AMORPHUS CARBON COATINGS FOR MITIGATION OF ELECTRON CLOUD IN THE CERN SPS

C. Yin Vallgren*, G. Arduini, J. Bauche, S. Calatroni, P. Chiggiato, K. Cornelis, P. Costa Pinto, E. Métral, G. Rumolo, E. Shaposhnikova, M. Taborelli, G. Vandoni, CERN, Geneva, Switzerland

Abstract

Amorphous carbon thin films have been applied to the liners in the electron cloud monitors and to vacuum chambers of three dipole magnets in the SPS. The electron cloud is completely suppressed for LHC type beams in the liners even after 3 months of air venting and no performance deterioration is observed after more than one year of SPS operation. In stainless steel (StSt) liners upon variation of the magnetic field in the monitors the electron cloud current maintains its intensity down to weak fields of some 40 Gauss. This is in agreement with previous findings and also with dark traces observed on the RF shields made of StSt, which are located between dipoles and quadrupoles. The dynamic pressure rise has been used to monitor the behavior of the dipole magnets. It is about the same for coated and uncoated magnets, apart from a weak improvement in the carbon coated ones under conditions of intense electron cloud.

SPS EXPERIMENTAL SET-UP

Electron-cloud is one of the main limitations for the LHC beam in the SPS [1]. The goal of this work is to investigate one of the most promising methods to eliminate the e-cloud in order to make the SPS able to deliver the ultimate beam to LHC and reach maximum luminosity for the machine. Thin film coatings produced by d.c magnetron sputtering with carbon have been tested on the existing SPS vacuum chambers.

To observe electron cloud we used the same type of monitors as in previous tests [1] [2]. The Electron Cloud Monitors (ECM) equipped with StSt liners with and without coatings are installed in special dipoles. Unless otherwise specified, during all the experiments the field was kept at 1.2 kGauss (the SPS injection value).

Four ECMs can be used at the same time. An ECM with a StSt liner has been used as reference. The StSt liner has been exchanged before certain Machine Development (MD) runs in order to have a non conditioned surface as reference (see different liners in Table 1). Various amorphous carbon (a-C) coatings have been tested in several MD runs, as well as a NEG (TiZrV), as listed in Table 1.

After successful tests with a-C coated liners in 2008 (see [2]), three dipole magnets of B-type (MBB) have been coated with a thin film of the same material and installed in the SPS in March 2009 (Fig 1). The total air exposure time of the coating before installation (on the ground and in the tunnel) was around one week. Pressure measurements (1 Hz sampling rate) were performed with Penning gauges installed on the pumping port between two uncoated dipoles used as reference and between a-C coated dipoles. In addition a gauge was placed between a coated and an uncoated dipole. The inter-magnet pumping ports with RF shields are of bare StSt. In MD 8, the RF shield between the two carbon coated magnets was also coated.

* christina.yin.vallgren@cern.ch

Table 1: The list of liners in the SPS experiments. CKr: coating of a-C with Kr as discharge gas. CNe: coating of a-C with Ne as discharge gas. C-strip: longitudinal strip with CNe of 40 mm width. C/Zr: CNe coating on top of rough Zr coating.

SPS experiment	Date	Liner
Scrubbing run	10 - 12 June, 2008	CKr4 NEG StSt1
MD1	8 July, 2008	CNe8 NEG StSt2
MD2	12 August, 2008	CNe13 NEG StSt3
MD3	6 - 8 October, 2008	CNe13 NEG StSt3
MD4 MD5 MD6 MD7 MD8	15 - 18 June, 2009 15 - 16 July, 2009 12 August, 2009 15 September, 2009 3 November, 2009	CNe13 C-strip C/Zr StSt4

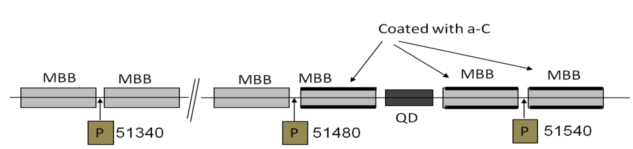

Figure 1: The position of the coated and uncoated magnets in the SPS. QD: quadrupole. P: Penning gauge.

RESULTS AND DISCUSSIONS

The Secondary Electron Yield (SEY) of a witness sample coated simultaneously with each liner was measured in the laboratory. The corresponding curves are reported in Fig 2.

From Fig 2, one can see very low SEY obtained for the a-C liners, compared to the threshold value (δ_{max} = 1.3) of the SPS with nominal LHC beam [3] [4]. More details about the SEY measurements are given in [5].

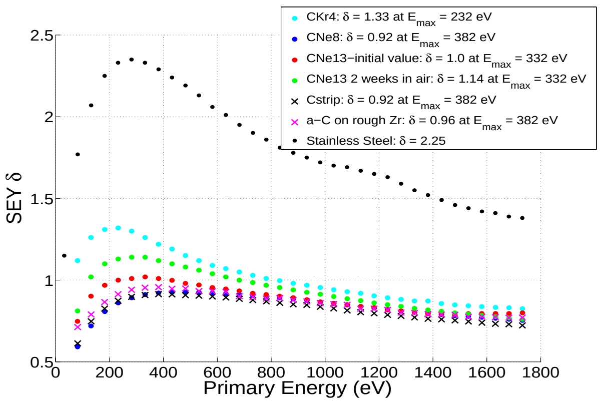

Figure 2: The overview of the SEY of a-C coatings.

