COLLIMATION IN THE TRANSFER LINES TO THE LHC

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Abstract

The intensities foreseen for injection into the LHC are over an order of magnitude above the expected damage levels. The TI 2 and TI 8 transfer lines between the SPS and LHC are each about 2.5 km long and comprise many magnet families. Despite planned power supply surveillance and interlocks, failure modes exist which could result in uncontrolled beam loss and serious transfer line or LHC equipment damage. We describe the collimation system in the transfer lines that has been designed to provide passive protection against damage at injection. Results of simulations to develop a conceptual design are presented. The optical and physical installation constraints are described, and the resulting element locations and expected system performance presented, in terms of the phase space coverage, local element temperature rises and the characteristics of the beam transmitted into the LHC.

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Abstract

The intensities foreseen for injection into the LHC are over an order of magnitude above the expected damage levels. The TI 2 and TI 8 transfer lines between the SPS and LHC are each about 2.5 km long and comprise many magnet families. Despite planned power supply surveillance and interlocks, failure modes exist which could result in uncontrolled beam loss and serious transfer line or LHC equipment damage. We describe the collimation system in the transfer lines that has been designed to provide passive protection against damage at injection. Results of simulations to develop a conceptual design are presented. The optical and physical installation constraints are described, and the resulting element locations and expected system performance, in terms of the phase space coverage, local element temperature rises and the characteristics of the beam transmitted into the LHC.

INTRODUCTION

Beams will be injected from the SPS into the LHC through the two transfer lines TI 2 and TI 8 [1]. The batches are extracted in 4/11 of an SPS turn or 7.86 $\mu$s. The transfer lines are pulsed and failures leading to local loss of the injected beam cannot completely be excluded. The damage level for fast losses is estimated to be around $2.3 \times 10^{12}$ protons [2]. Reference numbers are summarized in table 1.

<table>
<thead>
<tr>
<th>Table 1: Beam parameters for LHC injection.</th>
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<tr>
<td>Proton energy</td>
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<td>Normalized emittance</td>
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<tr>
<td>Nominal:</td>
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<td>Protons per injection</td>
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<td>Ultimate:</td>
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<td>Protons per injection</td>
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Collimation in the transfer lines should provide protection for nominal and ultimate beam intensities. This leads to the design goal for the transfer line collimators to provide a reduction in the peak energy deposition of at least a factor of $4.9 \times 10^{13} / 2.3 \times 10^{12} \approx 20$, to prevent damage by a mis-steered injected beam arriving at the LHC.

TRANSFER LINE COLLIMATION

The minimal available physical aperture of the LHC ring is estimated at about $7.5 \sigma$. It is planned to set the primary LHC collimators to $5.7 \sigma$ at injection and secondary collimators to $6.7 \sigma$. This reduces the tertiary halo of the circulating beams to below the quench level at physical apertures (on average about $10 \sigma$) [5]. However, wrongly injected beams could do damage before they even arrive at the collimation sections, requiring the use of transfer line collimators.

The transfer line collimators are considered as safety devices only. Their function is to reduce and dilute the beam intensity sufficiently in a single pass in case of (rare) failures. This requires two-sided collimators at several betatron phases. A setting of about $5 \sigma$ is foreseen, to allow for the expected beam position jitter and some mismatch [4]. Under good conditions, the beam should pass without noticeable loss, since regular beam-cleaning will be done by a set of scrapers in the SPS prior to extraction towards the LHC, where a ‘shaving’ to about $3.5 \sigma$ (corresponding to less than 0.05 % loss for Gaussian beams) is foreseen [3].

DESIGN AND APERTURE CONSIDERATIONS

The design has nine TCDI collimators in each of the transfer lines TI 2 and TI 8. One momentum collimator will limit energy offsets to a level of about $\pm 2 \times 10^{-3}$. Four vertical and four horizontal betatron collimators with flat jaws are arranged to provide complete phase space coverage, to limit the maximum amplitude of oscillation to about $5.4 \sigma$. Ideally, the collimators are located at 0, 45, 90 and 135° phase advance from the injection septum [6].

