BEAM SIMULATION STUDIES FOR THE UPGRADE OF THE SPS BEAM DUMPING SYSTEM

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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.
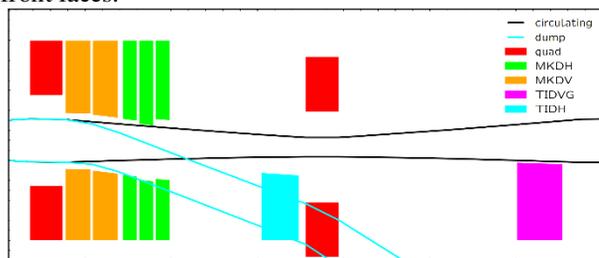

Figure 1: Layout of the present SPS beam dumping system (Figure courtesy of F. M. Velotti).

The present SPS beam dumping system (SBDS) has several limitations and issues [1, 2]:

- Incompatibility of upgrading present TIDVG for High-Luminosity LHC (HL-LHC) beam parameters;
- Production of high air activation;

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- High activation of the narrow area around the TIDVG without the possibility of full shielding;
- Interference with SPS injection system, which is also located in LSS1;
- The above mentioned forbidden energy zone;
- MKDV magnet reliability issues at high energy.

These limitations will be addressed in an upgrade of the SBDS [2, 3] in the frame of the LHC injector upgrade project (LIU) [4], which aims for upgrading the LHC injector chain to enable the production of high-brightness beams required for the HL-LHC era. For the LIU SBDS upgrade, the following changes are planned [2]:

- The relocation of the SBDS from LSS1 to LSS5. This will solve the interferences with the injection system;
- Replacing the two separate beam dump blocks by one newly designed for the entire energy range;
- Installation of an additional MKDV magnet with the full system operated with reduced voltage to decrease the risk of high-voltage breakdowns;
- Upgrade of MKDV main generators with new solid state switches;
- A new dump external shielding to reduce the surrounding dose.

The upgrade of the generators is currently under development and it is not clear if the present MKDV rise time of 1.1 µs can be preserved with the new system. A slight increase of the rise time to 1.3 µs might be necessary. To study the impact of the increased rise time on the beam, tracking simulations were performed using MAD-X [5].

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
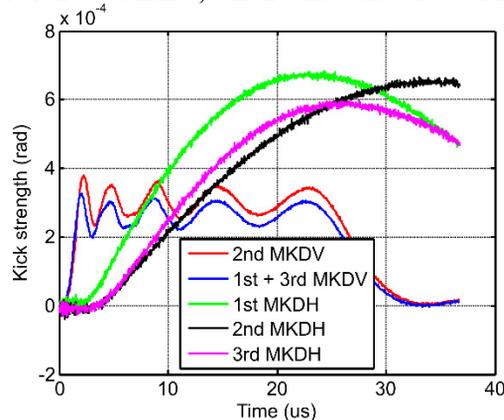

Figure 2: Waveforms of the vertical (MKDV) and horizontal kickers (MKDH) used for the simulation.

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

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

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
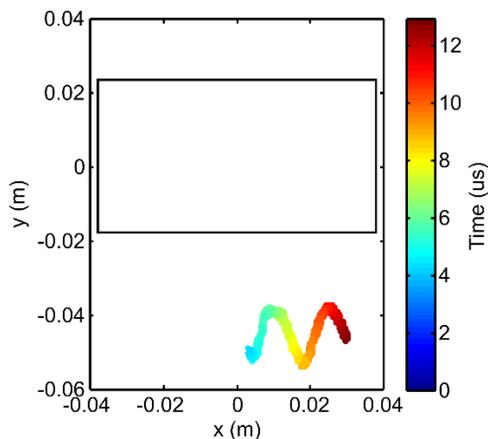

Figure 3: Protons of the LHC beam lost on the TIDVG front surface as a function of time within the beam (color-coded), when all kickers are firing. Rectangle indicates aperture for circulating beam.

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.
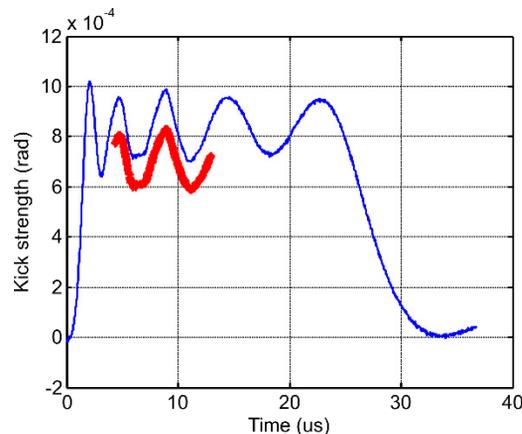

Figure 4: Kick strength seen by the tracked protons of the LHC beam (red) when all kicker firing. Kicker waveform (blue) for comparison.

