FEASIBILITY STUDY OF A NEW SPS BEAM DUMP SYSTEM

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Abstract

The CERN Super Proton Synchrotron (SPS) presently uses an internal beam dump system with two separate blocks to cleanly dispose of low and high energy beams. In view of the increased beam power and brightness needed for the LHC Injector Upgrade project for High Luminosity LHC (HL-LHC), the performance of this internal beam dump system has been reviewed for future operation. Different possible upgrades of the beam dumping system have been investigated. The initially considered solution for the SPS Beam Dump System is to design a new, dedicated external system, with a dump block in a shielded cavern separated from the machine ring. Unfortunately this solution is not feasible with the present technology. In this paper, the design requirements and the possible solutions are investigated, including considering a new internal beam dump in the Long Straight Section 5 (LSS5).

INTRODUCTION

The internal SPS beam dump system (SBDS) is a concern for the upcoming HL-LHC upgrade and also, after the recent observed damage [1], during current operation. The system has been designed for very different beam parameters, compared to those that will be used after the Long Shut-down 2 (LS2). As shown in [2] the internal high-energy absorber block (TIDVG) will not survive the nominal HL-LHC beam, and hence an upgrade is necessary to fulfil the requirements.

The internal SBDS is installed in LSS1. It is composed of two kicker systems (MKDV to vertically deflect the beam onto the absorber blocks and MKDH to dilute it), two main absorber blocks (TIDVG and TIDH for high and low-energy beams respectively) and three displaced quadrupoles (dog-leg) [3]. The presence of the dump system in LSS1 makes this area the most activated in the SPS. The TIDVG receives the highest beam power (Fig. 1) of all the SPS absorbers, which causes severe material and air activation, as well as radiation triggered material damage (cables, beamlines equipment, etc.) in its surroundings. Therefore, the post-LS2 high-brightness beam requirements and the heavy radiation related problems caused by the dump system in LSS1, translate into investigating an external dedicated solution, or an upgraded internal one.

The design of a completely dedicated external beam dump could profit from the existing extraction channels in LSS4 and LSS6. In [4], these two possibilities have been documented and both considered unsuitable due to the operational and civil engineering complexity.

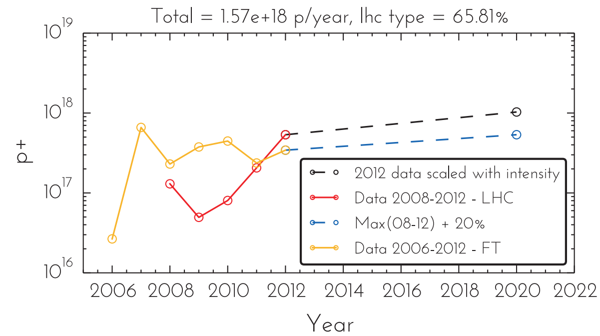

Figure 1: Extrapolation of the expected intensity to be dumped per year for post-LS2 era based on available data.

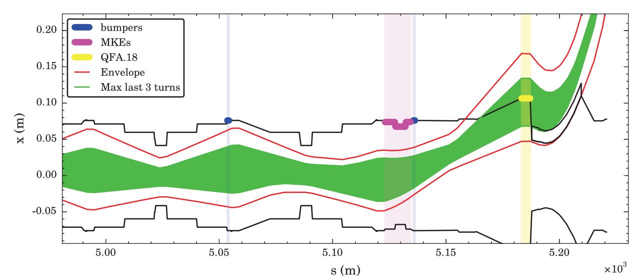

Figure 2: Proposed extraction channel in LSS5 using the same elements as in LSS4. In green the envelope of the last three turns trajectory of the particle with the maximum allowed amplitude at the extraction electrostatic septum ZS2 is shown. In red the beam envelope calculated as $A(s) = (D\delta_p + 1.2 \times \max\{6\sqrt{\epsilon\beta}, x_{3turns}\})1.1 + 6mm$.

It has also been studied to install a new external beam dump in LSS5 in order to fulfil all the requirements for a new beam dump. However this option suffers, as the other cited above, from the small extraction septum aperture and hence it will not be able to fulfil the design requirements within the time-line of the project.

In this paper the feasibility studies and main outcomes of an external dump using a new extraction system in LSS5 are presented. The design of a new internal system in LSS5 is also documented, covering most of the aspects that could undermine the feasibility of such a concept.

EXTERNAL SBDS IN LSS5

An extraction system for a beam dump exhibits several differences with respect to the classical fast extraction from the SPS, for example:

- energy-tracking elements, such as kickers, bumpers, septa and active transfer line elements though the whole beam cycle;
- apertures able to deal with the whole SPS dynamic range, as well as with all beam types;
- more stringent kicker requirements (rise-time, flat-top duration, etc.) due to the need to extract all beams in one machine revolution;
- dilution kickers in the transfer line;
- completely different extraction logic.

