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Pedro.Costa.Pinto@cern.ch

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P. Costa Pinto, A. Bellunato, T. Basso, Paul Edwards, M. Mensi, A. Sublet, M. Taborelli
CERN, Geneva, Switzerland

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Abstract

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INTRODUCTION

In view of the future High Luminosity Large Hadron Collider project, (HL-LHC), CERN launched a program to upgrade all injector's chain to cope with the required high beam brilliance and intensity (25 ns bunch spaced beams with 2.2×10^{11} protons per bunch). Electron Multipacting (EM) is one of the potential limitations of the SPS, the LHC injector, leading to build-up of clouds of electrons. This phenomenon may induce dynamic pressure rise, transverse emittance blow up, and beam losses. Among the mitigation techniques to treat EM [1], reduction of the Seconday Electron Yield (SEY) of the internal walls of the beam pipes was chosen. The maximal SEY, δ_{max}, to avoid multipacting in the SPS depends on the chamber geometry and vary from 1.1 in drift tubes, to 1.3 and 1.4 in MBB and MBA type dipoles respectively [2].

Two strategies are envisaged in order to obtain such a reduction of SEY: beam scrubbing and thin film coating. Beam scrubbing relies on the growth of a carbon layer with low SEY induced by the bombardment of electrons from the electron cloud itself [3, 4, 5]. The main advantage of this strategy is that it does not need hardware modifications. The main drawback may be the necessary time: as the SEY of the surface decreases, the flux of electrons impinging on the surface also decreases and the whole process slows down. To speed up the growth of this carbon layer, a new scrubbing strategy will be tested in the SPS during 2015 in order to obtain realistic scrubbing speeds [6]. The alternative to the scrubbing is the deposition of a low SEY thin film in the internal walls of the beam pipe. This was successfully done for the long straight sections of the LHC, coated with a Non Evaporable Getter (NEG) thin film [7]. After activation at 180°C for 24 hours, the δ_{max} reaches 1.1. Since the SPS is not a bakeable machine, CERN developed a carbon thin film with low SEY, which does not need thermal activation after air exposure. This coating is produced by sputtering and passed successfully through several validation stages: from laboratory assays on the ageing and EM induced by RF to accelerator environment tests in the SPS [5, 8, 9].

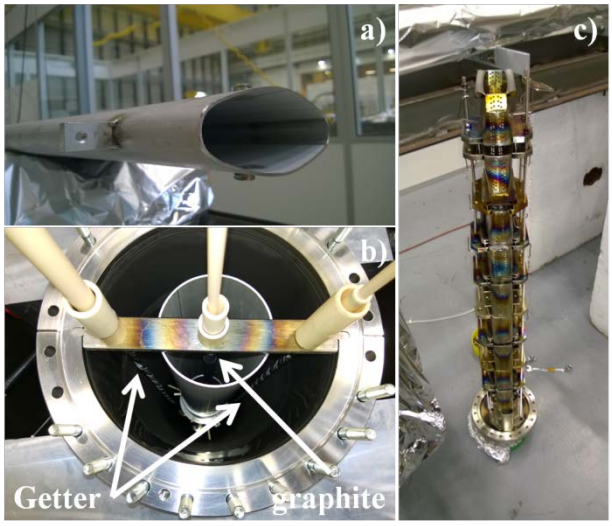

Figure 1: Parts coated by magnetron sputtering in cylindrical configuration: a) QF type chamber; b) QD type; c) assembly of 10 RF pumping port shields to coat.

The decision to coat or not the entire SPS will depend on the results of the scrubbing runs planned for 2015. In case conditioning with the beam will take too long, about 90% of the SPS will have to be coated. This includes the dipoles (744), the quadrupoles (216) and the straight sections. In view of an eventual large scale campaign to coat the entire machine, it was decided to have two magnetic cells of the SPS coated with carbon. For this purpose, 6 MBA and 6 MBB type dipoles plus 2 QD and 2 QF type quadrupoles and their respective RF pumping port shields (30 pieces) were coated recently. These 16 magnets will add to other 6 already coated and installed in the SPS, making a segment of about 120 m of carbon coated beam line. These elements have different geometries and require different sputtering configurations. The main goal of this operation is to identify issues related not only with the coating of the different

components but also with the logistics to dismount the elements from the machine, bring them to the coating laboratory and re-install after coating. The outcome from this experience will be used as input to define the coating strategy for the eventual large scale production. The quality control during production as well as the surface treatment will be discussed

