RADIO-FREQUENCY MULTIPACTING AS QUALITY CONTROL OF COATINGS FOR E-CLOUD SUPPRESSION

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Abstract

To mitigate electron cloud in particle accelerators a carbon coating with low SEY (Secondary Electron Yield) has been developed. In the case of the SPS (Super Proton Synchrotron), which belongs to the LHC injector chain, testing of the performance of coated beam pipes directly in the accelerator must cope with the schedule of the regular machine operation. For this reason an alternative tool based on RF induced multipacting in a coaxial configuration has been designed for ex-situ characterization of the main bending dipoles of the SPS. In this contribution we report the results obtained before and after coating for two 6.4 meter dipoles with different cross sections of the vacuum chambers. The multipacting is monitored by measuring the pressure rise and the RF reflected power. After coating, the power threshold to induce multipacting is strongly reduced indicating a lower propensity for electron cloud. The impact of the RF coupling on the sensitivity of the technique is discussed.

EXPERIMENTAL SETUP

A SPS dipole can be transformed into a coaxial resonator by stretching a tungsten wire within its beam pipe. The RF excitation is generated by a Vector Network Analyser, (VNA), amplified and injected through one extremity of the wire while the other extremity is short circuited. By choosing a frequency corresponding to one of the resonances of this system, most of the RF power injected is dissipated in the resonator and only a small fraction reflected. In case of multipacting, a cloud of electrons is generated and the RF power is strongly reflected by the resulting plasma. To determine the power threshold for multipacting we ramp up the RF power while monitoring the ratio between the reflected and input power in the VNA. In the absence of multipacting this ratio remains constant, but rises abruptly when the multiplication of electrons starts. To complement the RF diagnostic, the vacuum is monitored by a total pressure gauge and a Residual Gas Analyser (RGA). More details about the experimental set-up can be found in [1].

MEASUREMENT IN THE DIPOLES BEFORE AND AFTER COATING

The propensity of the beam pipes to multipact depends on their geometry, the SEY of their internal surfaces and the applied magnetic field. In the SPS the vacuum chambers of the two main types of bending dipoles, MBA and MBB, are made of 316LN stainless steel and have almost rectangular cross sections, but different internal dimensions (see Figure 1): the MBA is 35 mm x 152 mm; the MBB 48 mm x 128 mm. The length is about 6.5 meters for both types. One dipole of each geometry was first measured before coating, (stainless steel surface with maximum SEY of about 1.8), and after coating a central band, 70 mm width, with a carbon thin film, (maximum SEY of about 1.0 [2]).

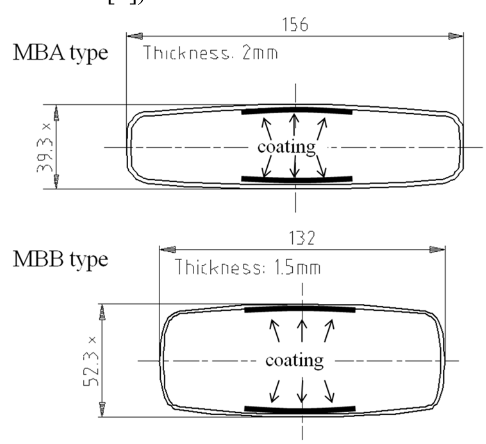

Figure 1: Transversal cross sections of the vacuum chambers of the main SPS dipole magnets.

The resonant frequencies chosen were ~130 MHz for the MBB dipoles and ~150 MHz for the MBA dipoles. The RF power was ramped from 1 W to 20 W in 5 seconds. Since the multipacting is enhanced in a magnetic field leading to cyclotron resonance,

$$B_r = \frac{2\pi m_e}{q_e} f ,$$

the sensitivity of the technique is optimized when the measurement is done at B_r [1,3], (m_e and q_e are the electron's mass and charge and f the frequency).

In Figure 2, the ratio reflected/input power is plotted as a function of the input power for the two types of dipoles before and after coating with carbon. The measurements were performed at B_r.

Before coating, the MBB dipole has a lower power threshold for multipacting, (~1 dBW), compared to that of the MBA, (~4 dBW), and a higher maximum of the ratio reflected/input power than the MBA. This higher propensity to multipact of the MBB is attributed to the difference in the geometry and is in agreement with the outcome of electron cloud simulations done by Rumolo [4] using the ECLOUD code. (For the MBA the simulations give an SEY threshold for electron cloud with SPS beam of 1.4, while for the MBB it is 1.3). After applying the thin carbon film, no multipacting activity is

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observed in the MBA dipole and in the MBB the power threshold increases to about 12 dBW while the maximum of the ratio reflected/input powers is only -22 dB, just slightly above the level in absence of multipacting -23 dB. The strong reduction in multipacting is due to the decrease of SEY and confirms the effectiveness of the carbon coatings on electron cloud mitigation.

