EXPERIMENTAL STUDIES OF CARBON COATINGS AS POSSIBLE MEANS OF SUPPRESSING BEAM INDUCED ELECTRON MULTIPACTING IN THE CERN SPS

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Abstract

Electron cloud build-up is a major limitation for the operation of the SPS with LHC beam above nominal intensity. These beams are envisaged in the frame of the LHC luminosity upgrade and will be available from the new injectors LPSPL and PS2. A series of studies have been conducted in order to identify possible means to suppress electron multipacting by coating the existing SPS vacuum chambers with thin films of amorphous carbon. After a description of the experimental apparatus installed in the SPS, the results of the tests performed with beam in 2008 will be presented.

SPS UPGRADE AND E-CLOUD EFFECT

An upgrade plan for the whole CERN accelerator complex has been proposed to allow full exploitation of the LHC in the future as well as to give new possibilities at lower beam energies. This plan foresees replacing around 2017 all the accelerators in the LHC injector chain by new machines (Linac4, LPSPL and PS2) except for the SPS [1]. In this scenario the SPS should be able to reliably accelerate much higher beam intensity than achieved so far and therefore all bottlenecks should be identified and sufficient improvements to the machine performance found and implemented on the same time scale.

The effects caused by the presence of the electron cloud are considered at the moment to be the most important intensity limitations in the SPS [2]. They lead to transverse emittance blow-up along the batch and instabilities, dynamic pressure rise, septum sparking, enhanced beam dump outgassing and probably even beam losses on the flat bottom [3]. Present cures include an annual scrubbing run, operation with high chromaticity in the vertical plane and active transverse damping in the horizontal plane.

With PS2 the injection energy of the SPS will be increased from 25 GeV to 50 GeV. This has beneficial effect for many possible limitations [4]. Measurements at different beam energies [2] suggest that the growth rate of the coupled-bunch instability in the H-plane scales as $\sim 1/\gamma$ and improvement can be expected at higher injection energy. However in the V-plane e-cloud simulations predict threshold reduction with energy which can be explained by the transverse beam size reduction with energy at constant normalised emittance. The intensive machine studies of the vertical e-cloud instability at different SPS energies in 2006 and 2007 (on a specially created magnetic cycle) confirmed this scaling law [5]. Possible measures against e-cloud effects are now under extensive investigation by the SPS Upgrade Working Group [6]. They include clearing electrodes, grooves and special surface treatments.

The most promising option at the moment seems to be a surface coating which should significantly reduce (below 1.3) the SEY (secondary electron yield) without need for future re-activation. The build-up of the e-cloud is enhanced by magnetic field and 80% of the SPS ring is occupied by magnets in which the vacuum pipe is not thermally insulated. Therefore possible surface treatment of the existing SPS stainless steel (StSt) vacuum chamber should satisfy the following conditions: coating applicable in situ with intrinsically low SEY, any baking below 80 deg C and no aperture reduction. The best candidates found so far are amorphous carbon (a-C) coatings produced by DC magnetron sputtering, both as a single layer and on a rough surface where a SEY below 1 has been obtained on many different samples [7]. The main problem is surface ageing with venting. This should be minimised, but cannot be completely avoided due to maintenance work.

SPS EXPERIMENTAL SET-UP

In 2008 the experimental set-up installed in the SPS for e-cloud measurements related to surface treatment included three Electron Cloud Monitors (ECM) each measuring the radial distribution of e-cloud (see [8] for detail description) and a special vacuum chamber with sample removeable under UHV for analysis in the lab of surface conditioning with beam. All the ECMs and special vacuum chamber are installed in dipole magnets having a field variation from 0 to 2 kGauss (1.2 kGauss is the SPS injection value).

The collecting copper strips are placed under vacuum below the beam pipe with 2 mm diameter holes giving a transparency of 7%. 47 channels are available for signal reading with 1.17 mm spatial resolution.

One ECM had a stainless steel 316LN (StSt) liner without any coating for reference, one had a carbon coating under study and the third had a NEG (TiZrV) coating [9] activated once only, at the beginning of the beam run.

RESULTS WITH BEAM

The SPS operational beams in 2008 were the FT and CNGS type beams with ~ 4000 bunches spaced at 5 ns and maximum bunch intensity around 10^{10}. This beam has

Table 1: Experimental programme with different liners in the SPS during 2008. The new StSt liner was installed each time together with new carbon liner. The NEG coated liner had one activation before the scrubbing run.

n	date	P_s [GeV/c]	test liner
0	10-12.06	26	CKr4
1	7-9.07	26-450	CNe8
2	11-13.08	26-450	CNe13
3	6-8.10	26-450	CNe13

significantly less e-cloud build-up than the nominal LHC beam which consists of 4 batches with 72 bunches at 25 ns spacing and intensity of 10^{11} protons/bunch. Therefore dedicated Machine Development (MD) sessions were necessary to set-up the whole injector chain to produce a high intensity LHC beam in the SPS. This beam was then used for e-cloud tests in our experimental set-up. Measurements were taken during scrubbing run and three MD sessions with 25 ns spaced beam and one with 25 ns, 50 ns and 75 ns LHC beams, all with similar ($\sim 10^{11}$), nominal bunch intensity [10]. During the scrubbing run the beam energy was limited to 26 GeV/c while the nominal LHC cycle with acceleration to 450 GeV was used later on.

