Abstract

The SPS at CERN currently uses a beam dumping system that is installed in the long straight section 1 (LSS1) of the SPS. This system consists of two beam stopper blocks for low and high energy beams, as well as two vertical and three horizontal kicker magnets, which deflect and dilute the beam on the dumps. Within the frame of the LHC injector upgrade project (LIU) the beam dumping system will be relocated to long straight section 5 (LSS5) and upgraded with an additional vertical kicker, new main switches and a single new beam dump, which covers the full energy range. The impact of a possible increase of the vertical kicker rise time on the beam has been studied in simulations with MAD-X for the different optics in the SPS. Furthermore, the impact on the beam in failure scenarios such as the non-firing of one kicker has been investigated. The results of these studies will be presented and discussed in this paper. Operational mitigation methods to deal with an increased rise time will also be discussed.

INTRODUCTION

The SPS presently uses an internal beam dumping system, which consists of two separate beam dump blocks for low and high energy beams installed in the long straight section 1 (LSS1, Fig. 1) [1]:

- TIDH, energy range 14 – 28.9 GeV
- TIDVG, energy range 102.2 – 450 GeV

There exists a forbidden zone for beam energies between 28.9 GeV and 102.2 GeV, where no programmed beam dump is possible. The deflection onto the dump blocks is performed with two vertical kicker magnets (MKDV). Three horizontal kicker magnets (MKDH) dilute the beam on the dump blocks to reduce the beam density on their front faces.

MKDV RISE TIME

The studies were performed using the present kicker waveforms, shown in Fig. 2, since the new waveforms are not yet available, scaled to the expected operational voltage. For the 3rd MKDV, which will be installed during the
upgrade, the same waveform has been assumed as for the first MKDV. The rise time is defined as the time needed by the field to increase from 2% to 100% of the nominal value, whereas the nominal value is the minimum field amplitude after the first overshoot.

**TRACKING SIMULATIONS**

MAD-X tracking simulations have been performed for LHC and fixed target (FT) beams at extraction energy with a granularity in time of 25 ns. This corresponds to 1 and 5 bunches per sample for LHC and FT beams, respectively. The most relevant beam parameters used for these simulations are listed in Table 1. For the LHC beam, the longest possible beam has been assumed, i.e. 80 bunch scheme, as this is the most critical for the TIDVG [6].

Table 1: Beam Parameters of LHC and Fixed Target Proton Beams

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LHC beam</th>
<th>Fixed Target beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optics</td>
<td>Q20</td>
<td>Q26</td>
</tr>
<tr>
<td>Injection energy</td>
<td>26 GeV</td>
<td>14 GeV</td>
</tr>
<tr>
<td>Extraction energy</td>
<td>450 GeV</td>
<td>400 GeV</td>
</tr>
<tr>
<td>Revolution time</td>
<td>23 µs</td>
<td>23 µs</td>
</tr>
<tr>
<td>N batches</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Batch spacing</td>
<td>0.2 µs</td>
<td>1 µs</td>
</tr>
<tr>
<td>Batch length</td>
<td>2.0 µs</td>
<td>10.5 µs</td>
</tr>
<tr>
<td>Bunches per batch</td>
<td>80</td>
<td>2100</td>
</tr>
<tr>
<td>Bunch intensity</td>
<td>1.3e11</td>
<td>1.07e10</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>25 ns</td>
<td>5 ns</td>
</tr>
</tbody>
</table>

During the tracking simulations, the longitudinal positions in the ring, where the particles are lost, are recorded together with their transverse coordinates, the turn in which they are lost and the kicker field they experienced. For an LHC beam entirely dumped on the TIDVG front face when all kickers are firing, the transverse coordinates of the lost particles on the TIDVG are shown in Fig. 3, with their temporal position within the beam color-coded. The beam hits the dump block as expected by design and the minimal distance of a particle from the aperture of the circulating beam, indicated by a rectangle, is 19.3 mm.

Figure 4 shows the kick strength seen by the LHC beam in relation to the total kicker waveform. It is obvious that the beam fills only a relatively small part of the flat top and an increase of the rise time should be therefore not at all an issue for this kind of beam.

Figure 5 shows as an example the simulation results of a FT beam shifted backwards by 0.4 µs. This beam is fully

![Figure 3: Protons of the LHC beam lost on the TIDVG front surface as a function of time within the beam (color-coded), when all kickers are firing. Rectangle indicates aperture for circulating beam.](image1)

![Figure 4: Kick strength seen by the tracked protons of the LHC beam (red) when all kicker firing. Kicker waveform (blue) for comparison.](image2)

![Figure 5: FT beam lost on the TIDVG front surface, when all kickers are firing.](image3)
Figure 6: Kick strength seen by the FT beam in relation to the total kicker waveform.

dumped on the TIDVG. The temporal relation between the beam and the kicker waveform should be approximately the same for injection energy, since the change in the revolution time is low (50 ns). Therefore, an increase of the rise time by 0.4 µs seems feasible.

Figure 7: Kick strength seen by the FT beam shifted backwards by 0.4 µs in relation to the kicker waveform.

FAILURE SCENARIOS

The failure of one out of three MKDVs is considered as a realistic scenario and has been studied for the shifted FT beam. The failure of the first MKDV is the worst case, since its phase with respect to the TIDVG is closer to 90° than for the other kickers. Figure 8 shows the coordinates of the particles lost on the dump block. The beam is still fully dumped on the TIDVG and the minimum distance from the circulating beam aperture is with 10.4 mm sufficiently large. Similar results have been obtained for the unshifted beam and LHC beam. In case of failure of two MKDVs the beam does not fully hit the beam dump. However, this is not considered a probable scenario.

Furthermore, asynchronous beam dumps have been simulated as failure scenario. In this case, 100 particles per sample have been used compared to 5 particles per sample for the other simulations. In case of a fully asynchronous dump at flat top energy the FT beam is still dumped on the TIDVG without losses elsewhere, however 5% of the beam

only in the second turn (Fig. 9). For the LHC beam, the result is similar; however, 0.26% of the beam are lost elsewhere in the machine and 14.4% only in the 2nd turn on the TIDVG.

Figure 8: FT beam with timing shifted backward by 0.4 µs dumped on TIDVG. 1st MKDV fails.

Figure 9: FT beam completely lost during a fully asynchronous beam dump on TIDVG in 2 turns.

OPERATIONAL MITIGATION METHODS

The impact of an increased rise time onto the beam can be also mitigated by operational means. Presently the FT beam consists of two 10.5 µs long batches with 1 µs gaps between the batches. To accommodate the increased rise time in one of the gaps an uneven batch spacing of e.g. 1.3 µs and 0.7 µs can be chosen and the rise time synchronized with the 1.3 µs gap. This method has been successfully tested with beam at the SPS in 2017.

CONCLUSION AND OUTLOOK

The tracking studies performed so far indicate that an increase of the MKDV rise time by 0.4 µs might be feasible. More simulations are planned, for example at injection energy and for the new Q22 optics for the LHC beam [7]. Operational mitigation methods could be a fall-back solution in case of unforeseen problems.
REFERENCES


