SPS SCRUBBING RUN IN 2014

H. Bartosik, G. Iadarola, G. Rumolo, CERN, Geneva, Switzerland

Abstract

Yearly machine scrubbing has been applied in the SPS since 2002 in order to reduce the amount of electron cloud in the machine and permit smooth operation with 25 ns beams. While a quick scrubbing is usually necessary to recover performance after any extended technical stop due to in vacuum deconditioning, a longer period needs to be envisaged when the machine stop is long and a large fraction of the machine is exposed to air. Therefore, the restart of the SPS after LS1 will offer a unique opportunity to qualify the machine degradation due to a long stop as well as quantify length and efficiency of a scrubbing run to recover the previous performance and possibly extend it to higher intensity beams. This information will be the key input to decide on the upgrade strategy for the SPS, as it will show whether the SPS can be operated with scrubbing also for future intensities or electron cloud needs to be actively suppressed through a-C coating. Goals, requirements (in terms of beam and instrumentation) and a possible planning of the SPS scrubbing run in 2014 will be covered by this presentation. In this context, we will also describe the doublet beam, which can be potentially used for enhancing the scrubbing efficiency.

INTRODUCTION

The electron cloud effect has been identified as a possible performance limitation for the SPS since LHC type beams with 25 ns spacing were injected into the machine for the first time in the early years of 2000. At that time a severe pressure rise was observed all around the machine together with transverse beam instabilities, important losses and emittance blow-up on the trailing bunches of the train [1]. Since 2002, Scrubbing Runs with a duration of one or two weeks were carried out almost every year of operation in order to condition the inner surfaces of the vacuum chambers and therefore mitigate the electron cloud. These Scrubbing Runs were usually performed at 26 GeV in cycling mode (with a cycle length of about 40 s) and are typically limited by heating and/or outgassing of critical machine elements (e.g. kickers, extraction septum, beam dump, . . .). The electron dose accumulated on the vacuum chambers throughout the years allowed achieving a very good conditioning state of the SPS in 2012, both in terms of dynamic pressure rise and beam quality. During the Scrubbing Run of the LHC at the end of 2012, the 25 ns beam was regularly extracted from the SPS Q20 optics with four batches of 72 bunches with $N \approx 1.2\times10^{11}$ p/b and normalized transverse emittances of about 2.6 μm [2]. Extensive machine studies showed that for this beam intensity the 2012 conditioning state of the SPS is sufficient for suppressing any possible beam degradation due to electron cloud on the cycle timescale [3].

THE 2014 SPS SCRUBBING RUN

While a quick scrubbing is usually necessary to recover performance after any extended technical stop due to in vacuum deconditioning, a longer period needs to be envisaged when the machine stop is long and a large fraction of the machine is exposed to air. The goals for the 2014 Scrubbing Run are therefore to qualify the loss of conditioning due to Long Shutdown 1 (LS1), to recover the 2012 performance with 25 ns beams and to quantify amount of beam/time needed for this recovery. The qualification criteria will be based on beam measurements. Ideally, 4 batches of the 25 ns beam with an intensity of up to 1.3×10^{11} p/b and emittances below nominal with no blow-up along the train should be achieved by the end of the allocated scrubbing time, which corresponds to the beam parameters achieved during machine development studies in 2012. Furthermore, it is planned to test the scrubbing efficiency of the doublet beam, which will be discussed in more detail below. The results of this Scrubbing Run will be the basis for setting the LIU strategy on electron cloud mitigation, i.e. the decision coating vs. scrubbing.

In the original planning of the 2014 Injector Schedule the Scrubbing Run was planned for two consecutive weeks (Weeks 39-40) before the start-up of the NA physics. In the end, the Scrubbing Run was split into a 7 day block in Week 45 plus an additional two-day mini-block in Week 50. Splitting the scrubbing run into two blocks was requested by the LIU-SPS due to several reasons:

- It gives time to analyze the first block?s results and adapt the strategy for the second block accordingly.
- It allows to Untangle the scrubbing from the machine commissioning, NA setup and vacuum conditioning of all the newly-installed or vented equipment.
- It allows for the setting up of the doublet scrubbing beam before the second scrubbing block and so its potential to scrub the SPS can be explored already in 2014. The experience gained will be also useful for the preparation of the LHC scrubbing in 2015.

