PERFORMANCE IMPROVEMENTS OF THE SPS INTERNAL BEAM DUMP FOR THE HL-LHC BEAM

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Abstract

The SPS internal beam dump has been designed for beam specifications well below the HL-LHC ones, and for modes of operation which may not be adequate for the HL-LHC era. The present system suffers from several limitations in the allowed intensity and energy range, and its vacuum performance affects nearby high-voltage kicker systems. In this report the limitations of the internal beam dump system are reviewed, and the possible improvements compared. Preliminary upgrade proposals are presented, taking into consideration the expected operational HL-LHC parameters.

INTRODUCTION

The Super Proton Synchrotron (SPS) internal beam dump needs to be a very reliable system which covers a wide energy range. The whole system is placed in the SPS Long Straight Section 1 (LSS1) and is composed of: 4 absorber blocks (TIDP, TBSJ, TIDH, TIDVG), 2 vertical kickers (MKDV), 3 horizontal sweepers (MKDH), 3 misaligned quadrupoles (QDA117, QFA118, QDA119) and 2 SEM grids (TFDH/V).

The TIDP is a collimator for off-momentum particles and the TBSJ is the block deputed to absorb the injected beam in case of failure of the injection kicker (MKP). The two main absorber blocks are the TIDH and the TIDVG: the first is for the low-energy beams (14-28.9 GeV) and the second is for the high energy beams (102.2-450 GeV). The TIDVG consists of a graphite, aluminium, copper and tungsten core, surrounded by an iron shielding block.

The three misaligned quadrupoles form a closed orbit bump of about 7 mm (negative y and positive x directions) in both planes at the QFA118 (Q26) to assist the kickers dumping the beam. This misalignment is less effective when the Q20 optics is used (4.1 mm offset in negative y direction at the QFA118).

The MKDVs deflect the beam, depending to the energy, onto the TIDH or TIDVG. Due to its waveform and the MKDHs (Fig. 1), the whole beam is spread on a relatively large part of the absorber block front face. The kicker parameters are summarised in Tab. 1.

In Figure2 is plotted a preliminary study of particle deposition, for HL-LHC nominal parameters ($\varepsilon_{Nx,y} = 2.5\,\pi$.mm.mrad, and 2.5×10^{11} protons per bunch), on the TIDVG front face. MAD-X tracking has been used to model the particle distribution on the absorber block also for LHC beams. The resulting particle density (protons per mm^2) of HL-LHC beam type was bigger than the LHC beam by a factor 2.5.

Nominal LHC ($\varepsilon_{Nx,y} = 3.5\,\pi$.mm.mrad) and CNGS ($\varepsilon_{Nx} = 12\,\pi$.mm.mrad, $\varepsilon_{Ny} = 7\,\pi$.mm.mrad) beam parameters are considered for aperture calculations.

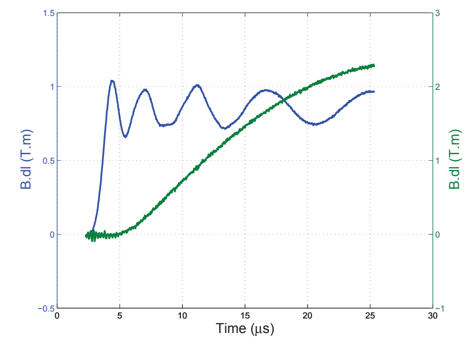

Figure 1: MKDV (MKDVA + MKDVB) waveform in blue and MKDH (2×MKDHA + MKDHB) waveform in green.

Table 1: Dump Kicker Parameters [1]. The MKDV Voltage has been Clamped at 41.4 kV Due to Switch Weaknesses.

Parameters	Unit	MKDVA/B	MKDHA/B
$H_{ap}(full)$	mm	75 / 83	97.1 / 106.1
$V_{ap}(full)$	mm	56 / 56	56 / 60
Length	m	2.56	1.256
Rise Time	μs	$\approx$ 1.1	$\approx$ 23
Max Voltage (2012)	kV	41.4	9.9
Kick Strength	T.m	0.49 / 0.41	0.92 / 0.77

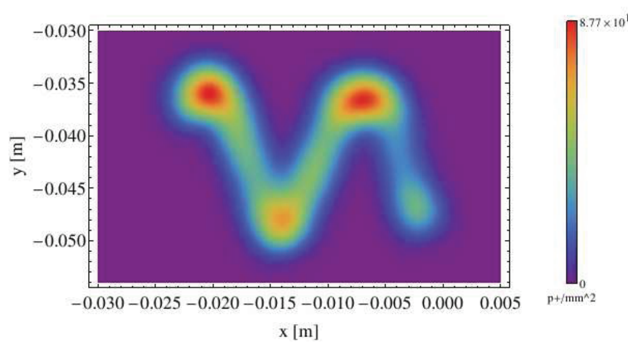

Figure 2: Particle deposition on the TIDVG front face for HL-LHC beams.

