RECENT ELECTRON CLOUD STUDIES IN THE SPS

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Abstract

It is important to qualify the present status of the SPS with respect to the electron cloud before the Long Shutdown of the CERN accelerator complex, which is taking place in 2013-2014. Therefore several electron cloud studies were performed during the 2012 run in order to get a full characterization of the behavior of the SPS with the LHC-type beams with 25 ns bunch spacing, which can be very sensitive to electron cloud effects. The collected information should allow to understand up to which extent this long period without beam operation - and the related interventions on the machine - will degrade the present conditioning state of the SPS, which has been achieved by "scrubbing" over several years. Several measurements with different beam conditions have been collected also on the electron cloud detectors installed in the machine. These results, in combination with detailed simulation studies, will provide the basis for defining strategies of electron cloud mitigation as required for the production of future high intensity and high brightness beams within the LHC Injectors Upgrade project.

INTRODUCTION

The Electron Cloud (EC) effect has been identified as a possible performance limitation for the CERN Super Proton Synchrotron (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, a *Scrubbing Run* with 25 ns beams was carried out almost every year of operation in order to condition (*scrub*) the inner surfaces of the vacuum chambers and therefore mitigate the EC. This allowed to achieve a good conditioning state of the SPS up to 2012, both in terms of dynamic pressure rise and beam quality. Most probably this good conditioning state will be degraded during the machine shutdown (2013-2014) due to the long period without beam operation and the related interventions on the machine. Therefore, it is important to qualify the present status of the SPS with respect to the EC in order to understand how difficult it will be to recover similar performance after the machine restart. Furthermore, within the LHC Injectors Upgrade (LIU) project, it is necessary to assess up to which extent EC effects could limit the production of the high intensity and high brightness beams foreseen for the upgrade and to define suitable mitigation strategies [2].

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BEAM OBSERVATIONS

With respect to EC effects, the injection plateau is the most critical part of the SPS cycle for LHC filling since the beam has to be stored for more than 10 s to accommodate four injections from the PS. Therefore in 2012 several Machine Development (MD) sessions were devoted to study the behavior of the 25 ns beams at injection energy in order to identify possible beam degradation from EC effects.

Using a new operation mode of the SPS wire scanners, the evolution of the transverse emittances could be measured bunch by bunch showing no blow-up when storing the full bunch train with nominal intensity (1.15×10^{11} ppb, 4×72 bunches) for more than 10 s at injection energy [3]. Moreover the best beam lifetime was obtained with small positive vertical chromaticity settings while in the past large chromaticity was needed for curing fast EC driven instabilities. This confirms that scrubbing accumulated over the years was enough to suppress any beam degradation due to EC effects for the nominal bunch intensity on the cycle timescale and indeed this beam could be regularly delivered to the LHC for the scrubbing run towards the end of 2012 [4]. Further experiments performed on the LHC filling cycle with the SPS low γ_t optics [5] showed that it was possible to inject the full train of the 25 ns beam with up to $\sim 1.35 \times 10^{11}$ ppb without transverse emittance blow-up and preserve the beam quality up to ex-

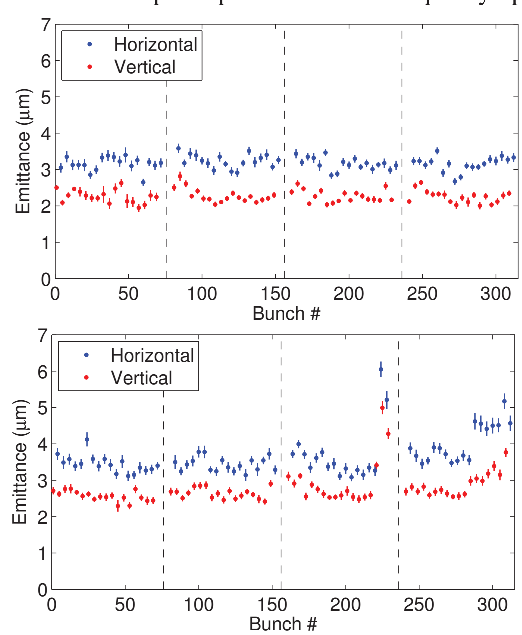

Figure 1: Bunch by bunch emittances measured at SPS extraction energy for 4×72 bunches of the 25 ns LHC beam with 1.34×10^{11} ppb injected (top) and 1.44×10^{11} ppb injected (bottom).

