ELECTRON CLOUD: OBSERVATIONS WITH LHC-TYPE BEAMS IN THE SPS

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Abstract

In August 1999, strong pressure increases were observed in the SPS in the presence of the new LHC-type beams. This paper reports on observations of the electron cloud phenomenon and the related pressure increase as a function of parameters such as the number of protons per bunch, the number of bunches per batch, the shape of the vacuum chamber and the electron current collected on pick-ups. Results of the observed clean-up, "beam scrubbing" will be presented as well as the consequences of the e^-cloud phenomenon on the SPS operation with the LHC nominal beam intensity.

1 INTRODUCTION

Pressure rises in presence of LHC-type beams were observed for the first time during an MD dedicated to LHC in August 1999. Fig.1 shows that the pressure increases occurs only in presence of the LHC-type beams. Before and after the MD session, with the normal SPS proton beams, the pressures recover with a time constant consistent with the vacuum system. The pressure increase which occurs all around the machine ranges between a factor of 3 to 60 depending on the size of the vacuum chamber and on the beam characteristics [1]. The pressure rise can be attributed to gas desorption due to beam induced multipacting [2]. To study the vacuum behaviour in more detail the pressures of 42 gauges placed in similar positions around the SPS ring were recorded with an acquisition rate of one measurement per second.

2 PROTONS PER BUNCH

The measurements shown in Fig.2 were made during a dedicated MD session with an LHC-beam duty cycle close to 45% (6.4s out of a total 14.4s SPS cycle) and with a maximum intensity of 7.4×10^{10}p/bunch. It can be seen that the pressure remains constant and low until a threshold is reached and from then onwards it increases approximately linearly with the number of protons. The same behaviour with a similar relative pressure increase is observed in many other positions around the SPS ring. These observations are consistent with the results presented at the Chamonix Workshop [1] with a smaller duty cycle of 4%. In this last figure, it appears that the threshold is slightly higher and more uniform for gauges far away from any magnetic field.

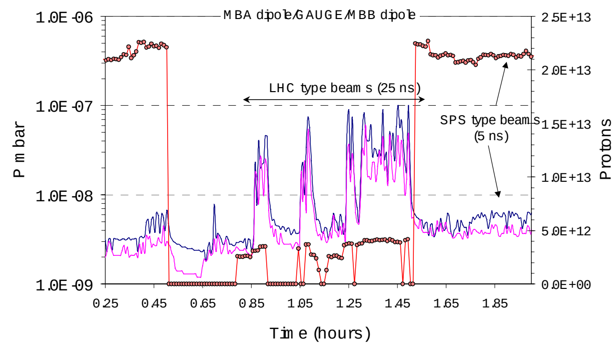

Figure 1: Pressure versus time, total number of protons=4.5×10^{12} (5.6×10^{10} p/bunch), duty cycle 62 %.

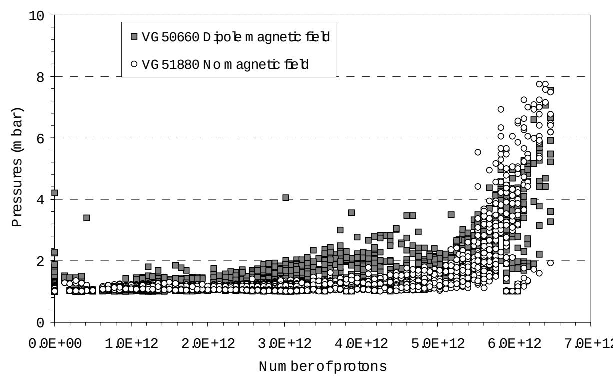

Figure 2: Pressure versus number of p/batch between two dipoles i.e. without magnetic field, duty cycle 45 %.

3 BUNCHES PER BATCH

Apart from the number of protons per bunch an important parameter has been the number of bunches in a batch. A batch consists of a train of 81 bunches separated by 25 ns. These measurements were made with a duty cycle of 4 %.

At 4.4×10^{10}p/bunch (full batch 3.6×10^{12}p), no pressure increase was observed when increasing the number of bunches in the batch to the nominal value of 81.

By increasing the bunch density up to 7.7×10^{10} (full batch 6.25×10^{12}p), the relative pressure increase is twice as large as with 6.5×10^{10} p/bunch (Fig.3). This density corresponds to two third of the nominal intensity to be injected into the LHC. The measurements show that the threshold of the pressure rise decreases from 34 down to 24 bunches in a batch when increasing the density from 6.5×10^{10} up to 7.7×10^{10}p/bunch (Fig.4).

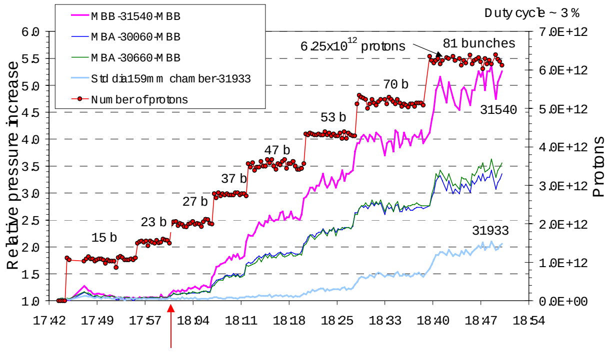

Figure 3: Relative pressure increase versus number of bunches at 7.7×10^{10}p/bunch.