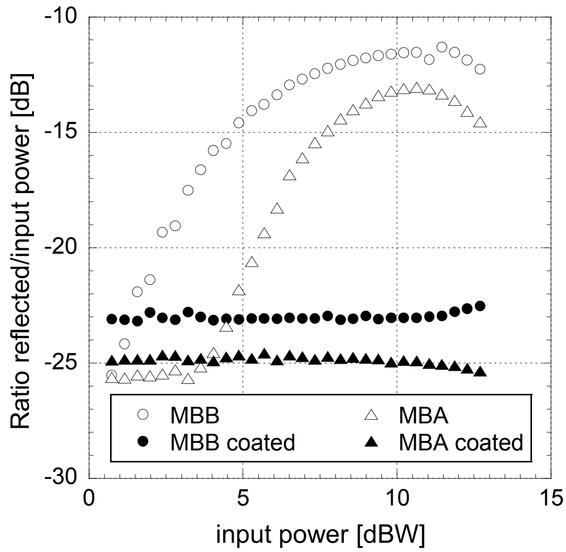

Figure 2: Ratio reflected/input powers as a function of the input power at B_r.

In principle, both the power threshold and the maximum of the ratio reflected/input power can be used as figures of merit to quantify the predisposition for multipacting, but the reliability of the latter depends on the measurement conditions. To check the reliability of the two criteria, we can vary the magnetic field in order change the propensity for multipacting and see the effect on the power threshold and on the maximal ratio reflected/input power. The results are shown in Figures 3 and 4.

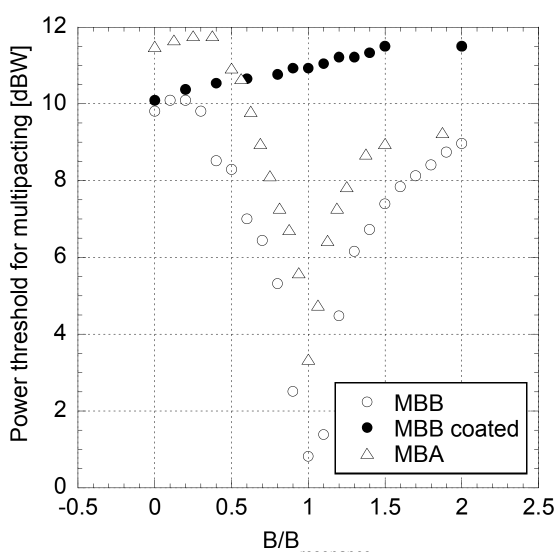

Figure 3: Threshold power for multipacting as a function of the magnetic field (normalized to B_r).

Before coating, the power threshold for both MBA and MBB dipoles decreases strongly in the vicinity of the field for cyclotron resonance B_r, confirming the expected correlation between the power threshold and the predisposition for multipacting. (For the coated MBB, due to the extremely weak multipacting observed, the measurement was not sensitive enough to detect any dependence of the power threshold on the magnetic field, while for the coated MBA no data are plotted since there was no multipacting activity at all.)

Regarding the evolution of the maximum of the ratio reflected/input power as a function of the magnetic field, the response is different for the two uncoated dipoles. The MBA behaves as expected: the maximum of the ratio reflected/input power correlates with the magnetic field and shows a maximum in the vicinity of B_r. In other words, only close to the resonance condition, B_r, the reflected power is a very large fraction of the input power. Instead in the MBB, the maximum of the ratio reflected/input power rises abruptly already at 40% of B_r and remains practically constant. The apparent saturation value of the maximum is very close to the maximum possible reflected power in the setup (in the measurement setup the maximum detectable reflection is not 0 dB, but close to -10 dB). A detailed understanding of this curve and the influence of the instrumentation need a deeper investigation.