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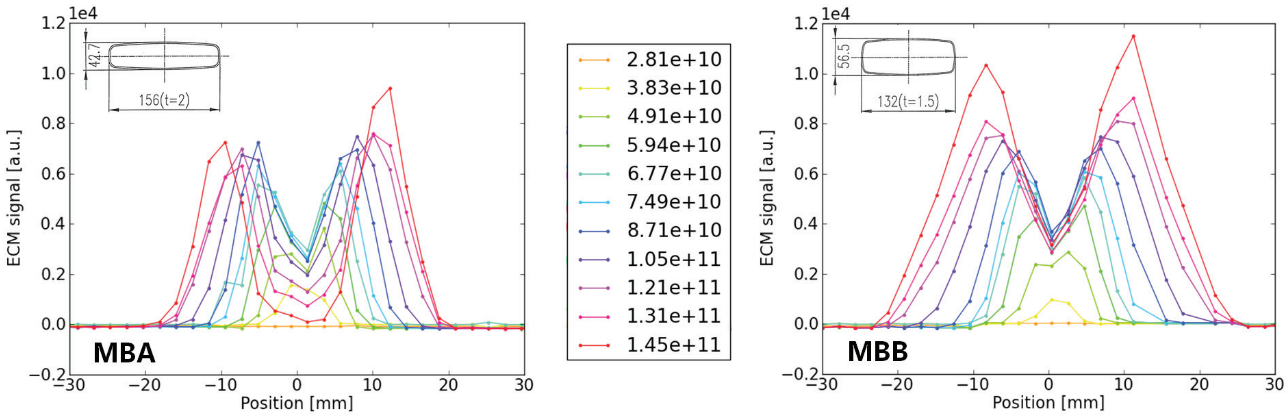

Figure 2: Horizontal distribution of the electron flux measured in two strip detectors with MBA (left) and MBB (right) shaped chambers (shown in the insets) for 72 bunches with 25 ns spacing for different bunch intensities.

traction energy, as shown in Fig. 1 (top). For higher intensities ($\sim 1.45 \times 10^{11}$ ppb injected) a transverse instability was observed after the injection of the third and of the fourth batch, leading to emittance blow up (see Fig. 1, bottom) and particle losses on the trailing bunches of the injected trains. The observed pattern on the bunch by bunch emittance is typical for EC effects but other sources (e.g. impedances) also need to be further investigated.

EC MEASUREMENTS

In 2012, during the scrubbing run and the MD sessions, several measurements with different beam conditions were collected on equipment dedicated to EC studies. These included: 1) a shielded pickup placed in a straight section, which allows to resolve the evolution of the EC along the passage of the bunch train; 2) strip detectors which provide the horizontal profile of the EC density and are placed in dipole magnets with different chamber shapes; 3) a microwave transmission setup which can detect the phase modulation introduced by the EC on a traveling wave; 4) a clearing electrode prototype from KEK, Japan; 5) a StSt sample exposed to the beam in a dipole magnet and then transferred under vacuum to a Secondary Electron Yield (SEY) measurement setup; 6) magnets and drift sections coated with amorphous carbon (a-C) and equipped with pressure gauges, for the validation of the EC suppression technique by a-C coating, which is being developed at CERN. The vacuum pressure on all the Penning gauges along the SPS ring was also logged during these EC studies. The main results of these activities have been summarized in [3].

Particular emphasis has been given to the investigation of the dependence of the EC build-up on the bunch intensity since this aspect is crucial for the LIU upgrade. Figure 2 shows the EC profile measured for different bunch intensities at injection energy on two strip detectors with vacuum chambers reproducing those installed in the two kinds of SPS main dipoles (MBA, MBB). The observed dependence on the bunch intensity is consistent with the predictions of the simulation models. No EC flux is observed in either chamber type for intensities lower than $3 \cdot 10^{10}$ ppb. For relatively small intensities ($3 \cdot 10^{10}$ ppb to $5 \cdot 10^{10}$ ppb) the electrons are confined within a thin stripe around the beam location, while for higher intensities the two stripes configuration typical for the EC build-up in bending magnets with LHC beams becomes more evident. The intensity increase leads to a widening of the region covered by the EC but at the same time the region closer to the beam (which should be the most critical concerning beam quality) exhibits a decrease in the electron population, especially for the MBA chamber. A stronger flux is observed in the outer regions of the chamber which were not reached by scrubbing performed before the measurements with the nominal bunch intensity.

For the validation of the a-C coating technique, the dynamic pressure rise, which is still observed on gauges close to the a-C coated magnets, has been investigated using a dedicated setup consisting of a long a-C coated drift tube equipped with solenoids [3]. These tests confirmed that the observed pressure rise is not coming from EC in the coated section itself but is mostly due to multipacting in the neighboring machine elements.

“DOUBLET” SCRUBBING BEAM

For the LIU project it is important to understand whether a mitigation strategy based on scrubbing only will be sufficient also for the future beam parameters or electron cloud suppression through a-C coating of a large part of the SPS vacuum chambers will be necessary. In this framework several studies have been devoted to the optimization of the scrubbing process and in particular to the definition and test of a possible ”scrubbing beam”, i.e. a beam to be produced specifically for scrubbing purposes, providing a higher scrubbing efficiency compared to the standard LHC type 25 ns beam.

