ELECTRON CLOUD STUDIES FOR THE UPGRADE OF THE CERN PS

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Abstract

The observation of a significant dynamic pressure rise as well as measurements with dedicated detectors indicate that an electron cloud develops in the CERN PS during the last stages of the RF manipulations for the production of LHC type beams, especially with 25 ns bunch spacing. Although presently these beams are not degraded by the interaction with the electron cloud, which develops only during few milliseconds before extraction, the question if this effect could degrade the future high intensity and high brightness beams foreseen by the LHC Injectors Upgrade project is still open. Therefore several studies are being carried out employing both simulations and measurements with the electron cloud detectors in the machine. The aim is to develop a reliable electron cloud model of the PS vacuum chambers in order to identify possible future limitations and find suitable countermeasures.

INTRODUCTION

Electron Cloud (EC) effects have been observed at the CERN Proton Synchrotron (PS) during the last stages of the cycle of the production of the LHC type beams. The first observations date back to 2001 when a distortion of the baseline was observed on electrostatic pickup signals both in the PS ring and in the transfer line towards the SPS [1]. In 2006 transverse instabilities immediately before extraction were observed for short bunches [2], and in 2007 an EC test setup with two shielded pickups was installed in one of the straight section of the ring and direct measurements could confirm the presence of EC in the vacuum chamber [3]. It is quite likely that EC is developing also in the main magnets, which constitute about 70% of the total length of the PS, but there is no direct confirmation since dedicated diagnostics will only become available after the 2013-2014 machine shutdown [4].

Despite these considerations, EC in the PS presently does not represent a limitation for the production of the LHC type beams. For example, in 2012 bunch by bunch transverse emittance measurements were performed in the SPS on LHC type beams with 25 ns spacing, for bunch intensities up to around 1.45×10^{11} ppb, and no EC signature was observed on the emittance pattern coming from the PS.

The reason for the absence of any visible degradation is that the beam does not interact with the EC for a sufficiently long time, since the structure of the beam becomes prone to the production of the EC only few tens of milliseconds before the extraction. This happens when the last

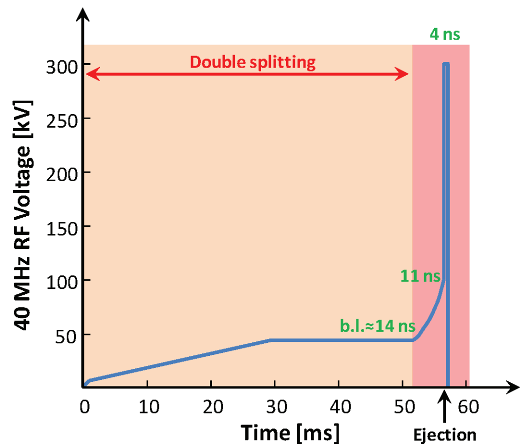

Figure 1: RF voltage (40 MHz) program during the last stages of the cycle for the production of the LHC type beams. The total (4σ) bunch length is reported in green.

bunch splitting is performed, giving the final pattern with 72 bunches and 25 ns spacing. As schematically shown in Fig. 1, the last bunch splitting starts ~57 ms before the extraction, with the ramp-up of the 40 MHz (h_{RF}=84) RF voltage, and it is completed less than 10 ms before extraction, after the end of the ramp-down of the 20 MHz RF system voltage. At this point the bunches are still about 14 ns long and need to be shortened to fit the 5 ns buckets in the SPS. This is done in two stages, namely: 1) an adiabatic shortening in which the RF voltage is increased in 5 ms from 40 kV to 100 kV achieving bunch lengths of about 11 ns and 2) a non adiabatic "bunch rotation" performed by pulsing the RF voltage up to 300 kV (and using also a second harmonic RF system at 80 MHz) in order to finally reduce the bunch length to values of about 4 ns.

Already in 2001, an experiment was performed removing the bunch rotation and "storing" the 11 ns long bunches for few tens of milliseconds. A strong horizontal instability was observed, which could be possibly ascribed to EC [1].

EC STUDIES FOR THE PS UPGRADE

Within the LHC Injectors Upgrade (LIU) project it is necessary to assess whether the EC instability, or incoherent effect, could degrade the beam quality on the timescale of the nominal cycle for the high intensity and high brightness beams foreseen for the upgrade. Therefore several studies are being carried out in order to develop a reliable electron cloud model of the PS vacuum chambers, identify possible future limitations and find suitable countermeasures.

