MULTIPACTOR FOR E-CLOUD DIAGNOSTICS

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Abstract

Electron cloud in particle accelerators can be mitigated by coating the vacuum beam pipe with thin films of low secondary electron yield (SEY). SEY of small samples can be measured in the laboratory. Verifying the performance of long pipes is more complex, since it requires their insertion in the accelerator and the subsequent measurement of the beam induced pressure rise. RF induced multipacting in a coaxial waveguide configuration is proposed as a test before insertion in the machine. The technique is applied to two main bending dipoles of the SPS, where the RF power is fed through a tungsten wire stretched along the vacuum chamber (6.4 m). A dipole with a bare stainless steel chamber shows a clear power threshold initiating an abrupt rise in reflected power and pressure. The effect is enhanced at RF frequencies corresponding to cyclotron resonances for given magnetic fields. Preliminary results show that the dipole with a carbon coated vacuum chamber does not exhibit any pressure rise or reflected RF power up to the maximum available input power. In the event of a large scale coating production this technique will be a valuable resource for quality control.

EXPERIMENTAL SET-UP

A tungsten wire is drawn alongside a vacuum chamber in SPS dipole magnets. The centered wire, in combination with the chamber walls, forms a resonant coaxial transmission line set-up[1, 2]. The far end of the electrical connection is short-circuited. Thus, RF power is reflected and the vacuum chamber works as a resonator. A vector network analyzer (VNA) is used to perform a RF power ramp over time on a resonant frequency, given by the geometry of the resonator. After the amplification, the output power reaches up to 40 W. The injected RF power provokes multipacting inside the chamber at certain locations with respect to the standing wave pattern. In the event of multipacting and the resulting electron cloud, power is reflected due to the plasma. The reflected power wave is coupled out by a directional coupler and will be compared to the input signal emitted by the VNA. Furthermore, vacuum diagnostics are used to observe the multipacting effect. A symptom of the multipacting process is the emission of various gas species from the chamber walls through electron stimulated desorption. This effect is monitored using a Prisma QMS200 residual gas analyzer, whilst pressure is measured using a Pfeiffer IKR270 cold cathode gauge. Figure 1 shows a block diagram of the used diagnostic methods.

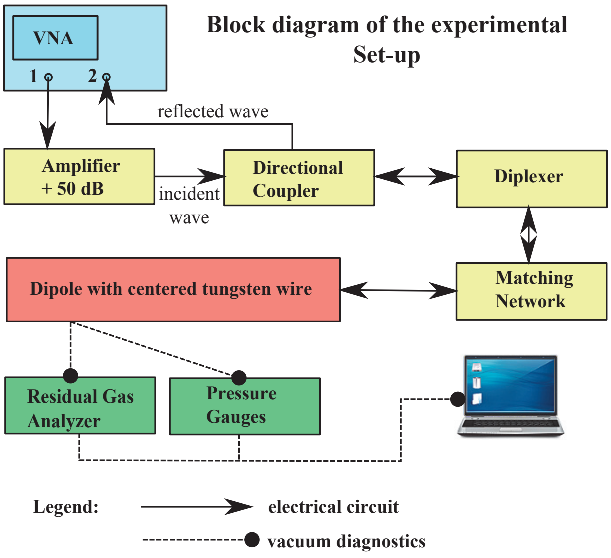

Figure 1: Scheme of the set-up, including electrical circuit and vacuum diagnostics.

RESULTS AS A FUNCTION OF MAGNETIC FIELD

During the commissioning of the experimental set-up, a pronounced maximum in outgassing has been observed in the very low magnetic field range. First assumptions were related to the cyclotron resonance condition (28 GHz / Tesla). The cyclotron resonance frequency is given by

$$f_{cyc} = \frac{|q| \cdot B}{2\pi \cdot m_e} \quad (1)$$

where q is the elementary charge, B the magnetic flux density and m_e the mass of the electron. For a power injection frequency of around 130 MHz, the corresponding B for cyclotron resonance calculates to 4.6 mT. In our set-up, the necessary current through the dipole for achieving this field calculates to 10.8 A. In order to verify whether this resonance condition will affect the multipacting behavior measurements were performed by varying the magnetic field in the corresponding region. Reflected power and outgassing pressure were monitored during the measurements. Figure 2 shows the outgassing due to the electron stimulated desorption as a function of varying currents through the magnet and figure 3 shows the corresponding reflected power. In figure 2 the increase of outgassing is clearly visible for the resonance region close to 10A due to a stronger electron stimulated desorption induced by multipacting. Moreover the threshold for the increase of the reflected power exhibits a clear minimum at resonance condition, as visi-

