BEAM SCRAPING FOR LHC INJECTION

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Abstract

Operation of the LHC will require injection of very high intensity beams from the SPS to the LHC. Fast scrapers have been installed and will be used in the SPS to detect and remove any existing halo before beams are extracted, to minimize the probability for quenching of superconducting magnets at injection in the LHC. We briefly review the functionality of the scraper system and report about measurements that have recently been performed in the SPS on halo scraping and re-population of tails.

INTRODUCTION

Nominal LHC injection intensities require extraction of up to 288 bunches of 1.15×10^{11} or together about 3.3×10^{13} protons in 4/11 of an SPS turn or 7.86 μs. This intensity exceeds the damage level (about 2×10^{12}) by over one order of magnitude and quench limits in the LHC (about 5×10^9 protons) by nearly four orders of magnitude.

Injection into the LHC will have to be very clean and safe. Several systems have been designed for this purpose.

For a more quantitative discussion, we will refer to aperture and beam sizes in multiples n_σ of the nominal r.m.s beam size. Most critical at injection is the physical LHC aperture in the arcs. Including tolerances, it corresponds to about $7.5\,\sigma$. The injected beams traverse several LHC arc sections before they reach the collimation sections.

The main tail diagnostics and cleaning device for LHC injection are the SPS-scrapers described here.

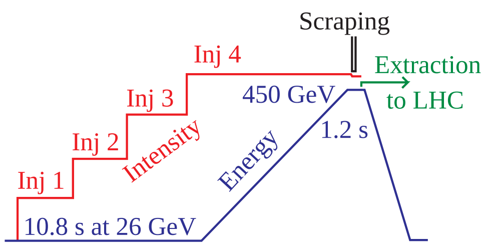

Figure 1: Schematic view of an SPS cycle for LHC injection. Protons are injected into the SPS at 26 GeV in several batches and then accelerated to 450 GeV. Beams will be scraped at about $3.5\,\sigma$ during the 1.2 second long plateau at 450 GeV before they are sent to the LHC.

As illustrated in Fig. 1 the scraping will be done at top energy in the SPS before the beam is sent to the LHC. The scrapers allow to detect and remove the beam halo. Under normal conditions, with initially gaussian beams at nominal emittance, the planned scraping at $3.5\,\sigma$ would only reduce the intensity by 0.2% and the luminosity by 1.4×10^{-3} in each the horizontal and vertical plane [1].

The beams extracted from the SPS will pass through nearly 3 km long transfer lines, the injection septa and will finally be vertically kicked on the central orbit in the LHC. The transfer lines are pulsed and failures cannot completely be excluded. They are equipped with collimators (TCDI) which will be set at $4.5\,\sigma$ and limit maximum amplitudes to $6.5\,\sigma$ [2]. The LHC itself is equipped with vertical absorbers (TDI, TCLI) designed to avoid damage in case of kicker failures. The TCDI, TDI and TCLI are single pass devices. They can take the full injection intensity in case of failures and provide for sufficient absorption and dilution to avoid damage (but not quenching) at injection in the LHC.

SPS SCRAPERS FOR LHC INJECTION

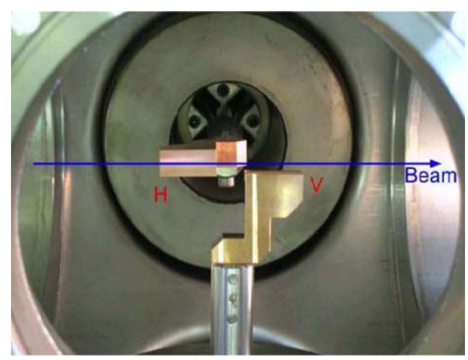

Figure 2: Scraper with H and V Cu jaws.

Fig. 2 shows a picture of the SPS scrapers as currently installed in the SPS. Both the horizontal and vertical 30 mm long Cu jaws are visible.

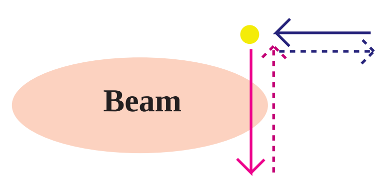

Figure 3: Schematic representation of the jaw movements for scraping of horizontal tails.

Fig. 3 illustrates how the scrapers move. The scrapers are normally fully retracted. Before the scraping, they are moved closer to the beam to an intermediated parking position. The scraper jaw moves vertically (horizontally) through the beam halo to scrape the horizontal (vertical) tails. The horizontal (vertical) position of the horizontal (vertical) scraper jaws can be adjusted with a precision of

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$10\,\mu$m by means of stepping motors. The sweeping speed of the jaws through the beam is 0.2 m/s.