In this framework, during the 2013-2014 machine shut-

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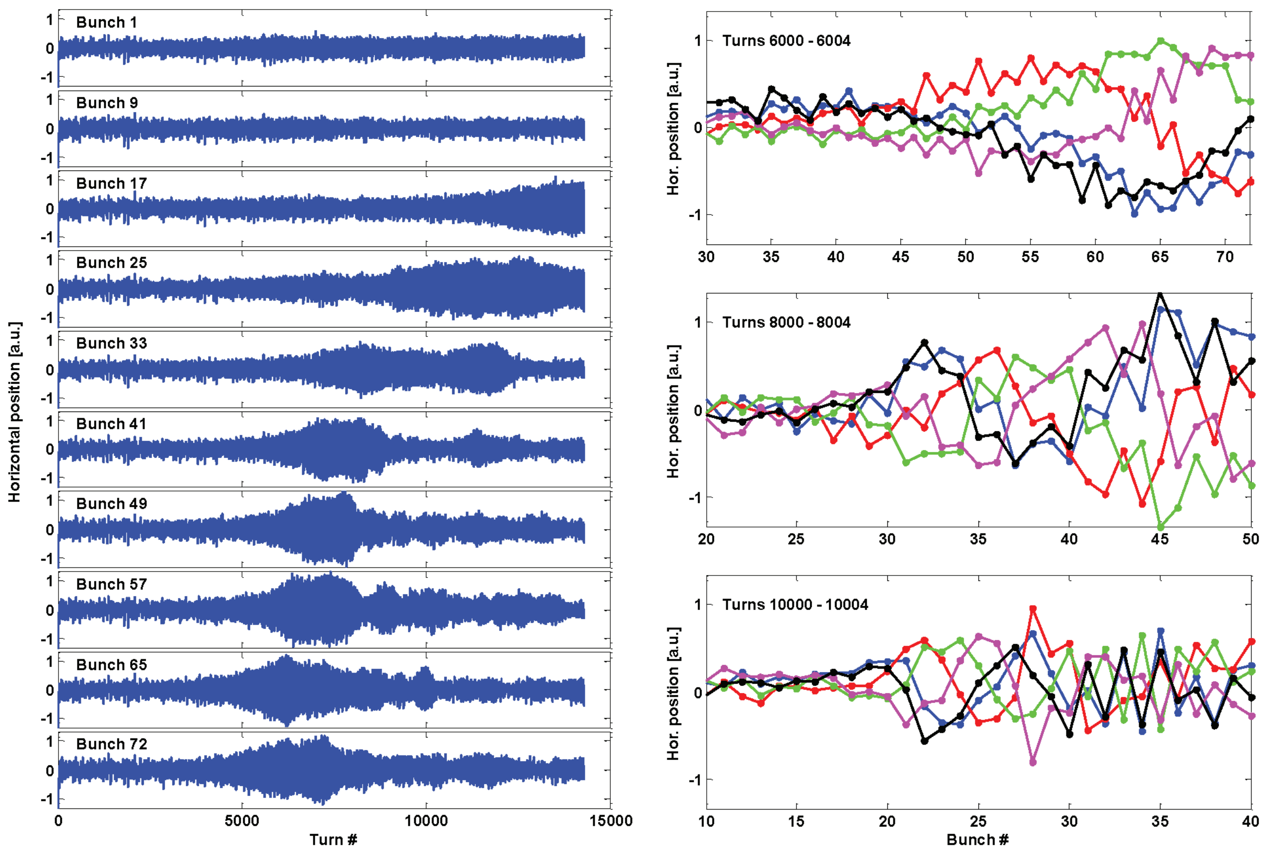

Figure 2: (Left) Evolution of the horizontal centroid position for selected bunches along the bunch train (t=0 roughly corresponds to the beginning of the bunch shortening); (Right) bunch by bunch position for five consecutive turns, at different moments during the store (the horizontal scale is chosen in order to better visualize the unstable bunches).

down, one of the main magnets of the machine will be equipped for electron cloud detection [4]. To support the design of the new detector as well as to improve our general understanding on EC effects in the PS, the possibility of simulating combined function magnets has been implemented in the EC build up code PyECLOUD [5] and is presently being used for the characterization of the different chambers. To have first crosschecks of our models and simulation codes several measurements with different beam conditions have been collected with the shielded pickups installed in one of the straight sections in the PS [6]. In 2012 several machine study sessions were also devoted to 1) further investigate the instability developing on the "stored" 25 ns beam and 2) investigate the possibility of modifying the 40 MHz RF voltage program in order to mitigate the EC without affecting the beam quality.

Transverse Instability

Several bunch by bunch position measurements have been acquired on a modified cycle without bunch rotation, which could store the beam for about 30 ms after the adiabatic shortening (h_{RF}=84, V_{RF}=100 kV). Transverse instabilities could be observed even for quite low intensities ($\sim 6 \times 10^{10}$ ppb). The oscillation in the horizontal plane was much stronger than in the vertical plane, as in [1], and actually the spectral content of the vertical motion was concentrated around the horizontal tune and it is therefore ascribable to the coupling of the machine. It could be noticed that the different bunches of the train have different behaviors, as shown in Fig. 2 (left). The rise time of the instability is almost the same for the bunches in the second half of the train and then it becomes longer and longer for bunches towards the head. The first 10-15 bunches actually look stable during the 30 ms store. This kind of behavior reminds the evolution of the electron density along the train in a typical EC build up. Moreover, the intra-train pattern revealed a clear coupled motion between bunches, whose mode number appeared to become larger when including bunches close to the train head, as shown in Fig. 2 (right). All these features look compatible with an EC driven instability but also other mechanisms (e.g. impedances) need to be investigated.

