DESIGN OF A MAGNETIC BUMP TAIL SCRAPING SYSTEM FOR THE CERN SPS

Ö. Mete#, J. Bauche, Y. le Borgne, S. Cettour Cave, F. Cerutti, K. Cornelis, L. Drøsdal, F. Galleazzi, B. Goddard, G. le Godec, L. Jensen, V. Kain, M. Meddahi, E. Veyrunes, H. Vincke, J. Wenninger, CERN, Geneva, Switzerland, A. Mereghetti, CERN, Geneva Switzerland, University of Manchester, UK

Abstract

The LHC injectors are being upgraded to meet the demanding beam specification required for High Luminosity LHC (HL-LHC) operation. In order to reduce beam losses, which can trigger the sensitive LHC beam loss interlocks, during the SPS-to-LHC beam injection process, it is important that the beam tails are properly scraped away in the SPS. The current SPS tail cleaning system relies on a moveable scraper blade, with the positioning of the scraper adjusted over time according to the orbit variations of the SPS. A new robust beam tail cleaning system has been designed which will use a fixed scraper block towards which the beam will be moved by a local magnetic orbit bump. The design proposal is presented, together with the related beam dynamics studies and results from machine studies with beam.

IMPORTANCE OF SPS BEAM TAIL CLEANING

During LHC beam filling particle losses localised at the end of the SPS-to-LHC transfer lines may exceed the thresholds of the LHC beam loss monitors, triggering beam dumps. This is a limiting factor during the filling of the LHC. The higher intensities required for the HL-LHC will result in higher beam losses, making this process even more challenging. The main sources for the injection losses are the transfer line collimators cutting into the transverse beam tails, un-bunched beam in the LHC and the SPS and unwanted bunch satellites. Different mitigation techniques are used to reduce the injection losses such as opening up the transfer line collimators (to still safe protecting positions); shielding between the TCDIs and LHC BLMs; the so called “BLM sunglasses”, (a configuration where losses from the outside of the vacuum chamber are not considered as a loss scenario for LHC BLMS for interlocking) and abort gap and injection slots cleaning [1]. Nevertheless, it is important to remove the tails of the circulating beam in the SPS before the LHC injections [2]. Since 2011 this cleaning is performed as a regular operational procedure. The scraping system is located in the SPS Long Straight Section 1 (LSS1). The cleaning is performed by moving a 1 cm long graphite block into each transverse plane of the beam. Due to its size and length, the current scraper block works like a spoiler (scattering particles rather than fully absorbing them).

#oznur.mete@cern.ch

NEW SPS BEAM TAIL CLEANING

Concept

The new proposed beam cleaning system relies on moving the beam onto a fixed scraper rather than moving a scraper block into the beam, as currently done. This method allows more precise beam positioning and less particle scattering thanks to the longer absorber block. A local orbit bump places the beam onto 1 m long scrapers by means of fast pulsed magnetic bumpers. A four-bumper scheme (two on each side of the scraper block) is needed to perform orthogonal steering in each plane.

General Layout

After evaluating all SPS LSSs in terms of available space, radiation environment and aperture clearance, LSS6 was chosen to possibly host the new scraping system. The fixed scraper physical boundaries should stay in the shadow of the aperture defined by the circulating beam for the CNGS (CERN Neutrinos to Gran Sasso) experiment. Therefore, the blocks are placed horizontally at 46 mm and vertically at 17 mm away from the ideal orbit. A 5σ CNGS beam envelope, with normalised emittances of 12π and 7π mm mrad in the horizontal and vertical plane, was used for this calculation. The locations of the scraper blocks were determined according to the available location along the ring, the required bumper strength, the beam clearance, the radiation protection issues and the integration feasibility. Shielding of the quadrupoles located downstream of the scraping region will be required to protect them from beam losses.