For the scrubbing run the carbon coating on the liner under test was produced by cylindrical magnetron sputtering using Krypton as the discharge gas (CKr4). For the first MD the sample was produced with Ne as the discharge gas (CNe8). Just before the second MD the sample was again replaced by a new a-C one with Ne gas used during the sputtering process (CNe13) and which had been kept in air for two weeks prior to installation in the ring. This sample was kept in the ring for 2 months before the last MD in October. Tests are summarised in Table 1 and the measurements of the initial SEY of witness samples prepared in the same coating run as liners are shown in Fig. 1.

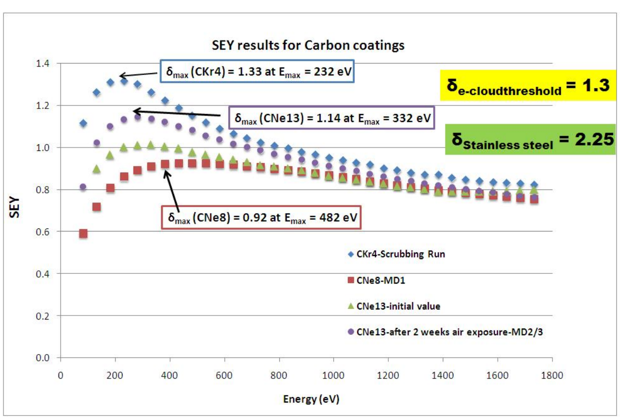

Figure 1: SEY of carbon coated liners before exposure to beam in the SPS as measured in the lab.

The effect of scrubbing can be clearly seen in Fig. 2 where the integrated e-cloud signal measured at ECM is normalised to the maximum beam intensity for a given cycle. Reduction of the signal by a factor of 3 was observed for StSt and almost by a factor of 5 for carbon (CKr4). The maximum initial SEY is estimated to be 2.25 for StSt, 1.33 for CKr4 and 1.1 for NEG (1.3 after saturation).

The effect of debunched beam (due to injection and capture losses) on e-cloud accumulation was also seen during the scrubbing run. At the moment the debunched beam completely fills the beam gap (7/11 of the ring), the e-cloud signal on the ECM increases. Cleaning the gap by the tune kicker suppresses the effect. A small slope in the main dipole magnet field (beam acceleration) on the injection plateau also helps. The scrubbing effect is very localised. When the beam was displaced radially on the sample by a 5 mm bump, the e-cloud signal increased again.

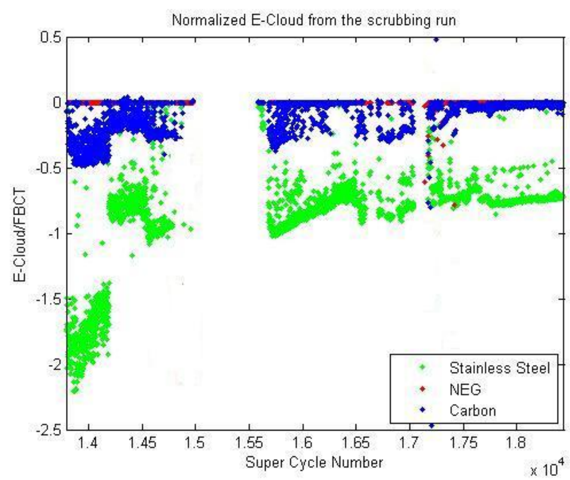

Figure 2: ECM signals from StSt, NEG and carbon (CKr4) liners during the SPS scrubbing run with (Super) cycle length of 43.2 s.

Measurements taken over 8 hours during the first MD with three LHC batches at nominal intensity accelerated to 450 GeV in a 21.6 s cycle show the scrubbing effect for the new StSt liner and a very low signal from the CNe8 sample (below NEG level), only a few nA current being measured in comparison to $\sim 2.55 \times 10^4$ nA for StSt and $\sim 0.5 \times 10^4$ nA for CKr4 at the end of the scrubbing run. The e-cloud signal registered during the scrubbing run cycle (43.2 s) for StSt and CKr4 and during acceleration cycle of the first MD for CNe8 and NEG is shown in Fig. 3. Note also that only one stripe is produced in the latter case.

For the second MD a new carbon liner (CNe13) was prepared. Its initial maximum SEY was around 1.0 increasing to 1.14 after 2 weeks of air exposure, Fig. 1. The e-cloud signal in Fig. 4 shows some scrubbing effect.