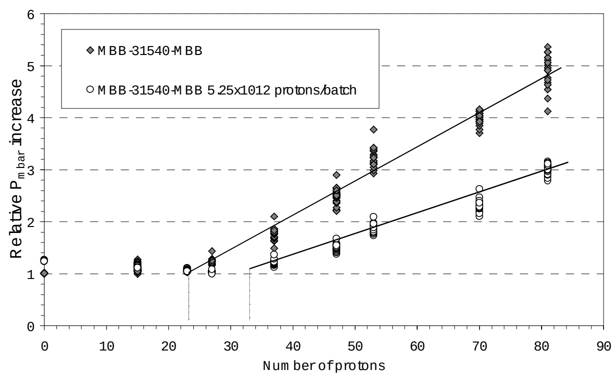

Figure 4: Relative pressure increases versus number of bunches per batch at 6.5×10^{10} and 7.7×10^{10}p/bunch.

4 PICK-UPS AND DAMPER

A pick-up collector, mounted on top of a dipole chamber was used to monitor the electron current produced by the e$^-$cloud. The pick-up electrode was shielded from the beam by a metallic grid and could be biased (+45 V) with respect to ground in order to suppress secondary electrons emitted from the collector itself.

At 3.6×10^{10}p/bunch (2.9×10^{12}p/batch), below the threshold, no pressure rise was observed and no signal could be seen on the pick-up. However, by increasing the number of protons above the threshold of the e$^-$cloud, the pick-up current showed distinct peaks separated by 23 µs which corresponds to the revolution time in the SPS. Fig.5 shows a picture of the fast scope for a proton bunch density of 7.5×10^{10} (6.1×10^{12}p/batch).

Special beam pick-ups are used in the SPS by the transverse feedback system ("damper") which damps injection oscillations and stabilises the beam against transverse coupled bunch instabilities. In presence of LHC beams, this damper was found to be strongly perturbed [4]. The electrostatic pick-ups used are equipped with high-impedance FET amplifiers. These amplifiers have been found to be sensitive to the beam induced position signal as well as to deposited charges. The performance of the damper system has suffered severely due to the electron cloud saturating completely the beam position signal. Fig.6 shows a vertical position signal for an LHC proton beam batch with a drift of the signal starting about half way through the 2 µs long batch. This drift is due to electrons hitting the pick-up electrode. The threshold intensity of this phenomenon has been found to vary between 2.5×10^{12} and 3.5×10^{12}p/batch. A solenoid magnet field of ~100 Gauss could suppress the effect up to about 5-6×10^{12}p/batch as can be seen in Fig.7, a clear indication of low energy electrons being the cause of the effect [4].

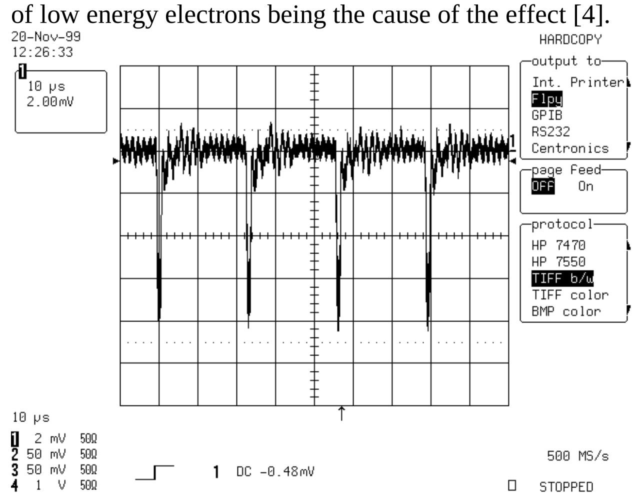

Figure 5: Structure of the current collected by the biased (+45 V) pick-up with a proton bunch density of 7.5×10^{10}

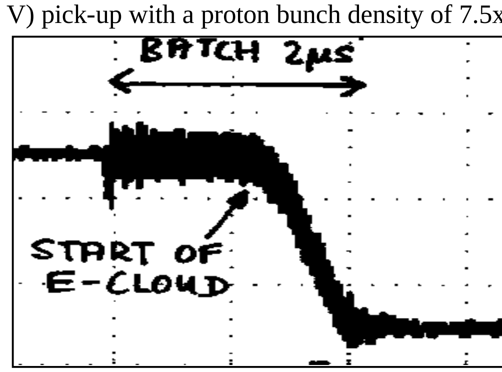

Figure 6: Vertical damper pick-up signal perturbed by the e$^-$cloud effect (5.5×10^{12}p/batch).