In the first scrubbing block the intensity with 25 ns beams will be ramped up during the first three days (ideally up to 5 injections – trying to push bunch intensity up to 1.5×10^{11} p/b) on a long 26 GeV cycle. The aim is to accumulate as much electron dose as possible and to monitor the evolution of beam parameters for both coherent and incoherent effects. During the remaining days, studies of residual electron cloud effects on beam lifetime and quality could be performed for the nominal beam (e.g. emittance growth, bunch shortening over long flat bottom) while keeping the vertical chromaticity at the minimum value that is required for beam stability. This scrubbing qualification includes beam quality measurements on both the long 26 GeV cycle and at the LHC filling cycle with acceleration to 450 GeV.

By the time of the second scrubbing block in Week 50 the doublet beam could be ready to be used for scrubbing in the SPS. The results of the tests with the doublet beam, such as the scrubbing efficiency and first experience with acceleration to 450 GeV will be important for the LHC scrubbing in 2015 [4].

THE DOUBLET SCRUBBING BEAM

Several studies have been devoted in 2012 to the optimization of the scrubbing process and in particular to the definition and test of a possible "scrubbing beam", i.e. a beam produced specifically for scrubbing purposes, providing a higher scrubbing efficiency compared to the standard LHC type 25 ns beam. A 25 ns spaced train of "doublets", each of these consisting of two 5 ns spaced bunches, has been proposed [5]. As shown in Fig. 1, PyECLOUD simulations predict that this beam has indeed a significantly lower multipacting threshold for large enough intensities compared to the standard 25 ns beam due to the shorter empty gap between subsequent doublets, which enhances the accumulation of electrons in the vacuum chambers of the SPS MBA and MBB type dipoles. For producing this beam with the existing RF systems of the injectors, long bunches from the PS ($\tau \approx 10$ ns full length) have to be injected into the SPS on the unstable phase of the 200 MHz RF system and captured in two neighboring buckets by raising the voltage within the first few milliseconds. Very good capture efficiency (above 90%) could be achieved for intensities up to 1.7×10^{11} p/doublet.

Figure 2 (top) shows the evolution of the longitudinal profile of the beam during the "splitting" right after the injection in the SPS. Figure 2 (bottom) shows the "final" beam profile, measured one second after injection. It was also verified that it is possible to rapidly lower the RF voltage and inject a second train from the PS without any important degradation of the circulating beam. Observations on the dynamic pressure rise in the SPS arcs confirmed the enhancement of the electron cloud activity as expected from PyECLOUD simulations. The enhancement was also observed with the dedicated SPS strip detectors as shown in Fig. 3 for the two SPS vacuum chamber types, MBA and MBB, where the electron cloud profiles measured with the standard 25 ns beam and with the doublet beam are compared for the same total intensity. In this experiment with a single batch from the PS, electron cloud formation in the MBA is only observed with the doublet beam due