In the third MD, the same sample having been 2 months in the ring, gave a normalised signal even smaller than measured for CNe8 during the first MD. Measurements of e-cloud signal as a function of accumulated dose show that for 25 ns spaced bunches the e-cloud signal in the StSt liner is similar to the previous (second) MD, for NEG it is 5 times higher (no re-activation) and for the CNe13 is 10

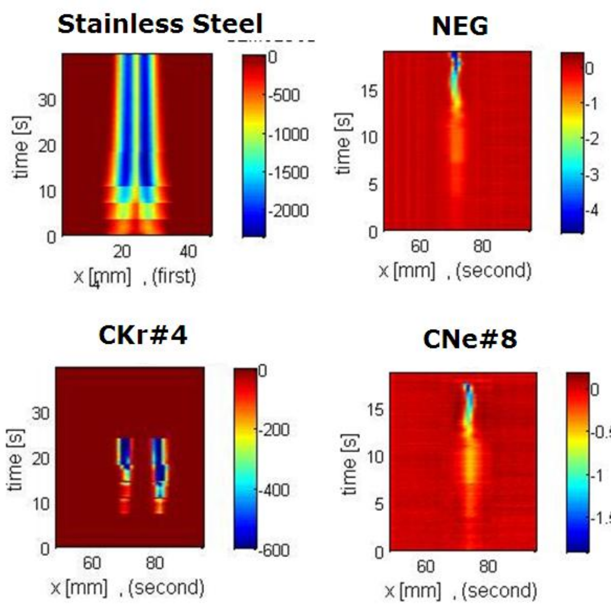

Figure 3: Electron cloud signal in ECMs with StSt, NEG and two carbon liners during scrubbing run (left) and acceleration (right) of nominal LHC beam in the SPS.

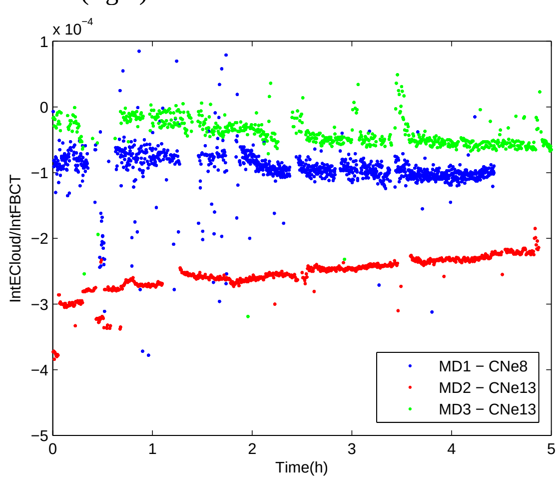

Figure 4: ECM signal (normalised to maximum beam intensity during the cycle) from amorphous carbon liners during the MDs with nominal LHC beam in the SPS.

times lower, Fig. 4.

During the last MD beams with different bunch spacing were also available. With a 50 ns and 75 ns beam the e-cloud signal for the StSt liner was 5 times lower than the signal with a 25 ns spaced beam. No e-cloud current (positive noise-like signal) could be detected on carbon liner.

No ageing could be observed for the CNe13 after two months in the ring (under vacuum). To continue this test it has been decided to keep the same carbon liner in the ring during the 2008/2009 shutdown with two months of air exposure for studying its ageing with beam in 2009.

The measurements of the StSt sample installed in C-magnet before the scrubbing run and taken out during the 2nd MD show a 40 mm wide region conditioned to a SEY of 1.5 (it went up to 1.7 after one hour of air exposure). Outside this region the SEY is around 2.0. This agrees well with the assumed SEY threshold for the SPS of 1.3.

FUTURE PLANS

An additional SEY reduction of 15% and slower ageing is expected for rough surfaces, so future plans include studies of C-coating on a rough (Zr) layer.

During the recent SPS shutdown the present experimental set-up in the ring was extended and has now three main parts. In the first, devoted to tests of different coatings described in this paper, two more places are now available to install new liners. They will be used for tests with the old a-C coating, a new a-C coating on a rough surface and a liner with a 4 cm wide a-C coating. As usual one detector will be with StSt liner as a reference. The second part (special magnet), housing exchangeable (without venting) samples will be used again for accurate surface post-examinations in the laboratory. The third and probably the most important part at this moment contains three 6 m long SPS dipole magnets with a-C coated vacuum chamber. These magnets as well as one similar uncoated magnet are equipped with microwave RF diagnostics [11] which should allow comparison of e-cloud density in coated and uncoated magnets. It is planned to keep these magnets in the SPS for a few years to see long term effects from operation with beam and shutdown interventions (venting).

Once the solution satisfying all criteria specified above is found and validated, it will be applied in the SPS. The infrastructure for implementation in the SPS tunnel already partially exists due to ongoing refurbishment of the SPS dipoles. According to the preliminary estimations ~ 750 vacuum chambers inside the magnets could be coated during three SPS shutdowns.

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