In [2] it was already demonstrated that for all beams and all energies an external beam dump solution was not possible with current technologies of the extraction elements. The main problem is the Fixed Target (FT) beam, with its very large emittance ($\epsilon_x^N = 12\,\pi$.mm.mrad) and low injection energy, which represents the most challenging beam to extract using elements designed for high-energy beams. In order to overcome this problem, the idea was to have an internal low-energy (between 14 and 180 GeV) absorber block just before the extraction septum.

The required improvement in terms of activation (factor of ten lower than the current situation in LSS1), translates in the need to deliver to the external dump the highest possible number of protons. According to the experts [5], the maximum number of protons at low energy (between 14/180 GeV) that would be dumped in the post LS 2 era is 6.6×10^{17} p^+/year. Even considering this, the external beam dump would carry a significant gain in the activation levels.

The most common beam dumped on the high-energy absorber block is the remaining ≈10 % of the FT beam (which has intensity of $\approx 4 \times 10^{13} p^+$ at 400 GeV), after being slow extracted. Due to the nature of the resonant third-integer extraction, the beam occupies most of the available horizontal aperture of the SPS, hence this case has to be explicitly considered when the apertures at extraction are evaluated. In Fig. 2 the process of extraction towards the external dump in LSS5 is shown for the just cited FT beam; the largest allowed separatrix amplitude is tracked for the last three turns before extraction. It is clear that the aperture at the quadrupole upstream of the septum is not sufficient to accommodate such a wide beam. This translates into the impossibility to fulfil the required activation reduction, hence this option was not considered attractive and was abandoned.

INTERNAL SBDS IN LSS5

The SPS first Long Straight Section, LSS1, currently hosts both injection and beam dump system. The lack of space makes it very difficult to optimise the shielding needed by the beam dump absorber blocks. A possible solution, that has also quite old roots [6], is to move the internal dump system in LSS5 in order to decouple it from the injection system.

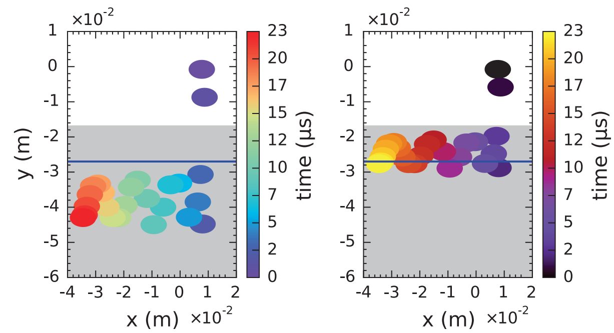

Figure 3: LHC 450 GeV beam at the front-face of the new TIDVG in case of nominal dump with 3 MKDVs (left) and in case of kicker missing (right).

The new location will guarantee sufficient space to lengthen the absorber block (first simulations indicate a possible active length of 6 m instead of the currently 4 m), as well as to shield it properly. Studies are still ongoing regarding both the absorber block and the shielding design.

Displacement of Current Dump System

A straight forward solution could be to displace of the internal beam dump system from LSS1 to LSS5. Of course this solution would also benefit from the already foreseen upgrade of the MKDV switches [3]. Due to the new semiconductor switch technology covering the whole SPS energy dynamic range, all beams at all energies can be dumped onto the TIDVG. The only limitation, in terms of aperture for the 14 GeV FT beam, is located at the quadrupole installed between the kickers and the absorber block. This problem can be overcome by changing the MKDV energy tracking function; the voltage will be varied quadratically with the beam energy up to 40 GeV, from where it is then increased linearly.

Optimised Internal Dump System in LSS5

In order to minimise the civil engineering excavation in the LSS5 zone, the beam dump block has to be moved upstream closer to the focusing quadrupole QFA.518, compared to the existing layout in LSS1. This means that more deflection is indeed needed from the MKDVs, which may impact their reliability due to the higher voltage required (≈ 15% more). A good solution, which also solves missing redundancy of the MKDV system introduced with the Q20 optics, would be the installation of a third MKDV kicker. In this way, the absorber block can be moved 6 m upstream and the 450 GeV LHC beam (most rigid beam in the SPS) can be dumped even with one MKDV missing (Fig. 3) and, in addition, the operational MKDV voltage can be reduced. A schematic view of this proposal is shown in Fig. 4. Here the envelope plotted is the minimum acceptance of one of the main bends family at 14 GeV.