COATING THE TWO MAGNETIC PERIODS

The quadrupole chambers and the RF pumping port shields (Figure 1) were coated by cylindrical magnetron sputtering from graphite targets in the CERN coating facility. Since the beam pipes are coated without flanges (to allow insertion in the yoke afterwards) a housing vacuum chamber is necessary. Additional targets of a getter material were added to pump the hydrogen outgassed from the walls of both the housing chamber and from the QD and QF external surfaces during the coating process. This is mandatory since the hydrogen present in the glow discharge during the film growth can increase the SEY of the coating. The tubes were new and degreased by immersion in P3 Almeco 18 detergent with ultrasonic agitation. Prior to coating, the system was baked 20 hours at 250°C. The coating takes about 24 hours, at a power density of 100 W per meter of cathode, 650 V, Ar pressure of 1.5×10^{-2} mbar in a magnetic flux density of 150 Gauss. The temperature rose up to 280°C. The thickness is around 400 nm. Details about the coating process and setup can be seen in [8]. The RF pumping port shields were coated by batches of 10, using two parallel graphite targets. The coating parameters were similar to the ones for the quadrupole chambers.

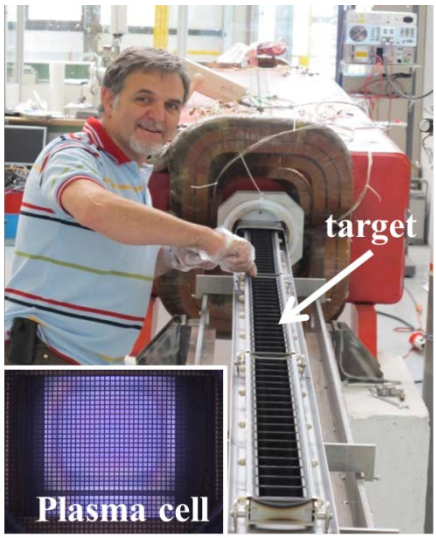

Figure 2: Coating assembly for the MBB type dipoles. The MBA type electrode has a similar geometry

The dipoles cannot be coated with the same sputtering configuration because the beam pipes are clasped inside the yoke. For this purpose, a hollow cathode configuration was developed. The target is made of a sequence of rectangular graphite cells, (51 mm x 48 mm), along 6.4 m. In the MBB case, the height is 30 mm, for the MBA 25 mm, to fit the respective beam pipe apertures. The plasma develops inside each cell and the ionization efficiency is enhanced by the pendulum movement of the electrons between cell faces. Before coating, the beam pipes were degreased by circulation of P3 Almeco 18 detergent. The dipoles were then pumped and kept under vacuum by pinch-off flanges until start the coating assembling. Only two stripes, (top and bottom), with 60~70 mm width are coated (where the cloud of electrons develops [2, 5]). Power density is 120 W per meter of cathode, voltage is 900 V, pressure 1.1×10^{-1} mbar and the maximal temperature reached at the substrate is below 60°C. To achieve a thickness of 400 nm, 20 hours of deposition are necessary.

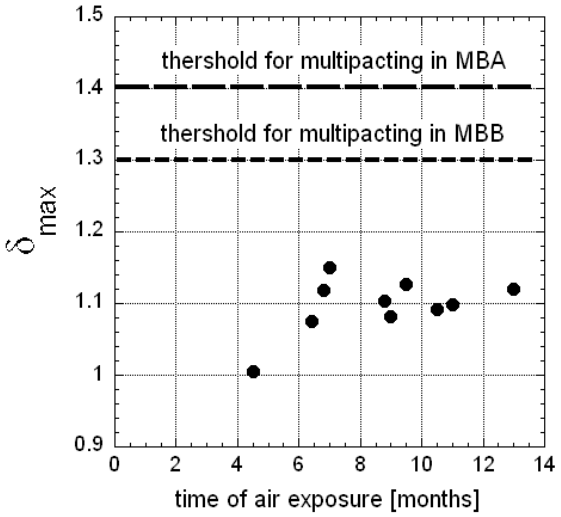

Figure 3: Evolution of the maximal secondary electron yield as a function of the time to air exposure on coupons coated with the dipoles.

The SEY measurement was done on samples coated together with the dipole beampipes. Even if after coating the beampipes were evacuated and filled with nitrogen, they might remain an uncertain time exposed to air in the tunnel during the installation phase. For this reason, the samples were kept in air until the SPS was closed and pumped. In Figure 3 we plot δ_{max} as a function of the time the samples were exposed to air, wrapped in aluminium foil. The average maximal secondary yield is 1.09 and remains below 1.15 even after more than one year of air exposure. To assess the impact of the carbon coating on the pumpdown time of SPS dipole, the decrease in pressure was recorded before and after coating. After 10 hours of pumping, the outgassing of the carbon coated chamber is 3.5 times higher than before being coated. The dominant gas specie is water in both cases.

