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EXPERIMENTAL ELECTRON CLOUD STUDIES IN THE CERN PROTON SYNCHROTRON

E. Mahner, T. Kroyer, F. Caspers

Indications for a beam-induced electron cloud build-up are observed since 2000 for the nominal LHC beam in the PS to SPS transfer line and during the last turns before ejection from the PS. A new electron cloud setup was designed, built, and installed in the PS. It contains shielded button-type pickups, a dipole magnet, a vacuum gauge, and a dedicated stripline electrode to experimentally verify the beneficial effect of electron cloud clearing electrodes. During the 2007 run, the electron cloud effect was also clearly observed in the PS and efficient electron cloud suppression has been obtained for negative and positive bias voltages on the clearing electrode. Here, we present electron cloud measurements with different filling patterns and bunch spacings in the PS.

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Abstract

Indications for a beam-induced electron cloud build-up are observed since 2000 for the nominal LHC beam in the PS to SPS transfer line and during the last turns before ejection from the PS. A new electron cloud setup was designed, built, and installed in the PS. It contains shielded button-type pickups, a dipole magnet, a vacuum gauge, and a dedicated stripline electrode to experimentally verify the beneficial effect of electron cloud clearing electrodes. During the 2007 run, the electron cloud effect was also clearly observed in the PS and efficient electron cloud suppression has been obtained for negative and positive bias voltages on the clearing electrode. Here, we present electron cloud measurements with different filling patterns and bunch spacings in the PS.

INTRODUCTION

Electron cloud (EC) effects are a serious issue for many existing and future high-intensity particle accelerators, including the CERN SPS and the LHC. In the PS, electron cloud effects and the related instabilities were seen already in 2000 with the LHC proton beam [1,2].

The PS Electron Cloud Experiment

During the 2006/07 shutdown, dedicated EC diagnostics were installed in straight section 98 of the PS. The setup consists of an elliptical stainless steel vacuum chamber equipped with a shielded Penning gauge for fast vacuum logging, two shielded pickups inside a dipole magnet, and a metallic stripline electrode assembled inside a small anti-chamber (Fig. 1). The latter was used to test the general performance of clearing electrodes; an upgrade to low-impedance ceramic-based electrodes, as proposed in [3], is possible. It was found that:

- An EC develops in the PS with nominal LHC beam, starting ≈40 ms before ejection, when the bunches are shortened by the RF gymnastics.
- The EC build-up can be suppressed by applying a large enough positive or negative clearing voltage (Fig. 2).
- With magnetic field the properties of the EC change; it starts earlier and may get more intense.
- For a combination of magnet fields and clearing voltages, islands appear with a large persisting EC. For large enough clearing voltages (+/- 1 kV) the EC could always be suppressed below the detection limit.

These results and the experimental setup are reported in more detail elsewhere [4]. Here we focus on the impact of the filling pattern and bunch spacing on the EC build-up as well as on the conditioning of the vacuum chamber surface.

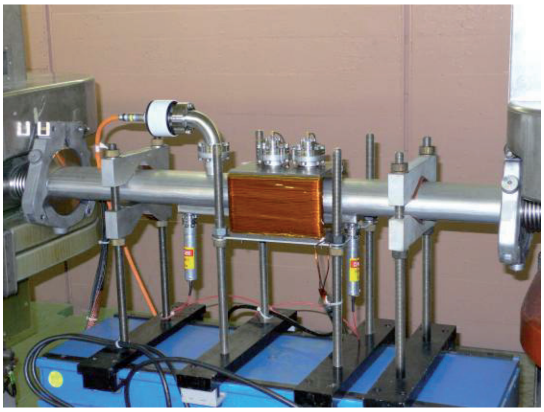


Figure 1: Picture of the PS electron cloud experiment comprising a fast vacuum diagnostic, shielded button pickups, a dipole magnet, and a clearing electrode.