In 2012 a new transverse feedback was commissioned in the PS [7], which could be also tested on the instability described before with very encouraging results. Since the feedback cannot be operated in Continuous Wave mode, it could not suppress the instability along the whole 30 ms store. On the other hand a delay of about 10 ms could be observed, which gives an important margin when compared to the timescales of the bunch shortening in the nominal cycle.

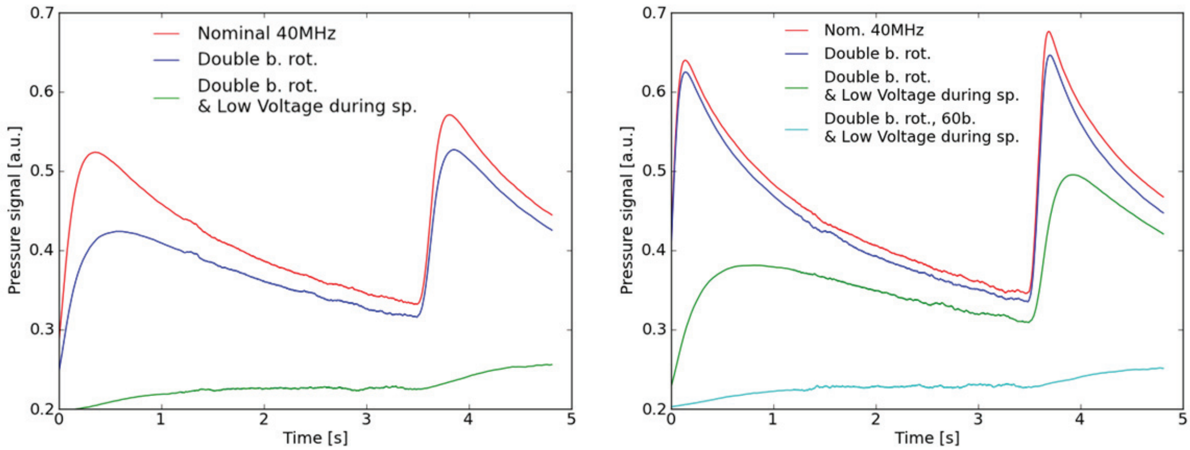

Figure 3: Pressure measured with two consecutive LHC type cycles (the beam is extracted at t=0 and t=3.6 s) for different RF manipulations. Comparison between two different bunch intensities: $\sim 1.25 \times 10^{11}$ ppb on the left and $\sim 1.45 \times 10^{11}$ ppb on the right.

Effect of the RF Voltage Program

Simulations and measurements have shown that the EC build up in the PS is very sensitive to bunch length variations. Therefore, two modifications were introduced in the RF voltage program in order to minimize the interaction of the beam with the EC: 1) the adiabatic bunch shortening was replaced with a bunch pre-rotation [8], which allows to shorten the bunch length from 14 ns to 11 ns in a much shorter time, i.e. $\sim$600 μs; 2) the 40 MHz RF voltage during the bunch splitting was reduced by 10%. Beam profile measurements confirmed that these modifications did not introduce any important degradation of the beam quality at the extraction from the PS.

For the tests the signal from a pressure gauge located in a straight section of the ring was used as a "time integrated" EC indicator. The effects of the modifications on the voltage program on the pressure signal are shown in Fig. 3 for a bunch intensity of 1.25×10^{11} ppb (on the left) and 1.45×10^{11} ppb (on the right). It can be noticed that the strongest reduction of the pressure rise comes from the relatively small reduction of the voltage (and therefore slightly longer bunches) during the splitting, while the introduction of the double bunch rotation has a non negligible effect only for the lower intensity. Moreover the combination of the two strategies gives an almost complete EC suppression for the lower intensity, while a significant pressure rise is still observed for the higher one. In this last case, the EC could be almost completely suppressed only by reducing the number of bunches from 72 to 60, and hence increasing the empty gap in the ring from 300 ns to 600 ns. This is due to the fact that, especially when the bunches are longer (which implies a longer EC risetime), the "memory effect" between subsequent turns plays an important role in the EC formation. Therefore a smaller number of bunches, and hence an increased gap in the ring, can give an important mitigation for the EC. This means that alternative RF schemes based on batch compression, which are presently considered for the production of higher brightness LHC type beams [9], should also be less critical in terms of EC effects thanks to the reduced number of bunches.

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