The maximum amplitudes apply only to one plane $(x, x')$ or $(y, y')$. Amplitudes up to a factor of $\sqrt{2}$ larger (or up to $7.65 \sigma$, larger than the LHC aperture) are in theory possible for coupled $x$ $y$ offsets; however, failures leading to such a situation are considered to be extremely unlikely.

Rotation and coupling effects have recently been studied [7]. Due to the geometry of the transfer line TI 8, a 53 mrad mismatch exists between the orientation of the injected beam and the circulating LHC beam, which can couple large $x$ and $y$ amplitudes into one or the other plane, leading to increased tails in the particle distribution. Scraping in the SPS will solve this, by removing particles with simultaneous large $x$ and $y$ amplitudes.

The optics functions and collimator positions in TI 8 are illustrated in Fig. 1 for betatron collimator section at the end of the line.

ENERGY DEPOSITION SIMULATIONS

Preliminary design studies have been completed and the system will be based on 1.2 m long movable carbon TCDI collimators, similar to the LHC secondary (TCS) collimators. These provide adequate dilution of the primary beam, with an attenuation of 13.5 and an emittance growth of about a factor of 100 per plane, resulting in an overall dilu-
tion efficiency factor of over 100 [8]. In order to protect local elements from shower and scattered particles, the TCDI must be followed by a 0.5 m Fe external shield (mask).

The detailed technical design studies are in progress for all transfer line collimators, to predict loss patterns and energy deposition in the event of worst-case failures. The 300 m downstream section of TI 8 was modelled in FLUKA, including all vacuum and magnetic elements, and energy deposition simulations made for full LHC ultimate beam with different impact parameters on the TCDI jaws. The modelling of the line geometry has been made with preprocessing scripts based on the MADX machine layout files, in such a way as to allow straightforward modification and reuse, and also extension to other problems. The magnetic fields in the dipole line elements were included.

An example of the geometry of a TCDI and adjacent mask and magnet is shown in Fig. 2. Full 3-dimensional energy deposition and temperature maps were produced for TCDIH315 and TCDIH225 as well as for the part of TI8 up to 30 m downstream of these collimators.

Fig. 3 shows the temperature profile for the 20 m downstream of the investigated TCDI for a $1\sigma$ impact on TCDIH315 and on TCDIH225. Note the higher temperatures obtained in the case of a $1\sigma$ impact on TCDIH225, due to the fact that the beam size is much smaller.

The energy deposition in the first MBI dipole magnet 15 m downstream of the collimator for a $1\sigma$ impact on TCDIH225 is shown in Fig. 5 and 6. The shadow effect of the mask (which has an elliptical opening) can be clearly seen in Fig. 5; the peak temperature rise in the MBI iron yoke is $175^\circ$.

For small impact parameters (in the order of $1\sigma$), a big fraction of the impacting beam is out-scattered from the jaw. The simulations showed that the adjacent magnet (quadrupole MQID87500 for TCDIH225) is sufficiently protected against the scattered and shower particles by the mask, see Fig. 4.

Especially for small impact parameters it turned out that the longer ($>5m$) the distance is between collimator and mask, with the mask close to the magnet, the better is the protection of the downstream magnet.

In case of larger impact parameters ($>5\sigma$) the sys-
CONCLUSION

The transfer line collimators (TCDI) provide passive protection against damage at injection into the LHC in case of failures. With a set of vertical and horizontal TCDI at 0, 90, 45 and 135° phase advance from the aperture bottleneck MSI, maximum amplitudes reaching the LHC can be restricted to 5-σ. The detailed mechanical design is in progress and is based on the TCS design. Simulations showed that a graphite jaw length of 1.2 m gives sufficient beam dilution to protect the LHC in case of failures before injection. For local protection of the line the system is completed with 0.5m long external Fe masks downstream of the collimators. An energy deposition simulation of the last 300 m of TI 8 has been set up. Preliminary results showed that the system TCDI-mask protects downstream elements from damage in failure cases; however, with the present layout, local heating is somewhat above design values.

REFERENCES