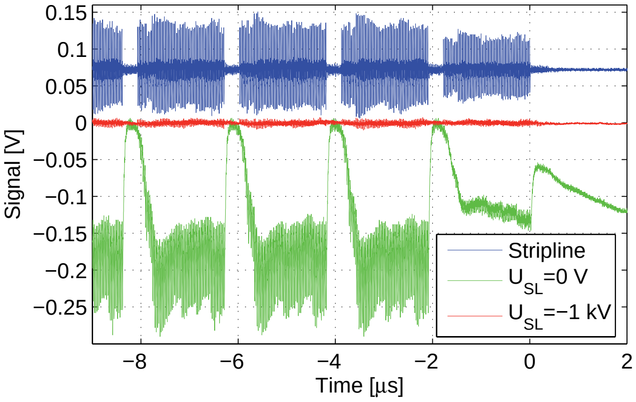


Figure 2: Measured signals in the PS electron cloud experiment during the last four turns of the nominal LHC beam before ejection at t = 0. A significant EC signal was found on the pickups (green), which is suppressed for a clearing voltage of -1kV (red). The beam signal on the stripline (blue) was used for synchronization purposes.

Filling Pattern

A possible approach for reducing the EC effect consists in varying the filling pattern of the machine. It is known that electrons surviving a gap with no beam may accelerate the EC build-up upon arrival of the next bunch train [5]. In order to investigate this effect, the gap in the filled machine was increased by reducing the number of bunches in the PS. In the present scheme, 72 of the 84 buckets (each 25 ns long) are occupied at PS top energy.

The pressure rises and EC signals were measured for different numbers of bunches using the Penning gauge and the button pickups. The measured pressure rises for 36 to 72 bunches in the PS are shown in Fig. 3. The EC induced pressure spikes decrease significantly by reducing the number of bunches from 72 to 48. Below 36 bunches no measurable pressure rise was found.

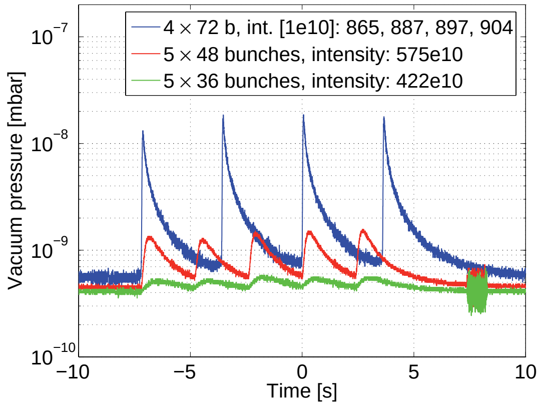


Figure 3: Electron cloud induced pressure rise for trains of 72, 48, and 36 bunches in the PS. The 72 bunches are injected every 3.6 s, the others every 2.4 s. The pressure spikes appear at PS top energy just before extraction.

A more detailed picture of the filling pattern behaviour on the EC is given by the pickup signals (Fig. 4), showing that for less bunches the EC develops later in the cycle and is mostly less intense. For 24 bunches, the EC becomes visible only in the last 80 μs before ejection, for 12 bunches no effect was found above the detection limit.

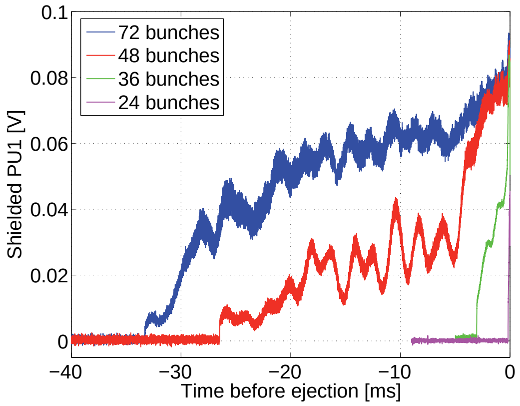


Figure 4: Electron cloud signal on the shielded pickup for different bunch train lengths in the PS. Data are shown for the last 40 ms before extraction at t = 0.

In addition to its strength, the EC build-up time is a crucial parameter. Here we used a more general definition than the time constant of an exponential growth, namely the 50 % rise time [4].

From data for the second last turn before ejection the build-up times were determined for beams with 24 to 72 bunches. The measured build-up time as a function of the gap between bunch trains is shown in Fig. 5. A clear trend was found, which quantitatively shows how the surviving electrons gradually die off with longer gaps. But since the build-up time shows no sign of saturating up to 1200 ns long gaps, a few electrons must survive at least that long, gaps longer than 1500 ns could not be studied due to the size (~100 m radius) of the PS machine.

