CERN-ACC-2014-0239

Francesco.Maria.Velotti@cern.ch

Performance Studies of the SPS Beam Dump System for HL-LHC Beams

F. M. Velotti, O. Aberle, C. Bracco, E. Carlier, F. Cerutti, K. Cornelis, L. Ducimetiere, B. Goddard, V. Kain, R. Losito, C. Maglioni, M. Meddahi, F. Pasdeloup, V. Senaj, G. E. Steele
CERN, Geneva, Switzerland

Keywords: HL-LHC, SPS

Abstract

The Super Proton Synchrotron (SPS) beam dump system is a concern for the planned High Luminosity LHC (HL-LHC) operation. The system has initially been designed for very different beam parameters compared to those which will reign after the completion of the LHC injectors upgrade, when the SPS will have to operate with unprecedented beam brightness. This paper describes the relevant operational and failure modes of the dump system together with the expected beam loading levels. Tracking studies are presented, considering both normal operation and failure scenarios, with particular attention to the location and level of proton losses. First FLUKA investigations and thermo-mechanical analysis of the high-energy absorber block are described.

Presented at: IPAC14, 15-20 June, Dresden, Germany

Geneva, Switzerland
October, 2014

PERFORMANCE STUDIES OF THE SPS BEAM DUMP SYSTEM FOR HL-LHC BEAMS

F. M. Velotti, O. Aberle, C. Bracco, E. Carlier, F. Cerutti, K. Cornelis, L. Ducimetiere, B. Goddard, V. Kain, R. Losito, C. Maglioni, M. Meddahi, F. Pasdeloup, V. Senaj, G. E. Steele,
CERN, Geneva, Switzerland

Abstract

The Super Proton Synchrotron (SPS) beam dump system is a concern for the planned High Luminosity LHC (HL-LHC) operation. The system has initially been designed for very different beam parameters compared to those which will reign after the completion of the LHC injectors upgrade, when the SPS will have to operate with unprecedented beam brightness. This paper describes the relevant operational and failure modes of the dump system together with the expected beam loading levels. Tracking studies are presented, considering both normal operation and failure scenarios, with particular attention to the location and level of proton losses. First FLUKA investigations and thermo-mechanical analysis of the high-energy absorber block are described.

INTRODUCTION

The upcoming upgrades in the CERN accelerator complex, in particular the LHC Injector Upgrades (LIU) and HL-LHC, represent an unprecedented challenge for the SPS and particularly for its internal beam dump. The system, installed in the Long Straight Section 1 (LSS1), is composed by two kicker systems (MKDV and MKDH), two main absorbers (TIDH and TIDVG) and three displaced quadrupoles (dogleg) [1]. A detailed analysis of the implication on the high-energy absorber block for operation with the high-brightness beams (Table 1), foreseen after the Long Shout-down 2 (LS2), was necessary.

The two main absorber blocks share the dumped beams; between 14 and 28.9 GeV and between 102.2 and 450 GeV, the TIDH and the TIDVG are used, respectively. This is realised varying the MKDV strength with the beam energy. The sweepers (MKDH), instead, are used to dilute the beam and the particle density delivered to the absorber front faces.

The MKDV powering system leads to different problems, as already pointed out in [1]. An upgrade of this system has already started and it will imply a major benefit to the whole SPS dump system. It will also bring a slightly different field waveform. To obtain a first estimation of the expected MKDV waveform, a preliminary measurement of the magnetic flux at PFN voltage of 300 V was done. Dividing the flux by the coil cross-section and scaling it up at 47 kV, a realistic kicker waveform is obtained, as shown in Fig. 1.

To estimate the expected beam loading at the TIDVG front face, an intense campaign of tracking simulations was done. First, the nominal operating conditions were simulated. Then, different failure scenarios originating by the malfunctioning of the kicker systems were considered. For all these possible events, beam loading at the TIDVG, and proton losses around the machine were checked. The particle distributions at the high-energy absorber block are used as input to evaluate the energy deposition on the TIDVG. Simulations using FLUKA [3, 4] and ANSYS [5] were carried out to estimate the thermo-mechanical behaviour of the TIDVG with the upgraded beam parameters.

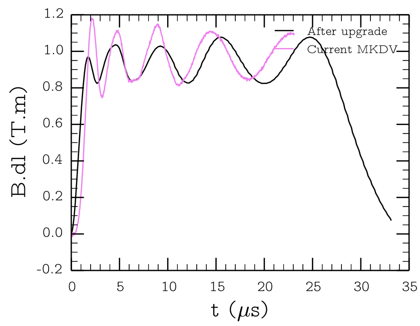

Figure 1: First estimation of the possible MKDV wave form after the foreseen upgrade of its powering system compared with the current one at 47 kV.

Table 1: Beam parameters used in simulations. The LHC beam type refers to the most extreme achieved case, i.e. the BCMS (Batch Compression, bunch Merging and Splittings) scheme production. The BCMS-LIU and HL-LHC beams represent the most challenging requested beams [2].