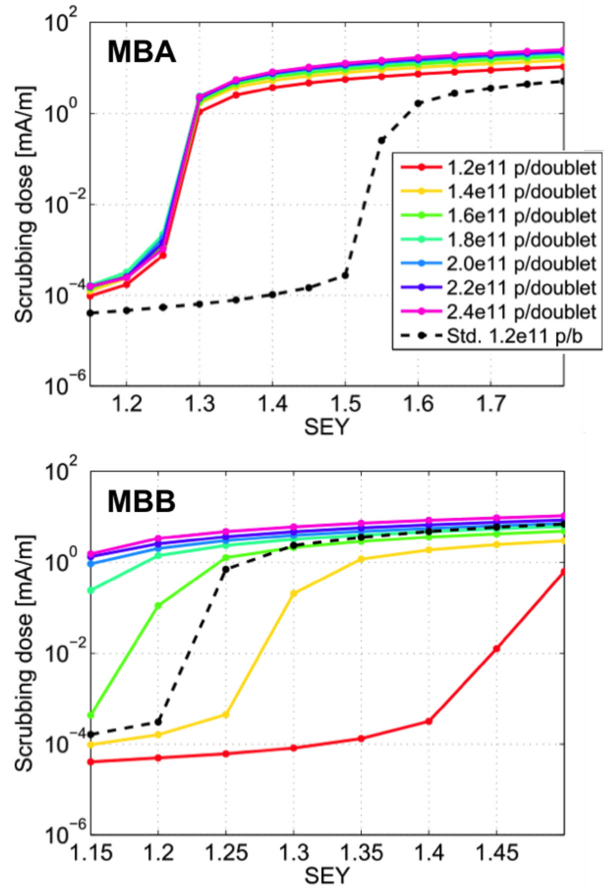

Figure 1: Scrubbing dose as a function of the SEY for different beam intensities of the doublet beam (coloured lines) in comparison to the nominal LHC beam (dashed lines) in the MBA and the MBB type dipole chambers of the SPS at injection energy.

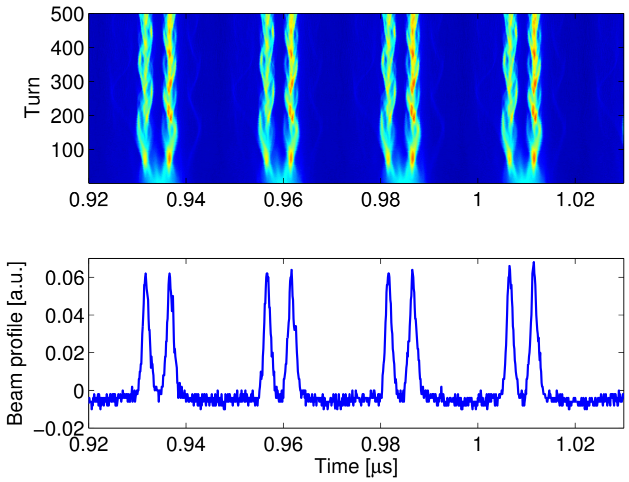

Figure 2: Evolution of the longitudinal beam profile in the SPS during the splitting at injection for the production of the doublet beam (top) and longitudinal bunch profiles of the doublet beam measured 1 s after injection (bottom).

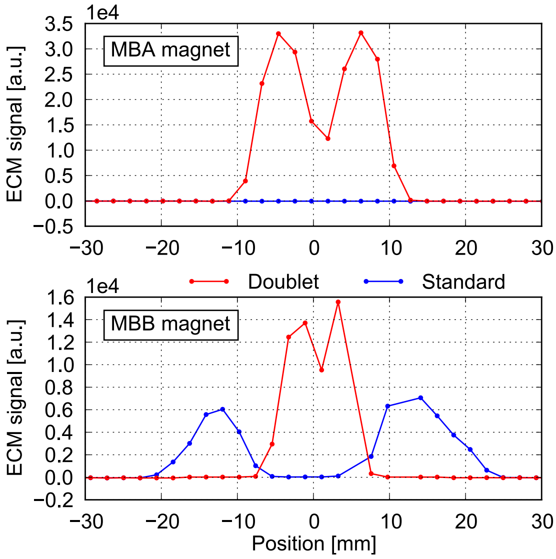

Figure 3: Electron cloud profiles measured in the strip detectors with MBA (top) and MBB (bottom) chambers with the standard 25 ns beam and with the doublet beam (same total intensity, 72 bunches from the PS with $N \approx 1.65 \times 10^{11}$ p/b).

to its lower multipacting threshold compared to the standard beam. In the MBB, where the nominal beam was still able to produce electron cloud, a clear enhancement of the peak electron density can be observed. It is important to note that the electron cloud produced by the doublets does not cover the full region to be conditioned for the standard beam. Therefore it is necessary to periodically displace the beam (using radial steering and orbit correction dipoles) during the scrubbing in order to achieve a satisfactory conditioning across the chamber surface.

