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REDUCTION OF E-CLOUD IN PARTICLE ACCELERATORS BEAM PIPES STUDIED BY RADIO-FREQUENCY MULTIPACTING

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Abstract

For a given beam structure, chamber geometry and magnetic field configuration, the electron cloud, (EC), intensity depends on the Secondary Electron Yield, (SEY), of the inner walls of the beam pipe. The observed reduction of the EC intensity as a function of the time of exposure to the beam, often called conditioning, is attributed to the growth of a low SEY carbon film due to the bombardment of electrons from the cloud itself. The full mechanism for the growth of carbon is not yet fully understood, but it depends on the dose of electrons and their energy. As the SEY of the beam pipe surface decreases, the flux of electrons from the EC also decrease and the conditioning decelerates. In the present paper we study the time evolution of the conditioning in stainless steel and copper beam pipes. The EC is induced by Radio-Frequency, (RF), multipacting using a coaxial resonator. Strip detectors are used to monitor the intensity of the EC. After each conditioning cycle, the SEY of beam pipes is measured and the growth of carbon analysed by X-ray Photoelectron Spectroscopy. The influence of the bias voltage, the composition of the base pressure with injection of C_2H_2 and $C_{12}H_{26}$, and the resilience of the conditioning after air exposure are tackled.

EXPERIMENTAL SETUP

The RF resonator to induce electron multipacting, (MP), consists of a tungsten wire drawn along the axis of a one meter long liner with a cross section similar to a CERN-SPS Main Bending magnet of type B (MBB) beam pipe. The liner is inserted in a cylindrical vacuum chamber, which is itself enclosed in a dipole magnet. The vacuum system is unbaked and operates at ~$1x10^{-7}$ mbar. The RF signal is generated by a Vector Network Analyzer (VNA); it is amplified and injected in the resonator. The network is matched to a frequency close to 100 MHz. To maximize the MP intensity, the dipole magnetic field is set close to cyclotron resonance (~43 Gauss). The RF excitations, (shots), are applied in power ramps from -30 dBm to -10 dBm in 30s, followed by a 90s pause to avoid overheating the wire. A measurement run consists of several thousands of shots and lasts several days. A DC bias voltage can be applied to the wire and is superimposed to the RF excitation. During the runs the pressure, the reflected RF power, and the MP current can be measured. Further details on the set-up can be found in [1]. The total pressure is measured by a cold cathode gauge and the partial pressures with a Residual Gas Analyser (RGA). The MP current distribution along the axis of the beam pipe is measured using a collector with 47 transversal stripes, (8 mm width, spaced by 0.17 mm, and bundled to 16 channels). The collector is separated from the beam pipe volume by a grid with a transparency of 7% to minimize the influence of the measurements on the MP process. The current on each channel is registered for every shot and the electron dose received by the beam pipe surface is calculated by correcting with the grid transparency. A similar strip detector with longitudinal stripes is used to measure the transversal distribution of the MP. Details about the strip detectors can be found in [2] [3]. Stainless steel (316LN) and electroplated copper liners were studied. Samples for SEY measurement (10 mm x 300 mm) are made of the same material of the liners and exposed to the MP in the beam pipe. Reference samples are placed in the same vacuum system but not exposed to MP. Before each measurement run, the liner and the samples are etched and cleaned following standard CERN procedures. At the end of the run, the system is vented to the laboratory air and the samples transferred to the SEY/XPS system for measurement [4].

RESULTS AND DISCUSSION

Effect of the Bias Voltage

It was observed that positive bias voltages enhance the MP and negative bias values below -100 V, suppress it completely. For positive bias from 0 V to 1000 V the MP current increases linearly. This might be an indication that the bias voltage increases the energy of the electrons hitting the walls, so that it approaches the SEY peak value. Figure 1 (top) shows the time evolution of the average of the doses measured in all the channels of the strip detector during one RF shot for stainless steel liners at 0 V and 1000 V bias and for a copper liner at 1000 V. To allow a direct comparison between the two voltages, during the 1000 V bias conditioning some points were measured by applying 0 V. The runs lasted 11 days. The current and dose per shot with the 1000 V bias is always the highest and it induces also a faster conditioning. After 3 days conditioning at 1000 V, no more MP could be observed at 0 V bias. After 11 days at 0 V the MP still remains (with a dose per shot ~$5x10^{-8}$ C/mm^2). This is due to the fact that at higher bias voltage the cumulated dose increases faster in time. Nevertheless, Fig. 1 (bottom) shows that the conditionings obtained with the two bias voltages have the same dose dependence.