Orbit and Aperture Studies

Figure 1 shows simulated orbit effects in the horizontal plane. The top plot represents an extreme orbit deviation, obtained by quadrupole misalignments (Gaussian error distribution with 100 μm standard deviation). Within the 1000 resulting orbits, the 3σ orbits were selected. The middle plot shows a local closed orbit correction performed at the scraper location, whereas the rest of the machine is unaffected. The bottom plot represents the orbit bump moving the beam onto the scraper block. Hence the bumpers should provide the required total strength needed to move the beam onto the scraper, while taking into account the largest possible orbit corrections (9 mm in the horizontal plane, 6 mm in the vertical plane). The beam clearance was evaluated in the presence

ISBN 978-3-95450-122-9

of orbit effects. The transverse clearance expressed in 1σ beam size is given as

$$Clearance_{x,y} = \left(Aper_{x,y} - \left|\left\{5\left(\Phi\sqrt{\varepsilon_{x,y}\beta_{x,y}}\right) + \Phi\left|D_{x,y}\frac{\Delta p}{p}\right| + \sigma_{mech.} + \mathrm{x,y}\right\}\right|\right) / \left(\Phi\sqrt{\varepsilon_{x,y}\beta_{x,y}} + \Phi\left|D_{x,y}\frac{\Delta p}{p}\right| + \sigma_{mech.}\right) \quad (1)$$

where $Aper_{x,y}$ is the SPS machine aperture; Φ is the safety margin taken on the beam size (10%); $\varepsilon_{x,y}$ is the beam emittance; $\beta_{x,y}$ and $D_{x,y}$ are, the betatron and dispersion functions; $\Delta p/p$ is the momentum spread of the beam; σ_{mech} is the mechanical precision (1 mm); x, y are the horizontal and vertical beam positions. The closed orbit shift was introduced through the orbit fluctuations.

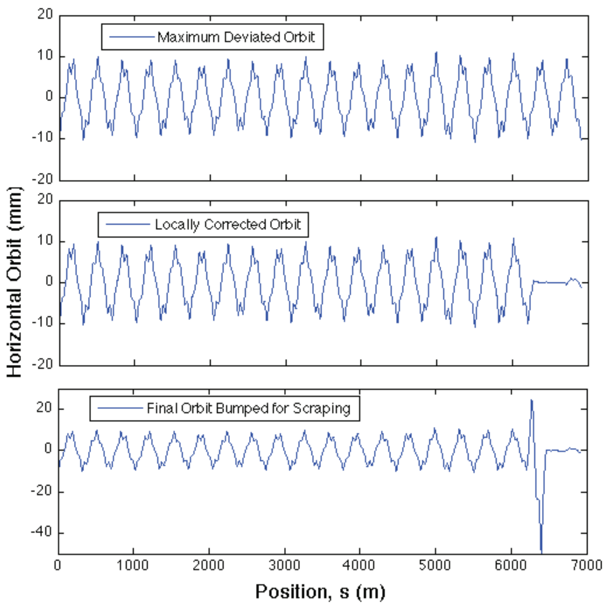

Figure 1: Variation of the horizontal orbit as a function of the position along the SPS.

Magnetic Bump Design

Four existing horizontal extraction bumpers were used to excite the scraping bump; in the vertical plane only two existing ones could be used. The locations of the two new vertical bumpers are optimized within the available LSS6 space such that the bump amplitude stays within the required clearance. The horizontal and the vertical planes during full scraping are presented in Fig. 2. Red lines denote the SPS machine aperture and black lines the circulating CNGS beam aperture. The beam envelope (5σ) is presented by blue stripes. As shown in the plots, local orbit bumps can be produced in the transverse plane providing a location where the full beam can be scraped away outside of the CNGS aperture limit while ensuring at least a 3σ clearance in the entire range of the bump. This can be achieved by adjusting the bump amplitude such that the beam centre intercepts the scraper jaw – enough to cover the full phase space in a circular machine – for the given bumper strengths shown in Table 1. The first four magnets in the list are the existing horizontal bumpers, which fulfil the strength requirements. The second set of magnets are the vertical bumpers; two of them are existing ones for which a renovation is needed to provide the required strengths, the other two, marked with "†", are the new bumpers added to the layout as a part of the vertical bump system.