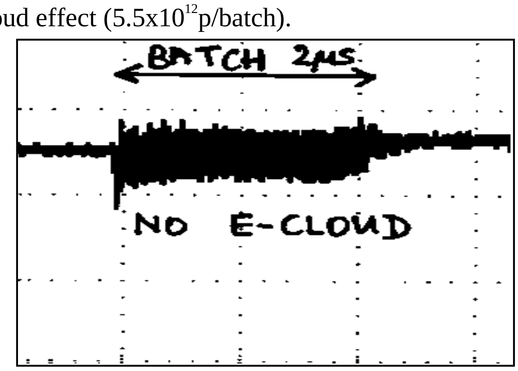

Figure 7: Vertical damper signal with a solenoid magnetic field of 100 Gauss to suppress the e$^-$cloud (5.5×10^{12}p/batch).

5 CLEANING OR SCRUBBING

A specific MD session was dedicated to the study of a possible cleaning effect by the beam. During approx. 14 hours, an LHC beam with a bunch density slightly above the threshold of the e^-cloud (5.6×10^{10}p/bunch) was maintained in the machine with a duty cycle of 3.4 %. The results [1] indicate that only three out of 20 gauges show a measurable pressure decrease, between 7% and 12%. Nevertheless, a clear correlation could be found between the intensity of the e^-cloud, as measured by the pressure increase, and the observed cleaning effect i.e. the larger the local pressure increase, the larger the cleaning.

Since the cleaning of the vacuum chamber with beam will be an important process for the future operation of the LHC, it was decided to repeat this measurement with a higher duty cycle of ~45%. The experiment was made with bunch densities ranging from 5.0×10^{10} up to 8.0×10^{10}p. In total 42 pressure gauges around the SPS ring were recorded.

Fig.8 shows the evolution of the relative pressure increase versus beam time for bunch intensities larger than the e^-cloud threshold value of 5.0×10^{10}.

This figure shows clear evidence of a cleaning effect of the vacuum chamber. No pressure increase could be seen after 56 hours of LHC beam time indicating that the multipacting threshold had increased beyond the operating conditions.

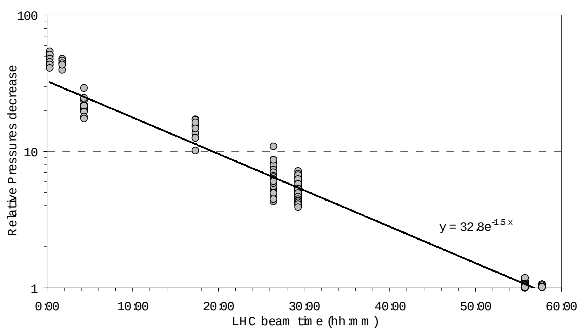

Figure 8: Relative pressure increase versus effective beam time. The effective time is the total time spent with LHC beams and bunch intensity above 5×10^{10}.

6 DISCUSSION - CONCLUSIONS

The experimental results show that the pressure increases only in presence of the LHC-type beam. The pick-ups measure electron current signals only in presence of LHC-type beams and the behaviour of the pressures versus bunch densities are consistent with observations in other machines such as PEP2 and KEKB. These observations clearly favour the e^-cloud phenomenon as the origin of the pressure rises observed in the SPS.

Even though this phenomenon was not anticipated to occur in the SPS more recent calculations are in good agreement with the observed threshold [3]. In deed the vertical dimension of the vacuum chambers in the dipoles of the SPS is very similar to the height of the LHC beam screen. The lack of synchrotron radiation and of the resulting photoelectrons in the SPS is not a sufficient guarantee against the electron cloud build-up since the avalanche may start, as in the ISR [2], with electrons created by residual gas ionisation as well as by many other processes. The simple threshold condition for wall to wall multipacting [2] depends only on the bunch intensity, the bunch distance and the vacuum chamber dimension (beam pipe radius). For the LHC-type beams, and for the SPS vacuum chamber, this threshold bunch intensity is 4.5×10^{10}p/bunch, in reasonable agreement with observations.

The observed increase of the SPS beam emittance above the electron cloud threshold is so far not fully understood. To explain this beam blow-up by residual gas scattering, the average pressure in the SPS would have to exceed by far the pressures measured during these experiments. A more likely explanation could be the emittance growth due to the direct interaction of the protons with the electron cloud.

Conditioning of the vacuum chamber with the LHC beam at intensities above the threshold for the onset of the beam-induced e^-cloud was performed. This showed an exponential reduction of the dynamic pressure rise in the presence of the LHC beam so that no significant pressure increase was visible after about 60 h of conditioning with beam. For the time being neither direct evidence of a reduction of the electron density is available nor of a reduction of the Secondary Emission Yield.

Finally, the installation of the pumping port shielding elements which are required to reduce the impedance of the so far unshielded SPS vacuum system will slightly reduce the pumping speed of the ion pumps and will reduce by a significant amount (~25 %) the efficiency of the titanium sublimation pumps. As a consequence of the reduced pumping speed from 70 l/s to 55 l/s, a corresponding increase of the average pressure must be expected.

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