Simulations showed that a possible candidate is a 25 ns spaced train of “doublets”, each of these consisting of two 5 ns spaced bunches. This beam has indeed a lower multipacting threshold compared to the standard 25 ns beam due to the shorter empty gap between subsequent doublets,

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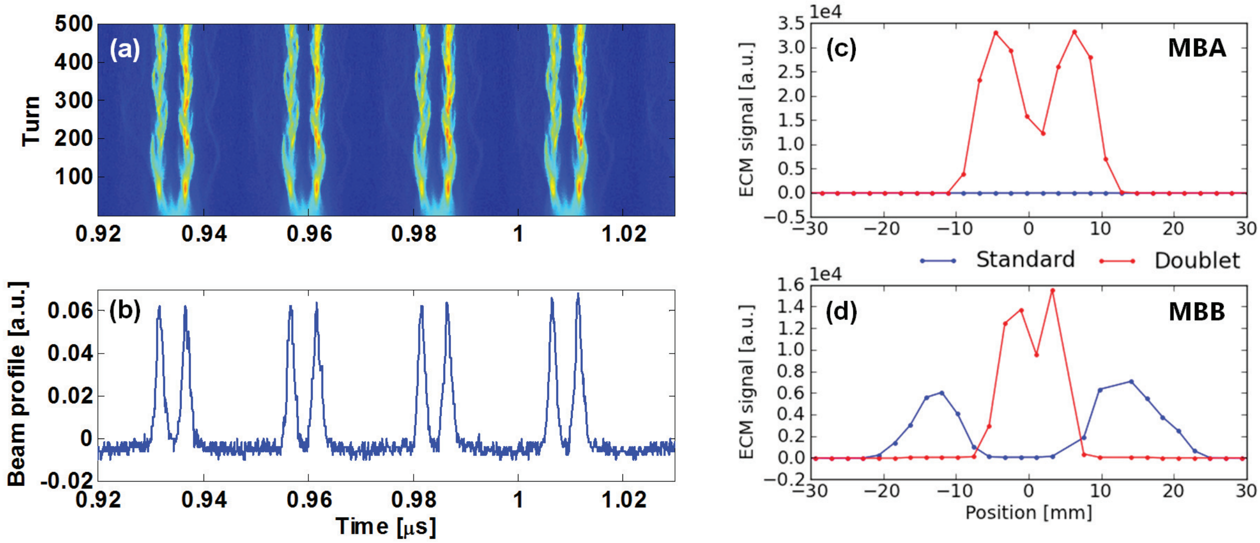

Figure 3: (a) Evolution of the longitudinal beam profile right after the injection in the SPS, during the splitting for the production of the doublet beam; (b) Longitudinal beam profile measured on the doublet beam 1 s after injection (courtesy of J. Esteban Muller and T. Argyropoulos); (c,d) electron cloud profiles measured with the strip detectors with MBA and MBB like chambers with the standard 25 ns beam and with the doublet beam (same total intensity, 72 bunches from the PS, $\sim 1.65 \cdot 10^{11}$ ppb).

which enhances the accumulation of electrons in the vacuum chamber. No easy solution was found to either produce these beams in the PS and transfer them bunch-to-bucket into the SPS, nor to produce them in the SPS with slip stacking. Alternatively, long bunches from the PS (∼10 ns full length) were 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.

Experiments were performed during MD sessions in 2012-2013 in order to test and optimize this injection scheme. A very good capture efficiency (above 90%) could be achieved for intensities up to $1.7 \cdot 10^{11}$ protons per doublet, when injecting with V_{RF}=1 MV and increasing it to V_{RF}=3 MV in 2 ms. Figure 3 (a) shows the evolution of the longitudinal profile of the beam during the "splitting" right after the injection in the SPS. Figure 3 (b) shows the "final" beam profile, measured one second after injection. It was also possible to verify 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.

Measurements with strip detectors as well as observations on the dynamic pressure rise in the SPS arcs could confirm the enhancement on the EC activity, which was expected from simulations. For example, Figs. 3 (c) and (d) compare the EC profiles measured in the strip detectors with the standard 25 ns beam and with the doublet beam, for the same total intensity (72 bunches from the PS, $\sim 1.65 \cdot 10^{11}$ ppb). For the MBA the conditioning accumulated before the experiments was enough to suppress the EC formation with a single injected train (72 bunches) of the standard 25 ns beam. In contrast to that a clear EC signal could be measured with the doublet beam with the same total intensity confirming the lower multipacting threshold as predicted by simulations. Concerning the MBB, where the nominal beam was still able to produce EC (even if in a smaller amount compared to Fig. 2 due to the scrubbing accumulated between the two measurements), a clear enhancement of the peak electron density can be observed, following the distribution expected from simulations. It is important to note that the EC 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.

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