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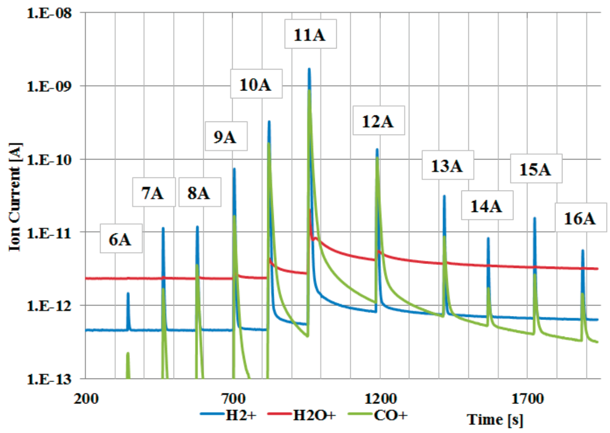

Figure 2: Outgassing for hydrogen, water and carbon monoxide at different magnetic fields with a pronounced maximum around the calculated resonant condition (10.8A).

ble in figure 3. The base levels are slightly different due to minor mismatches in the coupling between the external circuit and the tungsten wire. The minimum of the threshold corresponds well to the magnetic field value calculated for this frequency. This series of experiments was performed with two different RF frequencies in order to prove unambiguously the effect of the cyclotron resonance. The main desorbed gases are H_2, CO and CO_2. For water, which is the dominant residual gas in static conditions, almost no increase is observed. This is a clear fingerprint of electron stimulated desorption in contrast to thermally induced desorption. Various arguments can explain the lower threshold of reflected power and the higher pressure rise at cyclotron resonance. Due to the resonance the electrons gain a larger energy in the direction tangential to the surface of the beam pipe. Thus with higher energies, the multipacting electrons could then be more proficient at inducing electron stimulated desorption. In addition the electrons impact on the surface at a larger incidence angle (with respect to the surface normal) which results in a higher secondary electron yield. It is difficult for the moment to disentangle the two effects. Under cyclotron resonance conditions, a formation of plasma could be observed at the multipacting location through a small viewport. Figure 4 shows the plasma during the short period of multipacting. By applying the cyclotron resonance condition the sensitivity to changes in the surface properties are strongly enhanced thus amplifying the observable difference between stainless steel and carbon coated magnet chambers.

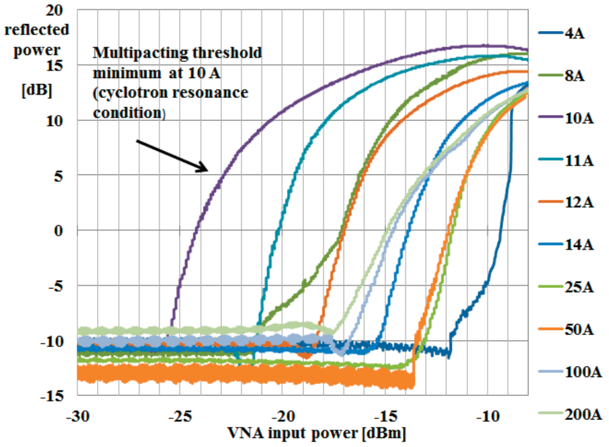

Figure 3: Reflected power, measured in the low magnetic field range on the uncoated chamber.

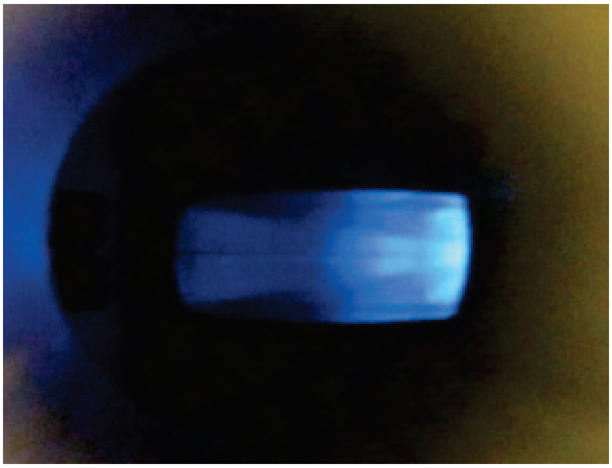

Figure 4: Evidence of plasma formation by emitted light in the blue visible spectrum.