As for the previous option, the aperture limitation is represented by the QFA.518. The largest beam is the 14 GeV

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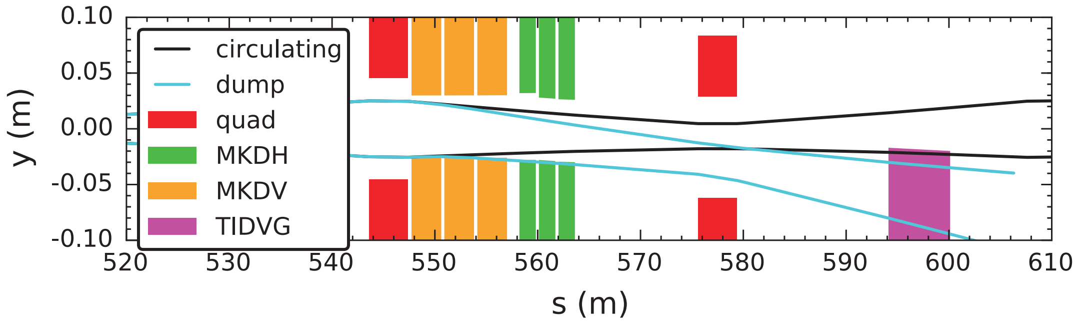

Figure 4: Schematic side view of the SPS dump system in LSS5 using three MKDVs. In cyan the $\pm 3.5\sigma_y$ 14 GeV FT beam envelope is plotted corresponding to the vertical acceptance of one of the main SPS dipole families.

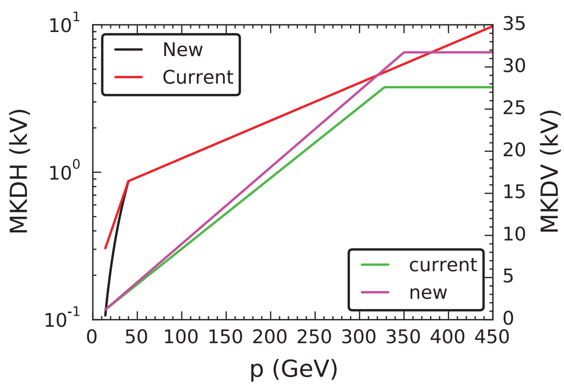

Figure 5: New proposed energy tracking functions for the MKDV (magenta) and MKDH (black, in logarithmic scale). The comparison is made for the equivalent of the current system but with three MKDVs, and the LSS5 option.

FT one, which can be accommodated by an optimisation of the horizontal and vertical kickers energy tracking functions. Figure 5 shows the two new proposed energy tracking functions. Only the first part of the tracking function will be modified for the MKDH, i.e. below 50 GeV $V(p) = p^{1.8248} V(50)/50^{1.8248}$. For the MKDV, the minimum required voltage will not be changed (hardware limit) and the curve is adapted as shown in Fig. 5. The different MKDH tracking function translates in less sweep at energies below 50 GeV, but this does not represent an issue for the future absorber block design [7].

Another demanding beam, in terms of aperture, is the slowly extracted FT beam. This defines the need to have the quadrupole dog-leg, that is in place for the current system [2], also for the new one. Figure 6 shows the cross-section of the QFA.518 while dumping the slowly extracted FT beam. The beam looks very tight inside the vacuum chamber aperture, which reflects the current operational situation.

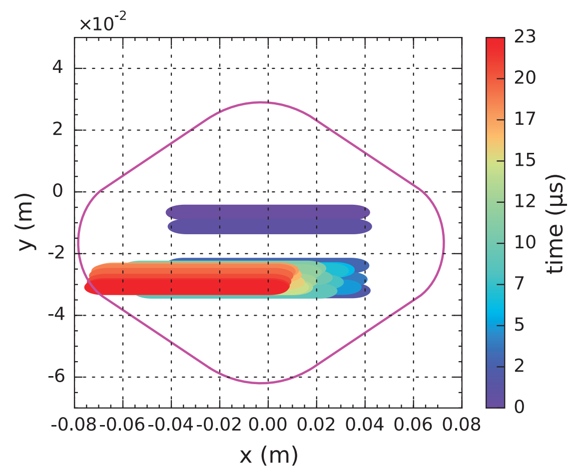

Figure 6: Cross-section of the end of quadrupole QFA.518 while dumping the FT beam remaining in the SPS after being slowly extracted. The beam envelope plotted refers to the formula given in Fig. 2. Here a spiral step at the ZS of 20 mm to calculate the last three turns trajectories was used.

CONCLUSION

Although multiple solutions have been investigated to try to design a completely external beam dump system for the SPS in view of the LIU operation, none of them was suitable for the improvements required within the technological limits. The main issue is the tight aperture of the extraction elements combined with the vast variety of beams that should be extracted, for obtainable kicker and septum strengths.

A very promising solution is to displace the internal beam dump system from LSS1 to LSS5. This new location offers enough space to properly optimise the current system to meet the activation, reliability and robustness requirements. A feasible concept has been presented, and studies are still ongoing.

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