Parameters	**LHC**	**BCMS-LIU**	**HL-LHC**
p [GeV/c]	450	450	450
$\varepsilon_{x,y}^N$ [π.mm.mrad]	1.4	1.3	2.1
I [p^+/bunch]	1.15e11	2.0e11	2.32e11
Bunches	240 (25 ns)	288 (25 ns)	288 (25 ns)
MKDV [kV]	41.4	47	47

NORMAL OPERATING CONDITIONS

Since 2012, the nominal SPS optics, for the LHC beams, is the so-called Q20 (*low transition energy optics*). The closed orbit bump created with the quadrupole dogleg (which helps centring the beam onto the absorber block) was matched with the Q26 optics. A smaller bump amplitude, at the dump location, is obtained when operating with the Q20 optics.

To evaluate the expected performance of the TIDVG with the new requested beams, the nominal LHC beam structure

(4 batches of 72 bunches with 25 ns bunch spacing) was simulated while experiencing the time-varying MKDV/H magnetic fields. The kicker waveforms were sampled with 25 ns sampling period to have one kicker value per bunch.

The synchronism between the beam and the MKDV is arbitrary chosen [1]. For the LHC beam, hence for the current MKDV waveform (not shown here), the maximum and minimum peaks are avoided. This leads to a maximum proton density at the TIDVG of 5.4×10^{11} p$^+$/mm^2.

The ame set of simulations, with BCMS-LIU and HL-LHC beam parameters (Table 1) and using the new kicker waveform (Fig. 1), were carried out. The proton density map at the absorber block for HL-LHC beam is shown in Fig. 2; the maximum proton density at the absorber block is 1.09×10^{12} p$^+$/mm^2. For the BCMS-LIU beam, the maximum proton density recorded is 1.13×10^{12} p$^+$/mm^2. Hence the most challenging beam, in terms of particle density, is the BCMS-LIU.

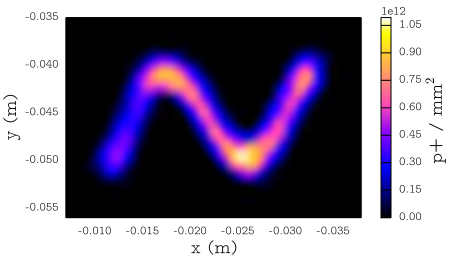

Figure 2: Particle density on the TIDVG front face for HL-LHC beam parameters (Tab. 1).

FLUKA results

FLUKA simulations used a realistic model of the TIDVG geometry and the particle density maps from tracking simulations as input. For comparative purposes the normal operating conditions for LHC, BCMS-LIU and HL-LHC beams were all simulated. Figure 3 shows the peak dose along the length of the TIDVG. Despite BCMS-LIU beams corresponding to a slightly higher maximum proton density on the front face of the TIDVG, the peak dose is higher for HL-LHC beams. For both BCMS-LIU and HL-LHC normal operation scenarios, the maximum dose, in all constituent core materials, is roughly twice that under nominal LHC beam conditions due to their higher intensity.

Preliminary Thermo-mechanical analysis

The calculations were performed considering the nominal HL-LHC beam (Table 1). In this scenario the TIDVG has to withstand a single bunch train lasting 7.2 μs. The TIDVG core is constituted by a series of blocks: 2.5 m of graphite (2020PT), 1 m of aluminium (EN AW 6082 T6), 0.5 m of copper (OFE C10100 H02) and 0.3 m of tungsten (DENSIMET 180).

During the short time of the bunch train no thermal diffusion can be observed. The thermal stresses on the TIDVG

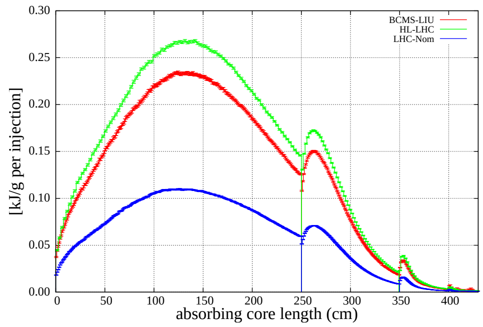

Figure 3: Peak dose along the TIDVG absorbing core for the different kinds of beams.

core are calculated based on the heat load estimated and imported from FLUKA in a transient quasi-static analysis. The equivalent Von Mises criterion is used for the mechanical stresses in metallic blocks (Aluminium, Copper and Tungsten) and the Stassi criterion is used for the graphite blocks.

The results show that the current design of the TIDVG core cannot withstand this upgraded beam. In particular the aluminium blocks reach stresses which largely overcome the ultimate strength of the chosen aluminium alloy (Fig. 4): in the temperature peak area (233 °C) the Von Mises stress is of 265 MPa, while at this temperature the yield strength is only 125 MPa. These results invalidate the current design for future beams as HL-LHC.

Proposals for the modification of the TIDVG core to be able to withstand the HL-LHC beam have been done and are being studied. It is also important to define limits for the beam which could be in reach after LS1 (especially BCMS schemes).