One of the MBA type dipoles was also tested by inducing RF multipacting (using the beam pipe as a coaxial resonator), before and after coating. Details of the setup can be found in [9]. After the coating, no signs of

multipacting could be detected, either by measuring the reflected power or by pressure rise.

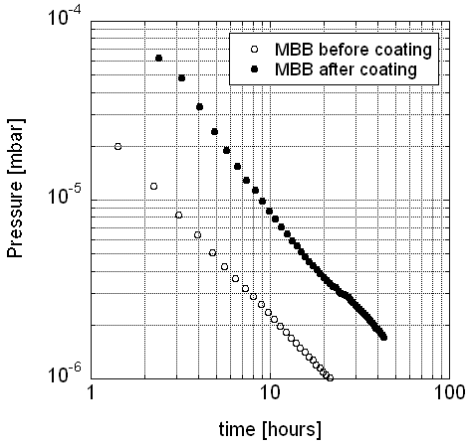

Figure 4: Evolution of the pressure during the pumpdown of a dipole chamber before and after coating.

ETCHING THE CARBON COATING

In case of a faulty coating, the carbon has to be removed from the surface. Due to its chemical inertness, graphite-like carbon is hard to etch by wet chemical processes. The length of the beam pipes, (6.4 meter for the dipoles), and the small apertures made it even more tricky to get a uniform etch. For this reason, it was chosen to implement an etching process utilising oxygen plasma. The coated beam pipe is polarized negatively, attracting oxygen ions that react with the carbon coating producing CO, CO_2 and other volatile species that are evacuated by the pumping system. The discharge works in diode mode and the anode, made of a rectangular cross section tube, is placed in the centre of the beam pipe. The oxygen is injected inside the anode and released uniformly along the dipole through 0.5 mm diameter holes (Figure 5). The system worked successfully in a MBB chamber. With a power density of 120 W per meter and oxygen flow of 3 mln/min, the carbon coating is etched in 3 hours.

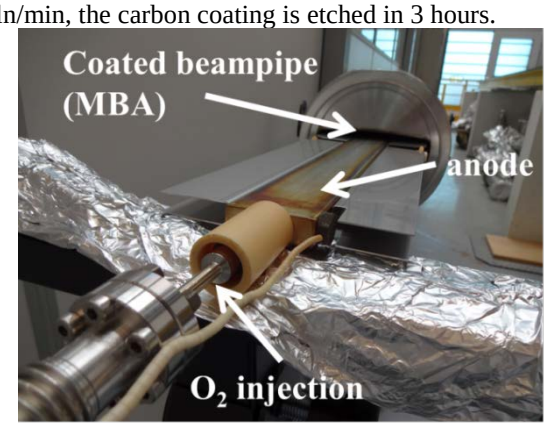

Figure 5: Anode for the etching process.

A test with the same anode was done in a MBA type, but the plasma was concentrated aside the anodes, favoured by the higher SEY of the stainless steel (compared to the carbon) and by the pendulum movement of the electrons between the top and bottom walls. To solve this problem, the anode was prolonged in order to intercept the electrons.

STRATEGY FOR LARGE SCALE PRODUCTION

The 960 magnets have to be removed from their positions and transported underground through the SPS tunnel up to a coating facility to be built at ground level. The full cycle to coat a magnet (including prior surface treatment) is 6 days. To fit this campaign in a single long shutdown of the LHC, it will be necessary to achieve a coating pace of 30 magnets per week. This requires 18 coating benches, (with two magnets per bench), operating in parallel. The number of benches can be reduced if the 216 chambers of the quadrupoles are previously coated and installed in parallel during the deposition of the dipoles. The RF pumping port shields can be coated in the present CERN coating facility but conflicts with the NEG coating production for the LHC have to be taken into account. For the cleaning surface treatment prior to coating, two options remain open: wet chemistry or oxygen plasma. The first one has the disadvantage of handling half a ton of water to be treated as light radioactive waste. The second one has the disadvantage of not removing dust.

CONCLUSIONS

Two magnetic cells of the SPS were successfully coated with carbon. The hollow cathode showed good reliability. Improvements shall be done to the cylindrical magnetron setup to coat the quadrupole chambers and the RF pumping port shields in order to facilitate assembling and disassembling. Etching a faulty carbon coating was proven in MBB configuration. The modifications for MBA are not validated yet. To coat the full SPS in a single LHC long shutdown will imply the implementation of a large coating facility and will be a logistical challenging endeavour, without major technical obstacles.

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