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ISSUES OF THE PRESENT SYSTEM

The original SPS dump system has been built for 300/400 GeV beams. During the last decades, several upgrades have been carried out to make it reliable for the current energy and intensity. The main issues that afflict the beam dumping system are:

- outgassing of the TIDVG block that causes a vacuum pressure rise in the downstream injection kicker magnets MKP;
- a forbidden zone that does not allow a clean dump between 28.9 and 102.2 GeV;
- activation of the area around the TIDVG;
- MKDV reliability issues due to the topology.

Outgassing

The sources of outgassing in the TIDVG are most likely the graphite or tungsten. It is driven by temperature rise and material contamination. The most critical cases are when the graphite temperature exceeds the bake-out temperature; this happens when the beam is repeatedly dumped (e.g. during MDs); when the graphite is exposed for a long time to atmospheric air; or after a new absorber block is installed (requiring several months of conditioning). Due to the TIDVG longitudinal position, the most significant effect is seen in the downstream MKP; the vacuum pressure rises up to 10^{-6} mbar which prevents further beam injection due to the risk of high voltage breakdown.

Solutions to this problem can be: further separate the MKP from the dump block; separate the graphite from the circulating beam aperture; increase the pumping speed between the absorber and the MKP possibly using NEG materials; modify the material composition of the absorber block.

Forbidden Zone

All MKDs are controlled by a tracking system which automatically chooses, depending on the energy, between TIDH and TIDVG to dump the beam. The SPS energy span is about 30 between the flat bottom and the flat top, too large for the maximum MKDV composite switch (thyratron and ignitron) dynamic operational range of about 10 [2]. Hence, between 14 and 28.9 GeV the beam is vertically dumped on the TIDH, between 102.2 and 450 GeV the beam is dumped on the TIDVG, still maintaining the safety distance of 10 mm between the beam and the TIDVG top surface. Between 28.9 and 102.2 GeV, as shown in Fig. 3, the kicker voltage is kept constant resulting in the progressive deflection of the beam between the TIDH and TIDVG, i.e. the so-called *forbidden zone*, which results in grazing impact on the TIDH and an increase in losses around the SPS.

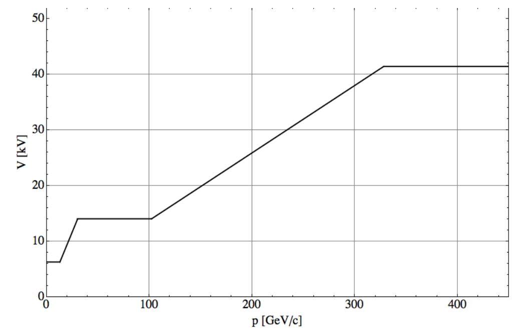

Figure 3: MKDV tracking function.

Activation

The high energy absorber block, TIDVG, is the most radioactive element of the whole SPS. After 30 hours of cool-down following normal proton beam operation, the dose rate is still bigger than 10 mSv/h [3]. This imposes very strict rules about the access to the TIDVG area. Depending on the preceding operation, it may be necessary to wait weeks before having the possibility to access this area safely. The best scenario to reduce the activation is an external dump, in order to have enough space to shield the absorber block properly [3].

Topology

The nominal operation voltage of the MKDV is 52 kV. Between 2006 and 2010 several modifications of the MKDV system have been performed [4]. In 2011 the PFN voltage has been clamped at 44 kV due to magnet sparking; finally, due to switch weaknesses, the voltage has been clamped at 41.4 kV in 2012.

The two MKDV systems are linked together by a third PFN [4]; this reduces the effective redundancy in case of magnet breakdown.

PROPOSED SYSTEM UPGRADE

Two proposed solutions to upgrade the current SPS beam dump system are: major modification of the TIDVG and MKDV, and a new external beam dumping system.