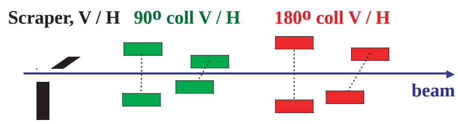

Figure 4: Scrapers and collimators.

The scrapers are followed in the SPS after approximately 90 and $180°$ phase advance by collimators, to allow to absorb the protons which are scattered in the scraper jaws, see Fig. 4. At present, the collimators can only be moved slowly and should normally remain at one fixed position during the SPS cycle. At constant normalized emittance, the transverse beam sizes decrease by a factor of $\sqrt{450/26} = 4.1$ during the acceleration in the SPS. The collimators will typically be set to about 3.5σ at 26 GeV which corresponds to about $15\,\sigma$ at 450 GeV.

More details on the hardware and results for earlier tests are given in [3]. A detailed functional specification can be found in [4]. It is forseen to upgrade the scraper system and to add a scraper jaw at $45°$ between the H and V planes to allow for scraping in diagonal direction, to better match the effectively round cold LHC ring aperture.

The current SPS scrapers were originally constructed for the ISR and have previously been used in the SPS in a different ring position, primarily as machine development tool at low intensity. They were moved in the long 2004 to 2006 SPS shutdown to a new position (SPS vacuum section 51659) which is more favorable for beam cleaning, with similar horizontal and vertical beta functions ($\beta_x = 53\,\mathrm{m}, \beta_y = 46\,\mathrm{m}$ and small dispersion ($D_x = 0.2\,\mathrm{m}$, $D_y = 0$). At the nominal $3.5\,\mu\mathrm{m}$ emittance, $1\,\sigma$ corresponds to 0.6 mm and scraping at $3.5\,\sigma$ to scraping at 2.1 mm from the beam axis.

The position of the beam axis at the scrapers can be extrapolated from orbit measurements and checked by scraping up to 100% for small beam intensities. The SPS orbit at top energy is very stable and we can expect that readjustments will only rarely be needed.

Alternatively, the scraper positions could also be adjusted such that they remove about 0.2% under stable conditions. This could also be applied in case of smaller than nominal emittances and would allow for more margin in aperture at LHC injection.

OBSERVATIONS IN RECENT TESTS

We now describe a series of tests and measurements which were performed in 2006 in the SPS.

The first tests were mainly used to technically recommision the system. An important issue was to check and resolve interlock and timing issues and to demonstrate that the scrapers can be used reliably and reproducibly.

We recorded beam intensities (BCT signals) and observed loss signals from three different monitors : scintillators installed close to the scrapers, standard SPS ring loss monitors and LHC loss monitors which have been installed in the SPS for tests. Wire scans were used to measure emittances. The measurements were performed with a small number (mostly 4) bunches in the SPS and at moderate intensities of few 10^{10} protons per bunch. SPS emittances and scraping was found to be very reproducible under these conditions, see Fig 5.

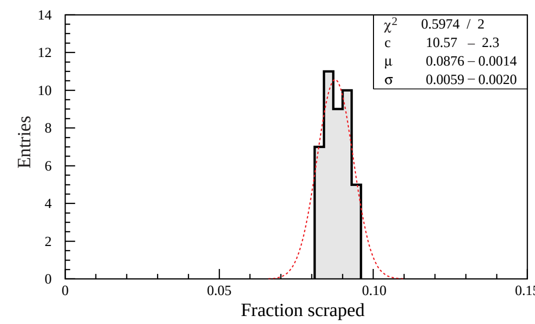

Figure 5: Reproducibility observed in horizontal tail scraping over 42 subsequent SPS cycles. The observed mean loss and cycle to cycle variation was $8.8 \pm 0.4\%$. The dashed curve and numbers show the result of a Gaussian fit to the observed histogram. A similar reproducibility was also observed in vertical scraping.

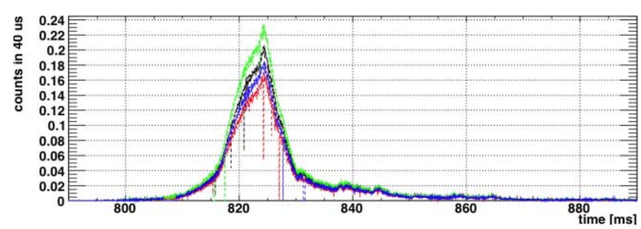

Figure 6: Beam loss signals versus time, recorded during a horizontal scraping of about 10% of the beam intensity.

The loss monitors are very sensitive and allow to adjust scraping at larger amplitudes than would be possible based on the BCT signals. Fig. 6 shows beam loss signals recorded in the SPS using the LHC-type beam loss monitors for horizontal scraping. The fast rise in loss rate observed is compatible with the speed at which the scrapers move (2 mm in 10 ms). The observed decay rate of about 5 ms or 200 SPS turns matches with predictions based on simulations for particles which are lost after multiple passages through the scraper [4].