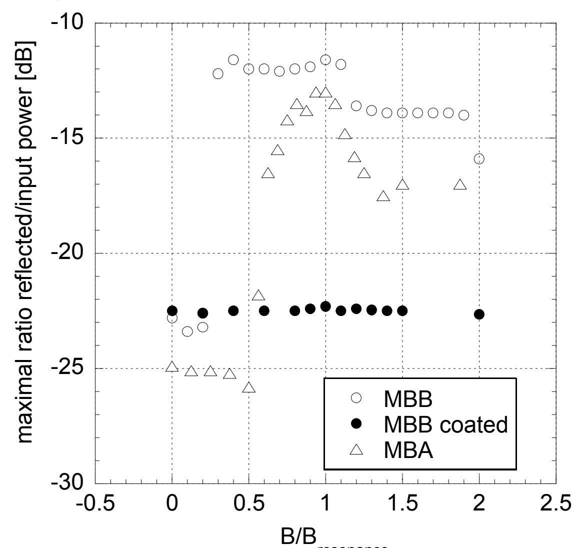

Figure 4: Maximum of the ratio reflected/input powers as a function of the magnetic field.

INFLUENCE OF THE RF COUPLING IN THE SENSITIVITY

In this work we define the coupling as the fraction of the power that is reflected in absence of multipacting and we quantify it by the ratio reflected/input power at the minimum power injected (~0.5 dBW). The best coupling is achieved when this ratio is the lowest. To study the impact of the coupling on the sensitivity of the measurement we have chosen the MBB coated dipole,

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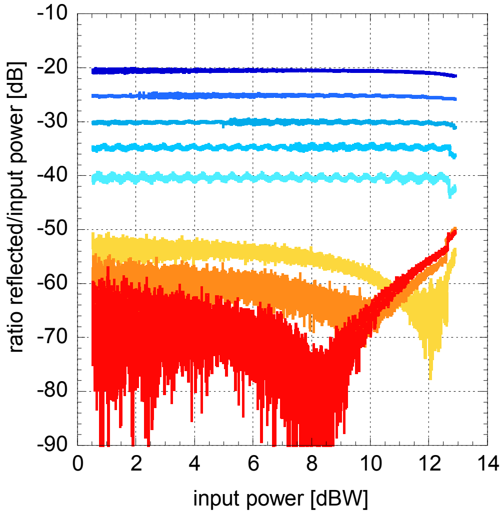
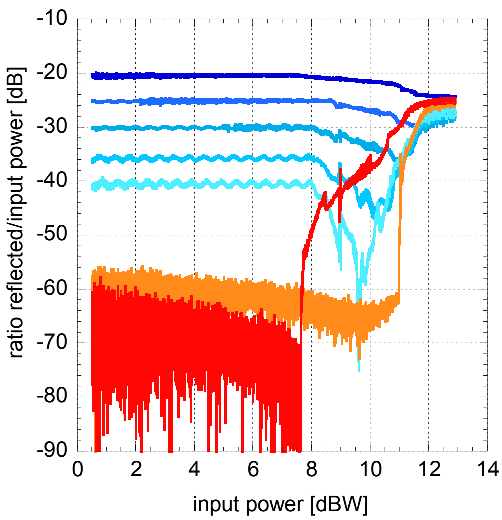
since it has extremely low propensity for multipacting (Figure 2). The coupling is changed by adjusting the frequency. The resulting ratio reflected/input power as a function of the input power for different levels of coupling is plotted in Figure 5 for two cases: a) in the absence of magnetic field; b) at B_r.



a) Without magnetic field



b) With magnetic field leading to cyclotron resonance (B_r)

Figure 5: Ratio reflected/input powers in function of the input power at different couplings for the MBB dipole after coating. (Different collars represent different coupling levels).

For both cases, the lower is the ratio reflected/input power at the beginning of the power ramp, (better coupling), the better is the sensitivity to the RF response to multipacting. At bad coupling levels the reflection due to multipacting is masked by the power reflected in absence of multipacting. It is evident from Figure 5 that the power threshold for multipacting is easily detected only for the curves having a sufficiently good coupling. Therefore especially in a situation of very low propensity for multipacting the coupling plays an important role on the sensitivity to the power threshold.

CONCLUSIONS

Two types of dipoles of the SPS were tested before and after coating with a low SEY carbon thin film. The method is sensitive enough to evaluate the slight different propensity for multipacting between the MBA and MBB type dipoles, in agreement with the simulations of Rumolo et al. [4]. In the conditions and for the parameters at which the measurements were performed, the power threshold was found to be more reliable to evaluate the propensity for multipacting than the maximum of the ratio reflected/input power.

After coating with carbon, (maximum SEY ~ 1.0), the multipacting in the MBB dipole is reduced to the limit of detection, while in the MBA type it is not observed at all (neither by RF nor vacuum diagnostics). Higher RF power is necessary to induce multipacting in the MBA coated dipole.

The RF coupling has an impact on the sensitivity of the measurement in case of low propensity for multipacting.

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