For all runs, full suppression of the MP was never achieved. The system approaches asymptotically the SEY threshold for MP. We remark that the distribution of the MP intensity along the liner changes during the conditioning process, probably due to the fact that the RF electromagnetic field is not uniform and the electron dose

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is different at different locations. A more detailed understanding of this effect could be obtained after calculation of the field pattern in the system. It is also observed that the electroplated copper liner conditions significantly faster than the stainless steel one.

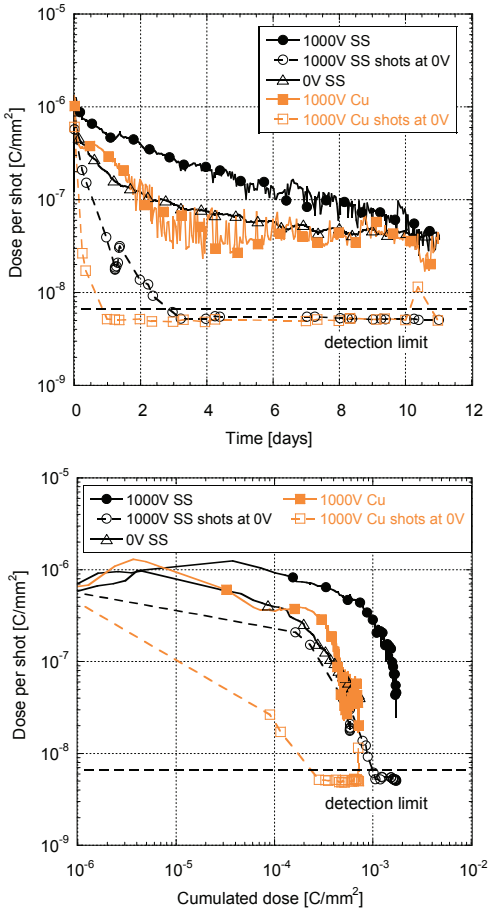

Figure 1: Dose per shot as a function of the time (top) and the cumulated dose (bottom) for the 0 V and 1000 V bias runs, for stainless steel and electroplated copper liners.

Pressure Rise During Multipacting

Once MP starts, a pressure rise is observed. The main species desorbed are hydrogen, carbon monoxide and carbon dioxide, while water vapour remains almost constant. This is a clear sign that the pressure burst results from particle induced desorption and not from thermal desorption (where water vapour would be dominant in an unbaked vacuum system). The ratio between the pressure rise (ΔPressure) and the electron dose per shot reflects the number of molecules desorbed per electron and gives a good indication of the trend of the electron stimulated desorption yield. This trend is plotted in Fig. 2.

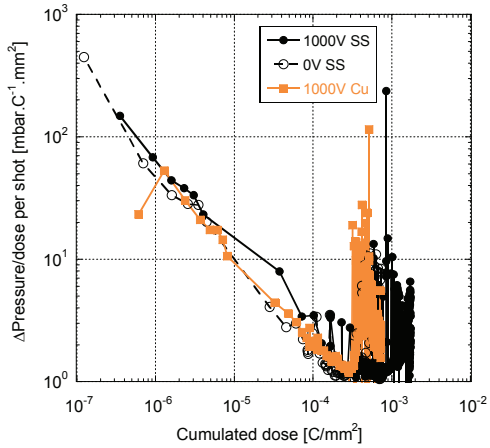

Figure 2: Ratio between the pressure rise and the dose per shot as a function of the cumulated dose.