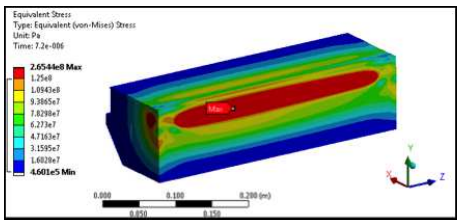

Figure 4: Von Mises stresses in aluminium block with HL-LHC energy deposition. Red parts are overstressed (>125 MPa). Only half of the block is represented.

FAILURE SCENARIOS

The failure of the MKDV and MKDH powering system determine the most critical scenarios for the SPS dump system. Six possible cases have been isolated and, for each, the expected load at the TIDVG calculated. In the following subsections these case scenarios are described and the highest expected particle density at the TIDVG given (BCMS-LIU beam).

MKDV related failures

A self-triggering of an MKDV power switch will determine an asynchronous beam dump with a longer rise time. The beam is swept vertically on the TIDVG following the rising part of the kicker waveform. The particle density at the TIDVG front face, in case of LIU-BCMS beam, is shown in Fig. 5. The probability of such event is expected to be about one per year after the MKDV upgrade. The maximum expected particle density at the TIDVG is 8.32×10^{11} p+/mm^2.

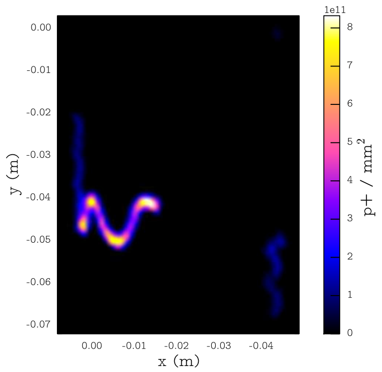

Figure 5: Particle density on the TIDVG for an asynchronous beam dump of requested BCMS-LIU beam.

If one of the two power switches does not fire, the second will take all the current. This causes a 100 ns longer rise time. It essentially reduces to the previous failure in terms of the sweep. This is expected to happen every few years.

A flashover in one of the MKDVs can induce, as extreme cases, 50% reduced or 50% increased deflections. This may happen few times per year. When the given deflection is half the nominal one, the beam will graze the graphite block and produces a proton density at the TIDVG of 9.7×10^{11} p+/mm^2.

A complete failure of the whole MKDV system causes the beam to be spread around the whole machine (Fig. 6), hence no beam load at the graphite block of the TIDVG is produced.

None of the investigated failures of the MKDV system will lead to a higher than nominal proton density at the TIDVG. The grazing impact and the losses around the machine should be carefully studied to evaluate their consequences.

MKDH related failures

In case of flashover in the MKDH, the worst scenario is a kick corresponding to one-third the nominal. This may determine a maximum proton density at the TIDVG of 1.48×10^{12} p+/mm^2.

A complete failure of the sweeping system is expected to give the worst particle density pattern, with a maximum of 3.6×10^{12} p+/mm^2.

All the sweep failures, partial or complete, will indeed lead to significantly higher particle density at the absorber block. Due to the low system voltage, the above failure cases have never been observed up to date and hence, they will be considered beyond design for the LIU-SPS TIDVG upgrade.

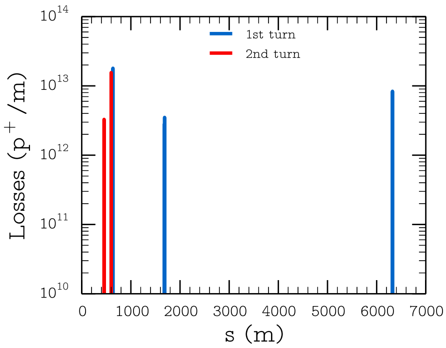

Figure 6: Expected losses around the SPS in case of complete failure of the MKDV system. This plot refers to HL-LHC beam.

CONCLUSION

The design studies for the LIU-SPS TIDVG upgrade have been started. The expected load on the TIDVG for post-LS2 beams is significantly higher than what the current absorber block can withstand. FLUKA studies indicate that the expected peak energy density is twice that under nominal LHC conditions. Preliminary ANSYS simulations are showing that the TIDVG needs a re-design to address these beams. Limits for presently achievable beams should also be investigated.

A very appealing way to reduce the annual beam load on the TIDVG is a high-energies external beam dump for LHC (and possibly also other) beams. Studies are ongoing to carefully evaluate the expected benefits and drawbacks of such a system. Nevertheless, the internal dump system will be still used for emergency dumps and thus still needs to be upgraded.

REFERENCES

[1] F.M. Velotti et al., “Performance Improvements of the SPS Internal Beam Dump for the HL-LHC Beam”, Proceedings of IPAC2013, Shanghai, China, 2013.

[2] G. Rumolo, “LIU Beam Parameters”, EDMS document, https://edms.cern.ch/document/1296306/1.

[3] A. Fasso et al., “FLUKA: A Multi-Particle Transport Code”, CERN-2005-10, 2005.

[4] G. Battistoni et al., “The FLUKA code: Description and benchmarking”, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6-8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, 2007.

[5] Swanson Analysis System, Inc., ANSYS Academic Research, Release 15.0, http://www.ansys.com.