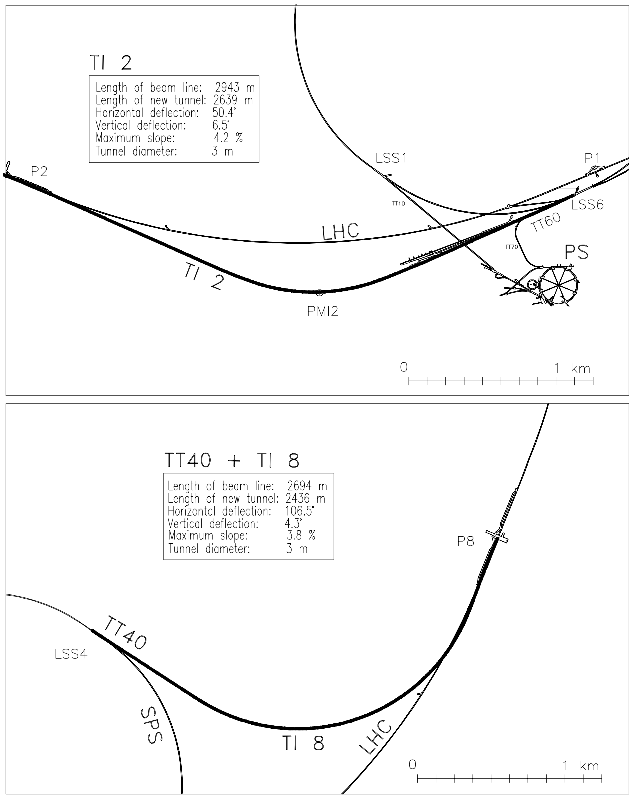

Figure 1: Layout of TI 2 (above) and TI 8 (below).

Figure 1 shows the geometrical layout. TI 2 re-uses the existing extraction facility in LSS6, branches off from the beam line TT60 and leads to the injection near LHC intersection 2. A new extraction facility will be built in LSS4 from where TI 8 will lead to LHC intersection 8. Both extractions will be of the fast type [2]. The first part of TI 8, called TT40, is intended to be in common with the possible future neutrino production line directed towards the Gran Sasso Laboratory [3, 4].

TI 2 and TI 8 will use in total over 700 room-temperature magnets of which 170 will be recuperated from then closed down installations. The 348 main dipoles (MBI, gap height 25 mm) and 178 main quadrupoles (MQI, inscribed diameter 32 mm) are being built by the Budker Institute for Nuclear Physics at Novosibirsk. Detailed information on the magnet system can be found in [5].

Both lines use a FODO structure with a half cell length of 30.3 m and 4 dipoles per half cell, resembling the SPS. An outline of the optics is given in [1].

Civil engineering for TI 2 and TI 8 has started in 1998 with the excavation of the access shafts PMI2 and PGC8. Series production of the MBI and MQI magnets is underway. The first use of the lines is foreseen for fall 2003 (TI 8) and mid 2005 (TI 2), respectively.

2 BEAM REQUIREMENTS

The successful and safe transfer of high energy, high intensity protons ($3*81$ bunches of $1.1*10^{11}$ p each [6] per SPS cycle) between SPS and LHC puts high demands on the stability of the extracted beams, the precise control of the beams over the length of the transfer lines and the safety and precision of the injection. The implications of these requirements will subsequently be discussed following the beams from source to destination.

2.1 Extraction

The required delivery precision of the beams on the LHC closed orbit is $\pm 1.5\ \sigma$, including all errors. The quality of the orbit control in the SPS and the stability of the extraction elements has to be such that the contribution from extraction imperfections stays well below this figure. If there are systematic effects (e.g. long-term drifts in trajectory and/or energy, intensity dependencies) they might be accounted for by a (preferentially automatic) follow-up of the transfer line steering. It is very desirable that such effects are at least negligible over the period of a filling process. Statistical effects (e.g. bunch-to-bunch jitter) cannot be corrected in the transfer lines, and must be dealt with by the LHC damper. It is suggested that measurements of the stability and the reproducibility of the extraction be made, under conditions which come as close as possible to the ones desired (LHC type beam, fast extracted).