Up to a few 10^{-4} C/mm^2, the number of desorbed molecules per electron decreases continuously, indicating the progressive reduction of adsorbates on the surface due to the impingement of the electrons. At higher doses the pressure rise remains relatively constant, with an increasing number of spikes as we approach the threshold for MP. One possible explanation for these spikes is linked to the displacement of the impact location of the multipacting electrons: if a region is sufficiently conditioned, the MP will move elsewhere, resulting in a sudden increase of the number of molecules released per electron (spike). The big spikes are associated with a change of channel where the maximal MP is detected.

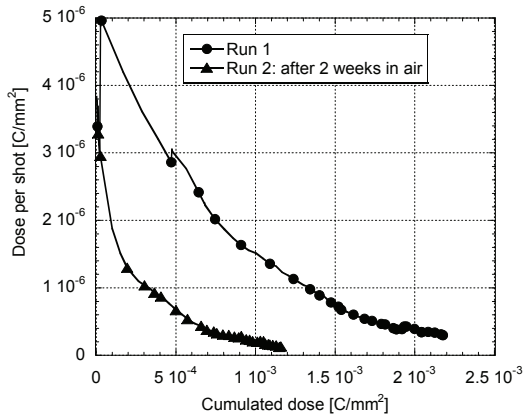

Figure 3: Stainless steel liner underwent two consecutive conditioning runs at 1000 V, intercalated by two weeks of air exposure.

Memory of the Conditioning

A stainless steel liner was conditioned at 1000 V bias during three days (run 1), then exposed to the laboratory air for two weeks (wrapped in aluminium foil) and finally conditioned for a second time (run 2). The results (Fig. 3) show that the conditioning is not completely lost after air venting. To reduce the dose per shot down to 3×10^{-7} C/mm^2 in run 1 it is necessary to accumulate a dose of 2.2×10^{-3} C/mm^2 while in run 2 already 8×10^{-4} C/mm^2 is enough.

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Injection of Hydrocarbons

Since the conditioning is related to the presence of carbon on the surface (see below), two types of gases containing carbon were injected during MP aiming at improving the conditioning efficiency. Acetylene, (C_2H_2), was chosen because of its high ratio carbon/hydrogen atoms, while dodecane ($C_{12}H_{26}$) for its high sojourn time. Figure 4 shows the evolution of the conditioning.

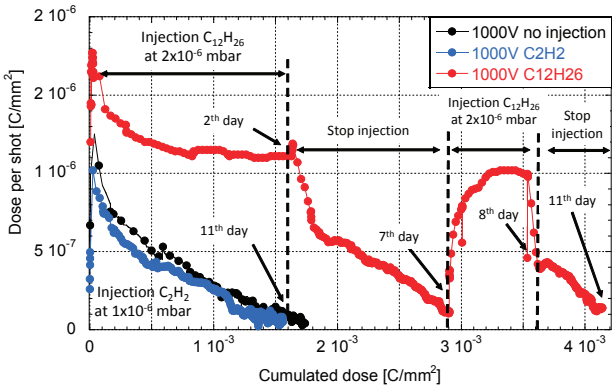

Figure 4: Conditioning while injecting acetylene or dodecane.

Acetylene was injected at 1x10^{-6} mbar during the run and the conditioning behaved as for a standard run without injection of gases (also plotted in Fig. 4 for reference). After 7 days, (cumulated dose of 1.3x10^{-3} C/mm^2), the supply of C_2H_2 was stopped and the last four days were done without gas injection. No change of behaviour was detected. For the dodecane, the pressure was set to 2x10^{-6} mbar. After a cumulated dose of 8x10^{-4} C/mm^2, the decrease of the dose per shot ceased and saturated to a stable level up to a cumulated dose of 1.5x10^{-3} C/mm^2. Then the injection was stopped and a rapid reduction of the dose per shot is observed followed by a less accentuated reduction. At a cumulated dose of 3x10^{-3} C/mm^2, the injection of dodecane was resumed and immediately the dose per shot increased by one order of magnitude. After 1 day, the injection was stopped for a second time and again a reduction of the dose per shot was observed. This behaviour suggests that during injection the SEY of the liner is determined by the amount of dodecane adsorbed and a steady state is obtained after 2 days at an SEY which is intermediate between the one of the initial surface and the one of a conditioned surface.