Figure 3 shows the normalized e-cloud signal versus time measured in four different MD runs for three different a-C coatings. CNe13 inserted with a SEY of 1.14 after 2 weeks' air exposure showed a higher e-cloud signal than CNe8 with lower SEY of 0.92. On CNe13 a visible decrease of measured electron current occurred after 5 hours of operation during MD 3 (3-4 batches of nominal LHC beam accelerated to 450 GeV/c) as shown in Fig 3. The dose of the electron bombardment on the CNe13 after 5 hours of MD is about $1.2{\cdot}10^{-6}$ C/mm^2. After two months in the SPS vacuum (10^{-8} mbar , unbaked) and with normal SPS operation (without LHC type beams but with the usual beam delivery to CNGS and other fixed target experiments) a new run with LHC type beam did not reveal any ageing from the e-cloud signal. In addition, the CNe13 liner was kept in the SPS during the 2008/2009 winter shutdown and was vented to air during two months. After re-pumping and operating the machine during 6 months, the test with the LHC type beam exhibited an even stronger reduction of the electron current signal on CNe13. The visible improvement of electron current on CNe13 cannot be explained by scrubbing effect, since the e-cloud was too low. The pressure from MD2, 3, 4 has been compared and the result confirms a significant improvement in pressure, by a factor of 10. The possible reason of the improvement of electron signal is the improvement of pressure in the SPS. In conclusion this liner remained more than one year in the machine, sustained a prolonged venting during shutdown and did not show any sign of deterioration. Testing for longer term is still in progress.

After the successful tests with the liners in 2008, a-C coatings were applied to the three SPS magnet vacuum chambers in March 2009. Microwave transmission measurements detected e-cloud related signals in one of the uncoated magnets and no signal was measurable in one of the coated magnets [6]. However, the static pressure measured

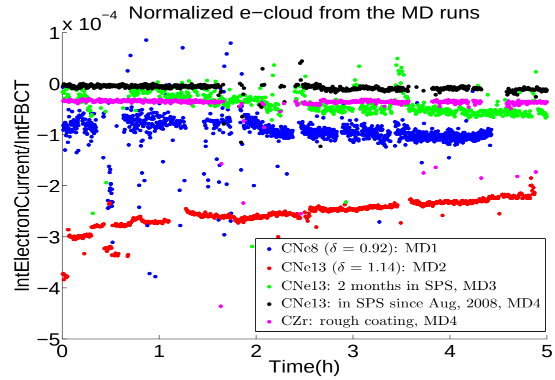

Figure 3: ECM signals from different a-C coatings: Integrated electron current signal for each supercycle devided by integrated FBCT for each supercycle as a function of time [nC/10^{10} protons per bunch].

in between two coated magnets was systematically slightly higher than the one between two uncoated reference magnets. This can partly be explained by the fact that the reference dipoles were already in the machine since a long time.

The dynamic pressure rise is shown in Fig 4 for an LHC type beam. The resolution of the measurement is only 1 s, but the cycle time (21.6 s) and the effect of the acceleration ramp is well visible. The scattering in the pressure rise is large and the pressure also changes with the various parameters (e.g. RF voltage). However it is obvious that the decrease in pressure rise due to the coating, if any, is not as marked as for the e-cloud signal in the ECM.

One explanation of the pressure rise in coated magnets could be the presence of e-cloud in the region between the magnets. Indeed, thin dark traces along the beam axis have been observed on top and bottom wall of the RF shields made of StSt, which are located between dipoles and quadrupoles. The dark traces could be induced by the electron bombardment by e-cloud. However, the magnetic fringe field between dipoles is very low (about 40 Gauss). A study of magnetic field dependence of measured e-cloud current has therefore been performed.

In Fig 5, the measured charge detected by the strip detectors with various currents applied on the dipole magnet and the simulation show that e-cloud effect can occur even at low magnetic field.

From the experiments with variable magnetic field in the e-cloud monitors and the corresponding simulation confirmed by the observation of a discoloration of the RF shields, one can conclude that 30-50 Gauss are sufficient to provoke the e-cloud with essentially the same intensity as for higher fields. As a consequence carbon coated RF shields were inserted between the two coated dipoles. However, no evident change was observed in the dynamic pressure rise.