Internal Beam Dump Upgrade

To solve the problem of pressure rise in the MKP downstream of the TIDVG, a solution can be to separate the graphite block from the circulating beam aperture. To isolate completely the graphite from the rest of the machine a vacuum window could be installed, as already done in TT66 [5]. The MKDV magnets would have to be upgraded to be used at the nominal voltage of 52 kV, and the oscillations of the MKDVs waveform, currently $\pm15\%$ the average value, would have to be reduced at $\pm12.5\%$ in order to let the beam hit the graphite front face. Also, the two kicker systems have to be made independent to make the system redundant, as well as the switches have to be upgraded, as proposed in [4], to limit the forbidden zone. The

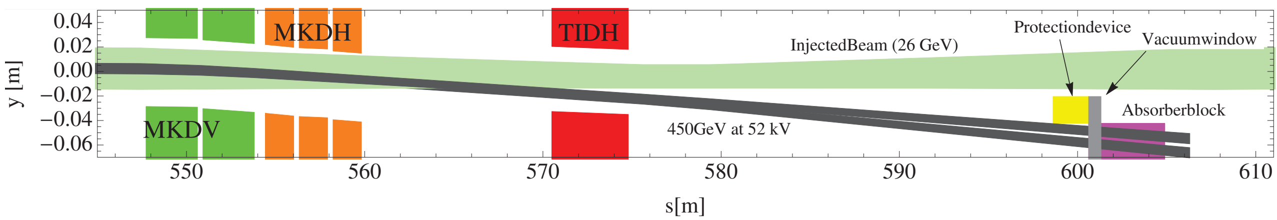

Figure 4: Schematic overview of the proposed internal SPS dump system upgrade realised with MAD-X. This represents an ideal dump of 450 GeV LHC beam ($\pm 5\,\sigma_y$), for the Q20 optics at MKDV voltage of 52 kV. The dumped beam is spread vertically of ±12.5% the average kick strength value.

principle of operation of this proposed upgrade is essentially the same as the current system: TIDH used for low energy beams and TIDVG for high energies. The MKDVs have to deflect the highest energy beam 65 mm below the nominal orbit to leave space for installing the vacuum window. A TPSG-like protection device, 2 m long, is foreseen to shield the beam pipe and the vacuum window's side part from direct impact of the beam, as shown in Fig. 4.

External Beam Dump

Different layouts have been analysed, all considering LSS5 as the place for an horizontal extraction system for an external dump. The major problem faced is the extraction septum vertical gap, because it has to be large enough to let all SPS beams pass through, while still maintaining a kick strength which keeps the kicker current below 40 kA. The tradeoff between extractable range of energy and current yields the concept in Fig. 5.

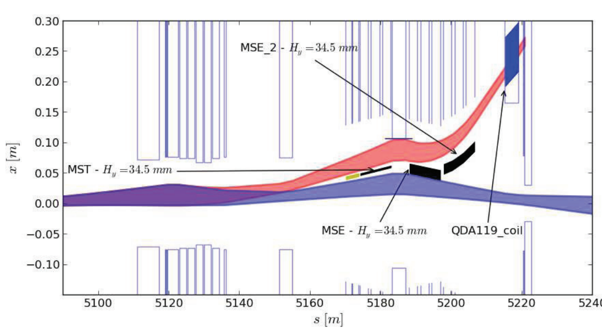

Figure 5: External dump extraction concept. Blue is the circulating beam and red the extracted beam. Both at 100 GeV considering $\pm 5\sigma_x$ for $\varepsilon_{Nx} = 12\,\pi$.mm.mrad.

Although the vertical aperture limit is, for 12 π.mm.mrad normalised emittance beam, 58 GeV, the major limitation is given by the horizontal aperture at the focusing quadruple before the septum (QFA.518). Below 100 GeV there is not enough aperture to extract the 12 π.mm.mrad normalised emittance beam. In the external dump line the high energy dump system is foreseen: sweepers and absorber block. For the low energy beam, the internal dump has to be kept and also it may need an upgrade, considering the HL-LHC beam type [6].

CONCLUSIONS

Current issues have been investigated and two major beam dump upgrade proposals have been presented. Although a completely new external dump system could in principle solve all problems, it will suffer heavy operational limitations (beams can be extracted only above 100 GeV). It would also involve a major SPS modification while high-energy dump-like blocks are already installed in the SPS transfer lines (e.g. TT40, TT60). The internal upgrade could be feasible, but accurate analyses are still needed to confirm this, for example the load on the TIDVG, protection devices, etc. Kicker upgrades are already foreseen [4] (to solve the forbidden zone problem and MKDV topology issues) as well as further studies on the absorber block response to HL-LHC beams. The study of a more efficient pumping configuration, in order to solve the pressure rise problem, is in progress. The feasibility of a high-energy absorber block in one of the existing transfer lines has still to be investigated.

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