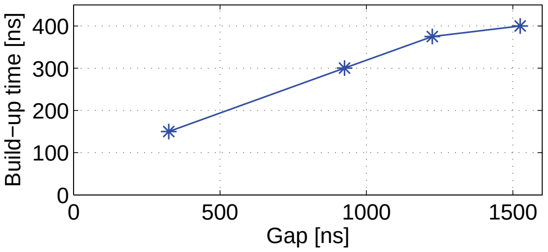


Figure 5: Electron cloud build-up time as a function of the gap length between bunch trains in the PS.

Bunch Spacing

Another possible approach to cope with the EC is to increase the bunch spacing of the LHC beam. If EC-induced instabilities turn out to be a problem in LHC it is possible to switch from 25 ns to 75 ns bunch spacing. During tests with the 75 ns LHC beam the EC characteristics were measured in the PS. As expected, the electron cloud signal on the pickups was dramatically reduced with the 75 ns bunch-spaced beam. A measureable EC developed only in the very last ~80 μs before ejection, and even then it remained very small. The improvement obtained after increasing the bunch spacing from 25 ns to 75 ns and keeping the bunch intensity constant is illustrated in Fig. 6.

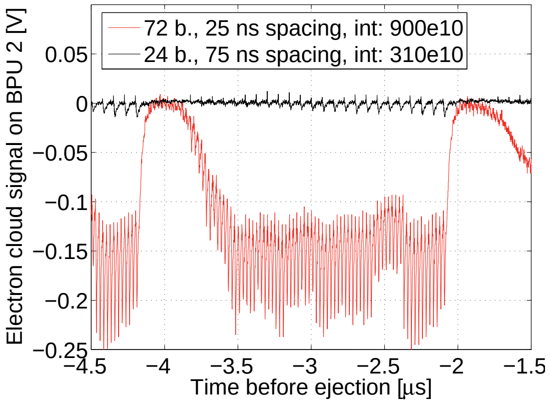
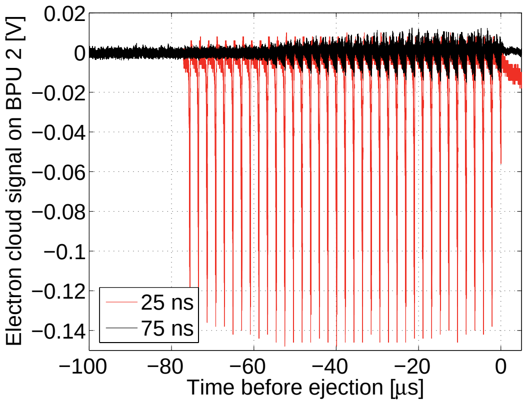


Figure 6: Electron cloud pickup signals for the nominal LHC beams with 25 ns and 75 ns bunch spacings. Signals are compared for the second last turn before ejection from the PS.

However, to get a fair comparison for the influence of the bunch spacing on the EC in the PS, a LHC beam with the same intensities should be used. The pickup signals of a beam with 24 bunches, 25 ns spacing, and a large gap (1225 ns) compared with a beam of 24 bunches, 75 ns spacing and a small gap (325 ns) are shown in Fig. 7. For both beams the EC becomes visible only in the last μs before ejection (~80 μs vs. 60 μs), but with a 75 ns bunch spacing the EC remains very weak, because its build-up is too slow.



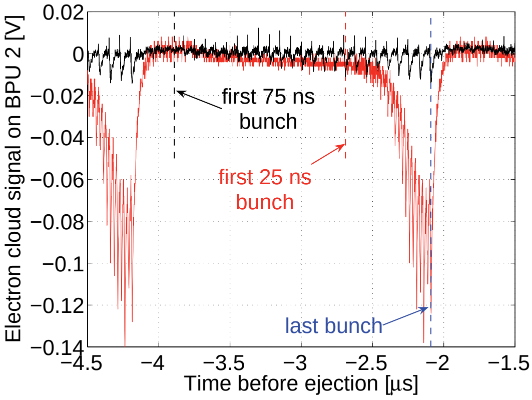


Figure 7: Comparison of the electron cloud pickup signals for a 24 bunch train with 25 ns spacing (red) and 75 ns bunch spacing (black). The 100 µs before ejection (top) and the second last turn (bottom) are plotted. The beam intensity was similar in both cases (280e10 vs. 310e10).