The SPS transverse feedback system has been upgraded during LS1 and has now a special mode for the doublet beam, in particular for coping with the transients during the bunch splitting at injection. The new system needs to be commissioned for all beam types and tested for the first time for the doublet beams. Furthermore, the SPS beam quality monitor (BQM) software has been also prepared to work for the doublet beam. This will be important in particular for the LHC, which might have to rely on the doublet beam for scrubbing in 2015, provided that 1) the required intensity for LHC scrubbing can be stably and successfully accelerated in the SPS, possibly on a cycle with slow acceleration, and transferred to the LHC, and 2) the interlock threshold on the BPMs in IR6 can be reduced according to the results on error studies for unbalanced doublets foreseen at the SPS in 2014 and at the LHC with single doublets in 2015 [4].
If we can produce and preserve a good quality (two batches, large bunch intensity), this beam will be already used during the two-day mini-scrubbing run at the end of the 2014 run. The acquired experience will be very important for the definition of the LIU-SPS strategy with respect to e-cloud and scrubbing as well as for the success of the LHC scrubbing in 2015.

SCRUBBING REQUIREMENTS

The main goal of the 2014 scrubbing run is to maximise the scrubbing efficiency. For this purpose, the following beam will be needed from the pre-injectors:

- 25 ns beam (standard production scheme and BCMS) with intensity up to 1.5×10^{11} p/b;
- 25 ns beam (standard production scheme and BCMS) with intensity up to 1.7×10^{11} p/b (as back up);
- 25 ns beam for doublet production with intensity up to 1.5×10^{11} p/b, long bunches at the PS extraction.

At same time, in order to collect new information about electron cloud effects and scrubbing in the SPS, it will be necessary to record data from the following instruments:

- Beam Current Transformers (BCT, FBCT);
- Beam Quality Monitor (BQM), mountain range (MR), Faraday cage scope;
- BBQ tune-meter, LHC type Beam Position Monitors (BPMs), Headtail monitor, fast pickup from High Bandwidth Transverse Feedback setup, new digitizers on BPW exponential pickups;
- Beam Gas Ionization (BGI) Monitor, Beam Synchrotron Radiation Telescope (BSRT), Beam Wire Scanners (BWS) in bunch by bunch mode;
- Pressure gauges along the ring (1 Hz sampling rate, with special attention to the a-C coated cells);
- Dedicated e-cloud equipment, i.e. electron cloud monitors (with lMBA StSt, MBB StSt, MBB a-C, MBB copper liners), shielded pickup, in situ SEY measurement (if available), removable StSt sample (for lab SEY measurement), COLDEX.

SUMMARY AND CONCLUSIONS

In the past, the SPS was strongly limited by electron cloud and it is likely to suffer again from electron cloud in the range of intensities required by LIU. After several dedicated SPS scrubbing runs between 2002 and 2012, beam induced conditioning proved to be an effective mitigation for electron cloud effects for 25 ns beams up to nominal intensity, so that 25 ns beams could be delivered to LHC in 2012 well within design report specifications.

A scrubbing run is foreseen in 2014 to recondition the SPS after LS1, since large parts of the machine were exposed to air. In the first block (7 days in Week 45), the main goals are to: 1) qualify the loss of conditioning due to LS1, and 2) recover the 2012 performance with 25 ns beams. The second block will only last 2.5 days (week 50) and will aim to test scrubbing with doublet beams (also in view of LHC in 2015 and for the future challenging LIU beam intensities). The experience gained will be invaluable to take the final LIU decision about the coating of SPS magnet chambers. The success of the 2014 scrubbing run will strongly rely on an adequate beam preparation from the pre-injectors and the correct functioning of all key beam diagnostics instruments in the SPS.

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