Measurements in coast at 270 GeV

The 450 GeV plateau length of 1.2 sec is sufficient for cleaning and extraction to the LHC but too short to study tail-repopulation using multiple scraper passages through the beam.

The SPS can be operated in a mode in which the energy is kept constant after acceleration for minutes or hours. The maximum energy in this mode is 270 GeV. This was used in our last study in 2006 to measure re-population times.

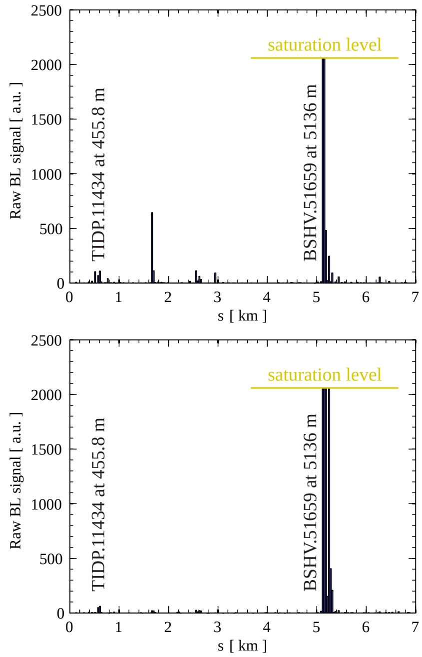

Figure 7: Loss distributions recorded for horizontal scraping at nominally 3 mm. Collimators were set to approximately 15 mm as compatible with injection in the top plot and to about 7 mm in the bottom plot.

The measurements in coast also allowed to move the collimators closer to the beams than possible in pulsed mode with injection. Fig. 7 shows the loss distributions which were recorded during horizontal scraping. We found in all cases, even with collimators fully retracted, that most of the particles get lost within 300 m downstream of the scrapers (labelled BSHV.51659). A small amount is lost at the TIDP.11434 block at 455.8 m which is set to 31 mm from the beam axis and serves primarily as off momentum collimator at injection and for the beginning of the ramp in the SPS.

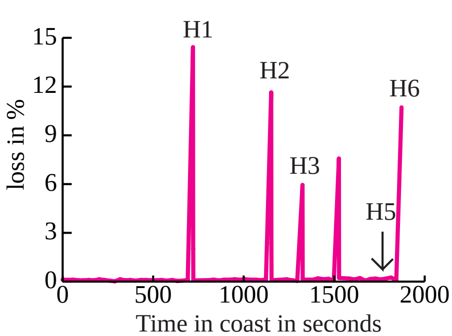

Figure 8: Losses observed in 6 horizontal scraper passages at nominally 3 mm, corresponding to about 2 σ. The 5th scraping (H5) was done at 4 mm and did not result in any significant intensity reduction.

Fig. 8 shows the reduction in intensity measured when scraping horizontally, at time intervals of the order of 100 s. To our surprise, we found significant tail re-population of the order of $2 - 3 \times 10^{-3}$/s. Changing tunes and turning off the rf-voltage had not significant effect. A possible cause is the transverse feedback which remained on during these measurements. Fig. 9 shows the result of two vertical scrapings performed in the same machine study under otherwise identical conditions. 5.63% of the initial population was removed in the first scraping. A second vertical scraping after about 8 minutes removed about 0.35% of the beam, corresponding to a tail repopulation of 0.007×10^{-3}/s or 200 less than in the horizontal plane.

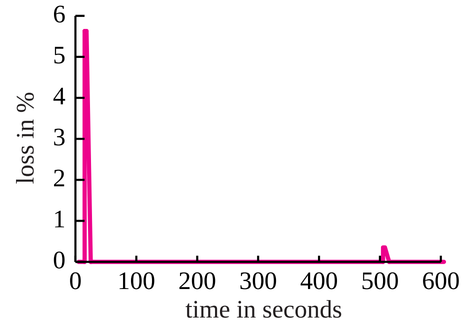

Figure 9: First and second vertical scraping after about 8 minutes, at nominally 1 mm from the beam in both cases.

SUMMARY AND FUTURE PLANS

The SPS scrapers are required to assure that the extracted beams are clean, to minimise the probability of quenches at injection of high intensity beams into the LHC. We have performed a series of tests at maximum SPS energy. The tests were performed using a small number of bunches and low level control software. We find that the scrapers work reproducibly under these conditions. To make the present scrapers operational will require work on interlocks, tests at higher intensities and high level control software.

It is planned to add a third diagonal scraper and to work on further upgrades or more likely a new system to assure long term reliability to full specification.

REFERENCES

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