Figures 5 and 6 show the corresponding simulation results for the FT beam. The minimal distance of dumped particles from the circulating beam aperture is in this case 22.8 mm. By investigating more precisely the curves in Fig. 6, it can be seen that the timing of the FT beam can be moved 0.45 μs backwards, without reducing the minimum kick amplitude seen by the beam, which is the kick amplitude in the minimum after overshoot 1. This time shift is equivalent to an increase of the rise time by the same amount. This estimate is conservative, since the slope of the increased rise time would be less steep than the one of the shifted waveform.

Figure 7 shows as an example the simulation results of a FT beam shifted backwards by 0.4 μs. This beam is fully
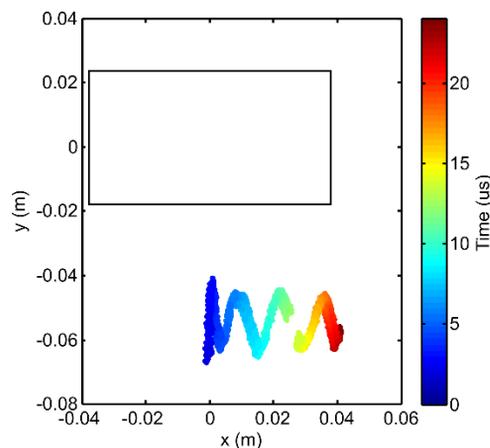

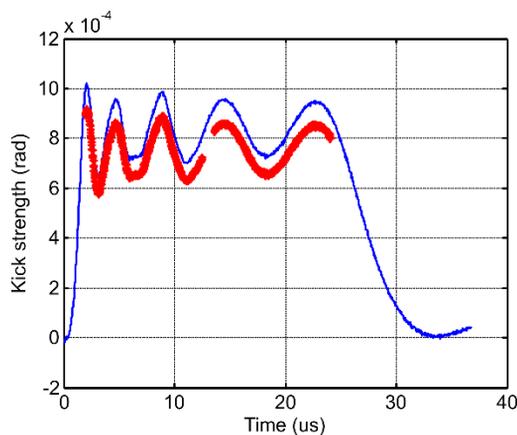Figure 5: FT beam lost on the TIDVG front surface, when all kickers are firing.

Figure 6: Kick strength seen by the FT beam in relation to the total kicker waveform.

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

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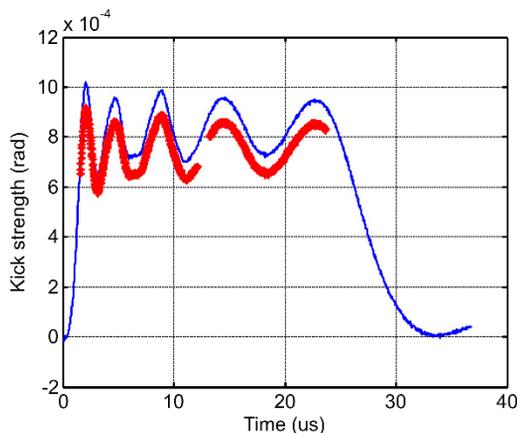
only in the second turn (Fig. 9). For the LHC beam, the result is similar; however, 0.26% of the beam are lost elsewhere in the machine and 14.4% only in the 2nd turn on the TIDVG.

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

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

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
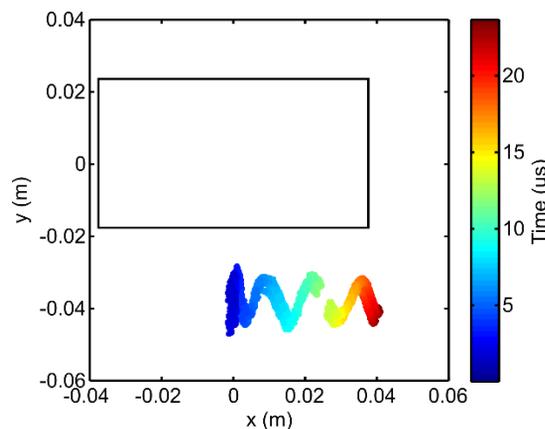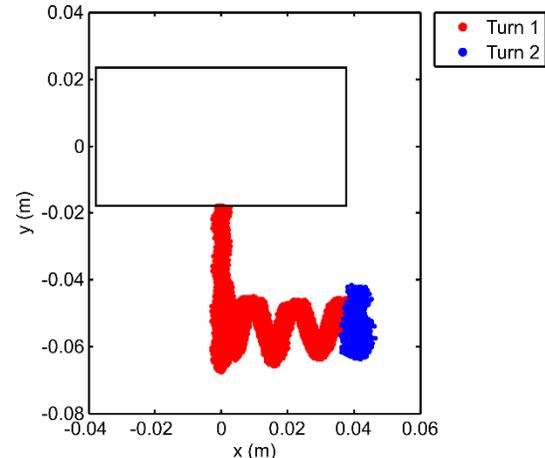
OPERATIONAL MITIGATION METHODS

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.

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