2.2 *Transfer Lines*

The need to preserve the transverse emittance of 3.5 μm rad (nominal normalised) requires very good betatron and dispersion matching at both extremities of the lines. For this purpose, an appropriate number of independently powered quadrupoles at the beginning and the end of both lines is foreseen, providing also some flexibility to accommodate the evolution in the optics of both accelerators. Adequate beam instrumentation in the lines is required to measure the optical parameters with good precision and to adjust the matching if necessary.

The beam parameters dictate that the bunches stay absolutely within the available aperture to avoid severe damage. The strongest aperture constraint comes from the MBI where most of the money and the electrical power goes. From their physical vertical aperture of 20.4 mm follows a maximally tolerable trajectory excursion of ±4.5 mm [7]. With expected uncorrected excursions up to ±35 mm an economic solution for trajectory correction is therefore an important issue. Following an in-depth study [7] a correction scheme is proposed in which two out of every four successive short straight sections (per plane) are equipped with correctors ("2-in-4" scheme). To allow precise steering at the extremities of the lines and to account for more severe aperture constraints in the matching sections a full correction is foreseen in these areas. The position monitors (BPM) will used button-type electrodes to be recuperated from LEP.

To measure beam intensity it is currently foreseen to install beam current transformers (BCT) at the beginning and end of each line. A number of beam loss detectors (BLD) is planned at aperture bottlenecks. Beam profile monitors, most likely in form of OTR type screens (BTV), are intended to be installed at the beginning of the lines for profile measurement, at appropriate locations in the course of the lines for emittance measurement [8], and again for profile measurement in front of the beam stoppers (TED) at the end of each line, behind the injection septum (MSI), and in front of the injection beam absorber/diluter (TDI). The detailed specifications of the instrumentation are currently being worked out.

2.3 *Injection*

The small available aperture in the LHC and the fact that the LHC uses a large amount of superconducting elements put even more stringent requirements on beam stability and safety in the injection zones. The delivery precision of ±1.5 σ cited above includes also power supply ripple and ripple of the injection kickers. The foreseen full correction scheme and the beam instrumentation in these areas have already been mentioned.

Failures of the injection kickers should not result in machine damage for full batch intensity or quenches of superconducting elements for repetitive pilot bunches, respectively. To protect the LHC a mobile beam absorber/diluter (TDI) will be installed downstream of the injection kickers in front of the LHC D1 dipoles. Its exact positioning, its principle design and whether additional collimators and/or shielding are required are presently being investigated by the LHC Injection Working Group.

3 COMMISSIONING

Before discussing the controls requirements it might be useful to consider how the commissioning phase might look like (fall 2003 for TI 8).

The first phase will consist of getting the beam through the line up to the TED, by adjusting the central momentum and measuring and minimizing the trajectory excursions from one position monitor to the next (threading), initially with low intensity pulses ($5*10^9$ p) but with higher intensities possible as the results get better. Once the beam passes up to the measurement section the optical parameters, emittance and profiles can be measured and the extraction matching be improved. The availability of a pencil beam (even as single bunch) with a low momentum spread of a few 10^{-4} would be very useful (the monitoring system should be able to cope with this beam).

When the beam passes the whole line up to the TED the stability and reproducibility of the lines can be investigated. If temperature or power supplies drifts or intensity dependent effects are detected appropriate countermeasures could be implemented into the steering software.

The TED can then be moved out and the beam be let on up to the TDI, with the injection kicker still off. This permits to set up very precisely the injection elements by using the information from the beam instrumentation devices in this area.

After that the injection kickers can be put into operation and the beam be threaded through the existing part of the LHC. Orbit oscillations can be measured and minimised through orthogonal steering of the injection elements. When the orbit is better known, the TDI and potential collimator positions can be adjusted to get the optimum trade-off between machine aperture and protection. Afterwards the orbit behaviour of the LHC can be studied in more detail to learn how the later routine injection is performed best. It should be noted that the TDI and the potential injection collimators have to be retracted once the beam has been injected.