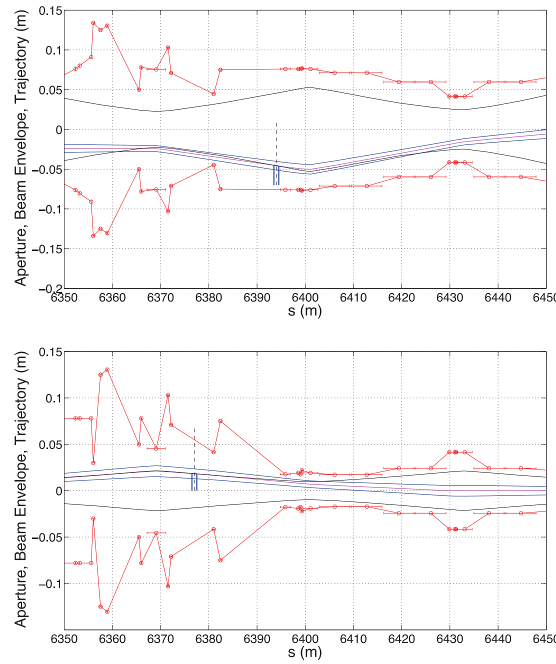

Figure 2: Horizontal (top) and vertical (bottom) machine apertures, beam envelopes and orbits vs. longitudinal position along the SPS.

Table 1: Specifications for Scraping System Bumpers

Bumper	Strength (mrad)	$\int Bdl$ (T.m.) @ 450 GeV
MPSH.61402	0.32	0.47
MPLH.61655	-0.69	-1.04
MPLH61996	0.27	0.40
MPSH.62199	-0.65	-0.98
MPSV.61503	0.13	0.19
†MPVN.6170X	0.20	0.30
†MPVN.6195X	-0.13	-0.20
MPSV.62103	0.32	0.48

† New proposed magnet for the given location.

Magnets and Power Converters

The preliminary mechanical design for the new vertical bumpers is presented in Fig. 3. In order to provide ~3σ beam clearance with the larger bump amplitude, the inner gap is 90/83 mm in the horizontal and vertical planes, respectively. The horizontal inner magnet gap had to be enlarged to 90 mm (existing design value is 83 mm). The yoke is trimmed down from the outer wall to provide clearance for the lateral vacuum chamber. Specifications for the magnet power converters were based on the most challenging magnet operational cycle and the magnet strength requirements.

ISBN 978-3-95450-122-9

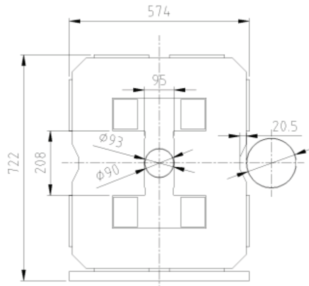

Figure 3: Preliminary mechanical design for the new vertical bumpers.

Material Choice for Scraper Block

After extensive energy deposition, thermal and structural simulations for various materials (Graphite R4550, Boron Nitride, Cfc 1.4, Cfc 1.7) [3], a carbon fibre composite material with the density of $1.7\ g\ cm^{-3}$ was proposed for the scraper. The simulation studies were done by FLUKA-SixTrack, coupling them with thermo-mechanical analysis of a finite element method tool, ANSYS.

Dose Rates and Radiation Protection

The scraper system was studied in terms of prompt and remnant doses resulting from beam operation [4]. A significant increase of the residual dose rate level is expected from the unshielded scraping system. The radiological impact in the area and on the surrounding equipment still needs to be assessed.