COMPARISON WITH CARBON COATED DIPOLES

The following measurements were performed with RF frequencies of around 130 MHz on a coated and an uncoated dipole at different magnetic fields. In the case of the uncoated chamber, multipacting occurred with the available power at all magnetic fields with a pronounced maximum under cyclotron resonance condition and stabilized at a certain level beyond 14 A. In the high magnetic field range, the threshold for the rise of the reflected power is almost independent of the field. This can be seen in figure 5. Small modulating oscillations on the curves are due to mechanical vibrations of the wire caused by e.g. the pumping system. After the characterization of the multipacting behavior for the uncoated chamber, the same measurement procedures were applied to the chamber coated with amorphous carbon [3]. The coated chamber doesn't exhibit any abrupt rise in reflected power nor pressure with one exception: In one single measurement at 3000 A a rise of reflected power and pressure occurred. Afterwards, reflected power didn't appear again, however, pressure activity remained for all consecutive measurements, even without magnetic field. Further tests have to be done to fully understand this exception. Figure 6 and figure 7 show the

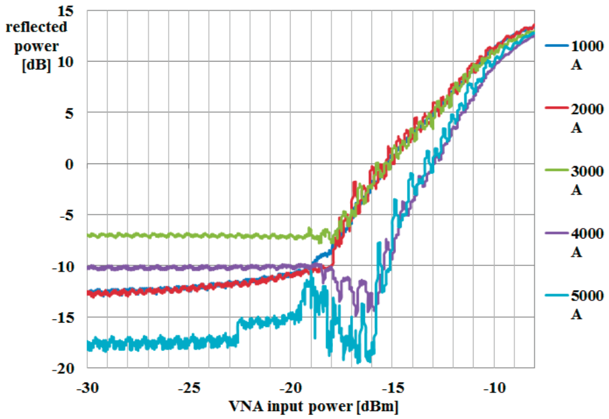

Figure 5: Reflected power, measured in the high magnetic field range on the uncoated chamber.

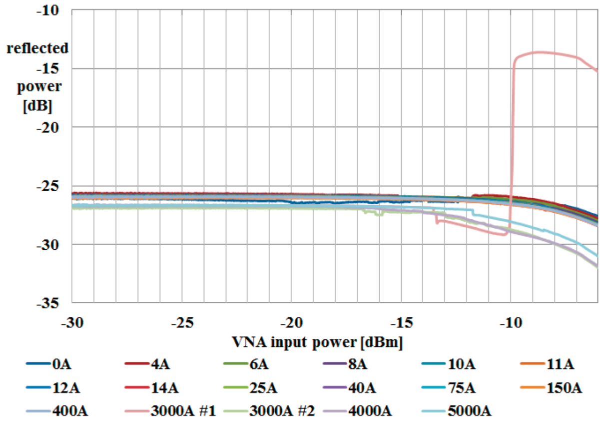

Figure 6: Reflected power on the coated chamber. Single increase at the first measurement with 3 kA. Decreasing signals towards the end of the power sweep are due to the compression of the amplifier.

reflected power for the coated chamber and the pressure data for both, coated and uncoated chamber, respectively.

CONCLUSION

The existence of the cyclotron resonance condition could be verified on two different frequencies and their corresponding magnetic fields. Under these conditions, a formation of plasma was observed in the chamber. Its application to the set-up strongly enhanced the amplification of the differences between stainless steel and carbon coated chambers. A comparison between stainless steel and carbon coated chambers has shown a huge difference in both, reflected power and outgassing. With one single exception, the multipacting did not just reduce but completely disappear on a coated chamber for the maximum available input power, even under cyclotron resonance condition.

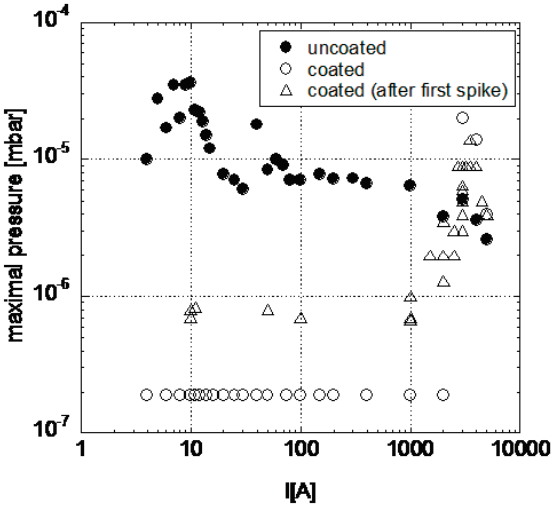

Figure 7: Pressure recordings for coated and uncoated chamber. The triangles show the remaining pressure activity after the 3 kA measurement.

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