4 CONTROLS REQUIREMENTS

4.1 *General functions*

From the above discussion follows a number of main functional ingredients which a comprehensive software suite for LHC transfer and injection should place at the user's disposal. They are given below in form of a list, grouped according to activities (items already listed don't re-appear if needed for several activities).

A. Steering

- control equipment (switch, set, move, read status)
- measure and view trajectories,
- minimise trajectory excursions,
- adjust central momentum,
- store and load settings of "golden trajectories" (tracking of potential time-dependent effects should be built in),
- read and view beam current transformers,
- read and view beam loss detectors.

B. Matching

- measure and view beam profiles,
- measure β_n, D_n (change energy and measure trajectory),
- write to and read from MAD for re-matching.

C. Injection

- measure and track LHC orbit,
- measure LHC orbit oscillations,
- adjust TDI and injection collimators.

D. Sequencing

- move in TDI and injection collimators,
- send pilot pulse(s),
- measure LHC orbit oscillations (re-adjust injection setting and TDI/collimators if necessary),
- inject full batch,
- retract TDI and collimators,
- dump beam if injection is incomplete or otherwise unsatisfactory,
- change cycle rapidly between different clients (LHC injection, fixed target, NGS).

E. Surveillance, Post-mortem, Interlocks

- store and view equipment surveillance and post-mortem data,
- view interlock conditions.

It seems in general that automation will have to play an important role. The software must be easy to use. The users should be freed as much as possible from writing down numbers, cutting and pasting between application windows, typing complicated commands, etc.

It is presently assumed that the described functionality will be provided in the framework of the SPS2001 Software Project [9] which aims at a complete re-engineering of the SPS software.

4.2 Surveillance, Post-mortem, Interlocks

In view of the beam parameters and the LHC safety requirements the question of interlocks, equipment surveillance to anticipate performance degradation and the availability of appropriate post-mortem information to track down the reason of faults has to be taken very seriously and thus merit separate mentioning.

General equipment and environmental parameters like vacuum pressures, temperatures of water, air and magnets should be logged at an appropriate rate. Magnet temperatures have of course to act as interlocks on power supplies.

Parameters vital for the transfer performance and important status signals like power supply readings, injection kickers charging voltage, position of TDI and collimators, "LHC beam dump available", "LHC ready to receive beam", etc. must be checked immediately before the beam transfer takes place.

For each injection the key equipment and beam data have to be stored for offline performance monitoring or unambiguous reconstruction of fault histories; examples are power supply readings, injection kicker pulse shape, amplitude, and timing, bunch-wise beam positions, profiles, intensities, and losses.

If a fault is detected different measures have to be taken depending on the moment in the cycle. If the beam has not yet been extracted, the SPS extraction has to be disabled and the beam to be dumped in the SPS. If the error condition is detected after the extraction has been initiated but the injection process has not yet been started, the injection kicker has to be disabled and the beam deposited on the TDI (LHC injection inhibit). If a fault occurs during the injection process or if the injection kicker accidentally fires into already circulating bunches the safety of the LHC elements has to be ensured by the TDI and the injection collimators.

5 CONCLUSIONS

The transfer of protons from SPS to LHC and their injection into the LHC put high demands on beam precision and control. Good trajectory control is necessary in view of the relatively tight apertures. Perfect optical match is necessary to avoid emittance blow up.

A comprehensive and user-friendly suite of software tools is needed to make efficient use of the transfer lines, involving a high degree of automation. Well-thought and well-maintained interlocks are primordial to ensure a safe transfer to the LHC. Last, but not least, operational procedures should be applied in a rigorous manner.

ACKNOWLEDGEMENTS

The realisation of these lines is the collaborative effort of many people from various CERN Divisions and outside institutions. The author would like to thank them for the efficient and pleasant co-operation.

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