Coating of the MBBs was performed in different conditions than for the liners of ECM. In the first case during

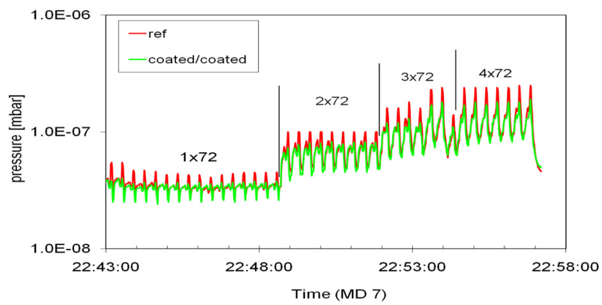

Figure 4: The pressure measured in the uncoated and coated dipoles for the nominal LHC beam of 1, 2, 3 and 4 batches with 72 bunches at 25 ns spacing and intensity of 10^{11} p/bunch.

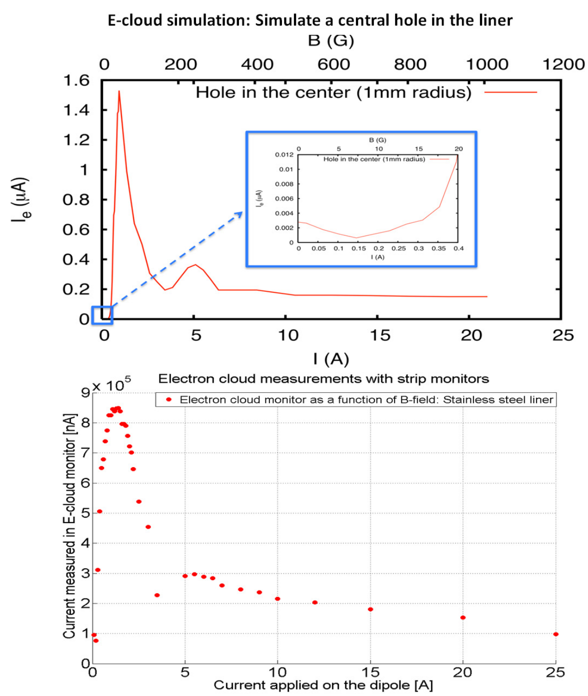

Figure 5: The current of electrons on StSt as a function of current applied on the dipole. Top: Simulation of the total charge into the hole of 1 mm in diameter in the center of the liner. Bottom: The total charge measured by ECM.

sputtering the magnetic field of the dipole was used (perpendicular to the cathodes), whereas in the second case the chambers were inserted in a solenoid (field parallel to the cathodes). In addition due to the weak thermal contact of the liners to the surrounding vacuum chamber used during coating the surface temperature can rise to 250°C during the process. Instead the power during the coating is kept low for the dipole magnets in order to avoid overheating and damaging of the coils' insulation. Witness samples coated simultaneously with the dipoles showed an initial SEY close to 1.0, but also exhibited a rather fast increase of the SEY upon air exposure compared to other carbon coatings. The samples had an SEY of 1.3 after storage during one year in the pumping ports of the dipoles. After the recent extraction of one of the coated MBB dipoles from the machine, the vacuum chamber was cut open and inspected. It has a laterally non-uniform coating color indicating differences in thickness and possibly composition.

Beyond the e-cloud, other mechanisms inducing the pressure rise could be residual gas ionization by the beam leading to ion bombardment and proton losses. The first one can only explain effects which are orders of magnitudes lower than the observed pressure changes. The integral proton losses were around 15-20% for each cycle, but the local losses on each dipole are unknown.

CONCLUSION AND FUTURE PLANS

In conclusion the experiments have shown that a complete suppression of e-cloud can be achieved by coating of liners with a thin layer of amorphous carbon, which has an SEY close to 1.0 as measured in the laboratory. The coating does not show ageing after more than one year of exposure in the SPS vacuum with the machine in operation with beams used for fixed target and few periods with LHC beam (MD runs). The inspection of the coated magnet confirmed that the coating in the magnets was significantly inferior to the coatings in the liner, which gave a complete suppression of e-cloud. The future activity will now be focused on modifying the coating system in order to find a solution to coat the dipole magnets with the same quality of coating as in the ECMs. Once the found solution satisfies all criteria, it could be applied to 750 vacuum chambers inside the SPS magnets as well as all the RF shields.

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REFERENCES

[1] *Measurement of the Electron Cloud Properties by Means of a Multi-Strip Detector in the CERN SPS*
G.Arduini et al. EPAC 2002, Paris, France.

[2] *Experimental Studies of Carbon Coatings as Possible Means of Suppressing Beam Induced Electron Multipacting in the CERN SPS*
E.Shaposhnikova et al. PAC09, Vancouver, Canada.

[3] *Which parts of the SPS do we need to coat?*
G.Rumolo, AEC09, 12 October 2009, CERN.

[4] *Amorphous Carbon Thin Films for the mitigation of electron clouds in particle accelerators*
S.Calatroni et al. HHH-2008 Proceedings

[5] *Low Secondary Electron Yield Carbon Coatings for Electron-cloud Mitigation in Modern Particle Accelerators*
C.Yin Vallgren et al. IPAC10, Kyoto Japan.

[6] *Electron Cloud Measurements of Coated and Uncoated Vacuum Chambers in the CERN SPS by Means of the Microwave Transmission Method*
S.Federmann et al. IPAC10, Kyoto Japan.