EXPERIMENTAL RESULTS

To demonstrate the feasibility of this method, machine studies were performed [5]. The protective shield of the LSS6 extraction septa was used as a fixed scraper block, while the LSS6 extraction bumpers were gradually increased to produce the scraping bump (Fig. 4).

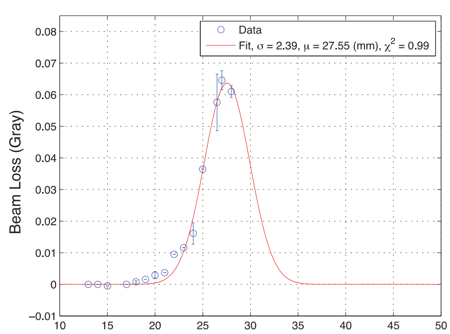

Figure 4: Beam profile measured using the TPSG mask.

The concept of scraping with a fixed mask was demonstrated by using an SPS protective shield (TPSG) as the fixed mask and the cleaning is confirmed by the beam scans performed with the present operational scraper (Fig. 5). These tests provided data to evaluate the cleaning properties, to estimate the possible side effects and to perform further energy deposition studies. The beam cleaning with the new scraping system is faster than the operational one and provides more flexibility within the SPS cycle. The cleaning speed was shown to have a quadratic dependence on the beam angle. It is independent of the bump duration as long as the duration is larger than the field in the bumpers remains stable (~150 ms). The beam losses were localised in the scraping region. Beam scans within one SPS cycle were also achieved with the new scraping method (Fig. 6).

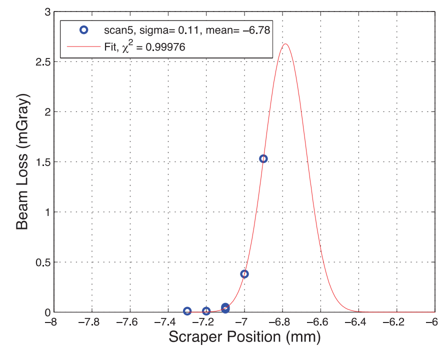

Figure 5: Beam profile acquired by the operational scraper scan after the beam cleaning onto the TPSG; an orbit amplitude of 36 mm and 1.11 mrad was used.

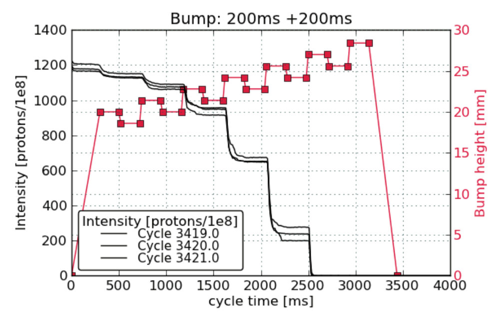

Figure 6: Beam scraping within one SPS cycle in steps of 200 ms separated by 200 ms.

CONCLUSIONS

A new magnetic beam cleaning system was designed and proposed for the future SPS operation for LHC beams. During machine studies, the concept of cleaning/scraping with a fixed scraper was demonstrated. The feasibility of beam cleaning within one SPS cycle was shown. In addition of being a fast and efficient cleaning tool, a magnetic fixed scraping system was proven to be useable as beam profile monitor. The overall beam scraper study is documented in a Technical Design Report [2].

REFERENCES

[1] V. Kain, "Injection – Issues and Potential Solutions" Chamonix LHC Performance Workshop (2011).

[2] L. Drøsdal, "SPS Scraping and LHC Transverse Tails", MOPWO032, IPAC2013.

[3] "Technical Design Report of the LIU SPS Scraping System" (in progress).

[4] H. Vincke, "Preliminary RP Remarks", LIU-SPS Scraping System Review.

[5] Ö. Mete et al., "Fixed Scraping Concept", EDMS#1254658 and EDMS# 1252467, SPS MD Reports.