Conditioning

In order to check for a potential decrease of the secondary emission yield through beam conditioning during normal operation, the EC signature (pressure rise, pickup signal height) was observed during the 2007 run of the PS. Only a slight decrease in the maximum pressure rises of $\Delta p \approx 3 \times 10^{-8}$ mbar, recorded for four consecutive shots of the nominal LHC beam (72 bunches, 25 ns spacing), was measured in June 2007 [4]. After 4 months of operation the maximum pressure rise had only decreased to about 2×10^{-8} mbar (see Fig. 3) for the same beam and a similar intensity, but the previously observed smaller pressure increase, which occurred at transition energy [4], had disappeared. A small decrease was also found in the EC signals on the button pickups, an example is displayed in Fig. 8. To summarize, the conditioning effect observed for the unbaked 316LN stainless steel vacuum chamber was very small, which is a direct consequence of the low EC "duty cycle" in the PS. The EC was found only with the LHC beam during the last ≈40 ms before extraction. In comparison to a ≈40 s long PS super-cycle, one shot of the nominal LHC beam corresponds to a ratio of 10^{-3}, which explains qualitatively why only very little scrubbing is observed in the PS.

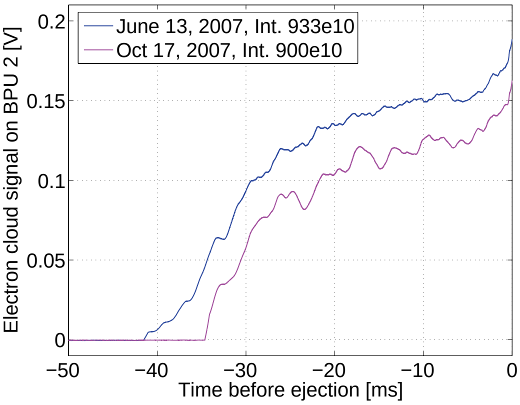


Figure 8: PS electron cloud pickup signals for the nominal LHC beam with 25 ns bunch spacing. Data were taken with comparable intensities at the beginning of the 2007 SPS scrubbing run in June and after 4 months of PS operation when a slight EC decrease and a later onset in respect to beam ejection at t = 0 was found.

CONCLUSIONS

In the 2006/07 shutdown, dedicated electron cloud diagnostics were installed in the CERN PS. The presence of an electron cloud in the last 40 ms before ejection was shown for the nominal LHC beam. The efficiency of clearing electrodes for EC suppression was also demonstrated [4]. After four months of proton run no significant beam conditioning was found, which is most likely due to the short appearance of the EC compared to the entire PS super-cycle length. The electron cloud induced dynamic pressure changes are currently not an operational problem for the PS. An increase in the length of the beam-free gap yielded a substantial EC reduction. However, electrons were found to survive gaps beyond 1 µs. An increase in bunch spacing from 25 ns to 75 ns resulted in a drastic EC reduction. The influence of the machine filling pattern and the bunch spacing on the PS electron cloud confirm earlier observations made in the SPS [6].

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REFERENCES

[1] R. Cappi et al, PRST-AB **5**, 094401 (2002).
[2] R. Steerenberg et al, Proc. PAC 2007, p.4222.
[3] T. Kroyer, F. Caspers, E. Métral, F. Zimmermann, Proc. Mini-Workshop on Electron Cloud Clearing, Geneva, 2007; http://care-hhh.web.cern.ch/care-hhh.
[4] E. Mahner, T. Kroyer, F. Caspers, paper submitted to PRST-AB, April 2008.
[5] J.M. Jimenez et al, Proc. LHC Performance Workshop, Chamonix XII, 2004.
[6] J.M. Jimenez et al, LHC Project Report 632, 2003.