Carbon Growth and SEY

Figure 5 shows the maximal SEY, (SEY_{max}), as a function of the amount of surface carbon measured at the end of each run and after air exposure. Encircled points are for reference samples exposed to the same vacuum during the multipacting, but not bombarded by the electrons. Typically, after a CERN standard degreasing treatment, stainless steel samples have about 20~30 at% of carbon on the surface and a SEY_{max} 1.8~2.0.

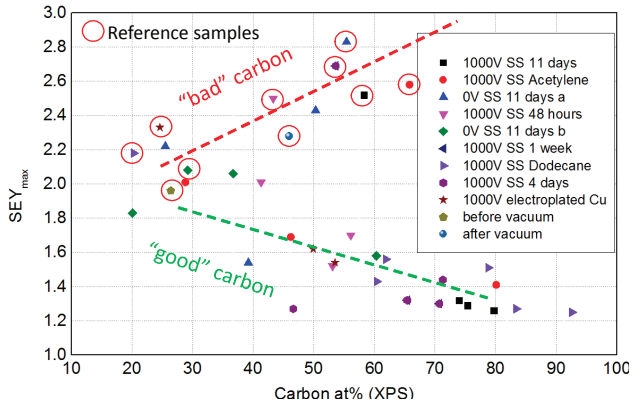

Figure 5: The maximal SEY as a function of the carbon measured on the samples by XPS.

After conditioning, two trends are observed: on the samples bombarded by the electrons, the increase of carbon lowers the SEY_{max}, (what we call here "good" carbon), while on the reference samples, the increase of carbon leads to an increase of the SEY_{max} ("bad" carbon). The different character of these two types of carbon is confirmed by the XPS spectra. Compared to the "good" carbon, the "bad" carbon presents a broader C1s peak, with evidences of C-O and C-H bonds, and is slightly shifted to higher binding energies. This carbon probably originates from adsorbed hydrocarbons present in the residual gas or desorbed from the bombarded surfaces. For the conditioned samples, the shift of the C1s peak towards lower binding energies correlates with higher cumulative doses, indicating a tendency to go for "graphite like" carbon, (increase of the ratio between sp^2 and sp^3 carbon-carbon bonds), consistent with the decrease of SEY_{max}. Up to cumulative doses of ~4x10^{-3} C/mm^2, the SEY_{max} decreased down to ~1.3, (although presenting a relatively large spread), and then it never reached values lower than 1.25, even for cumulative doses of 8x10^{-3} C/mm^2.

CONCLUSIONS

Higher bias voltages increase MP currents, but do not change the dose dependence of the conditioning. The conditioning depends only on the dose of irradiation and was never sufficient to suppress MP in the discussed setup. In a stainless steel liner, the conditioning was not completely lost after two weeks of air exposure. The injection of acetylene had no impact on the conditioning speed. Injection of dodecane accelerates the dose accumulation, but its presence on the surface hinders a fast conditioning. Further studies would be necessary to see whether a further electron dose after stopping injection would produce a conditioning which is particularly robust with respect to air exposure. The amount of carbon on bombarded samples increases with the cumulated dose. The higher the dose, the more "graphitic like" is the carbon and the lower the SEY. Carbon also increases on samples exposed only to the vacuum, without electron bombardment, but in this case the SEY increases.

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REFERENCES

[1] P. Costa Pinto, et al, "Multipactor For e-Cloud Diagnostics", proceedings of IPAC'12, New Orleans, Louisiana, USA.

[2] Y. Vallgreen et al, "Amorphous carbon coatings for the mitigation of electron cloud in the CERN Super Proton Synchrotron", Phys. Rev. Spec. Top. Accel. Beams 14 (2011) 071001.

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

[4] P. Costa Pinto et al, "Carbon Coatings with Low Secondary Electron Yield", Vacuum 98 (2013) 29-30.

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