MULTIPACTING TESTS WITH MAGNETIC FIELD FOR THE LHC BEAM SCREEN

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Abstract

In connection with electron-cloud induced heating of the LHC beam screen, multipacting tests with a resonant coaxial cavity have been successfully performed in presence of a solenoid and a dipole magnetic field. We have developed a simple and reliable technique, based on amplitude modulation of the input signal, to detect electronically the onset of multipacting and to monitor the field and power level in the resonator. Several multipacting patterns have been systematically investigated under the effect of a variable DC-bias applied to the inner conductor of the coaxial setup. The results at room temperature are qualitatively similar to those obtained during cold tests (below 20 K in a cryostat) with a dipole magnetic field up to 7.5 T. A weak solenoid field of about 50 Gauss is usually sufficient to stop the multipacting, but the same longitudinal field is ineffective in presence of a strong vertical dipole field (up to 1.5 T). We have also measured the rise time of the multipacting versus the intensity of the solenoid field. Moreover, a substantial decrease of the multipacting threshold is observed when the dipole magnetic field has an intensity such that the electron cyclotron frequency is equal to the resonant frequency of the coaxial cavity.

1 INTRODUCTION

A high secondary electron yield of the LHC beam screen surface may lead to the build-up of an electron cloud with potential implications for beam stability and heat load on the cryogenic system [1]. In presence of a strong magnetic field with orientation different from the normal to the surface, one may conjecture a significant reduction of the secondary yield due to a lengthening of the electron trajectories in the metal or to an immediate reabsorption after their emission. The secondary yield and its possible reduction by a magnetic field can be inferred from the multipacting level reached under suitable conditions in a resonant coaxial setup. Comparing experimental results and computer simulations provides also a very useful 'calibration' for the numerical predictions concerning heat load on the LHC beam screen.

Here we report about successful multipacting tests performed at CERN [2] using a wide-band power amplifier and a coaxial resonator accommodated either in the cold bore of an 8.4 T superconducting magnet or in the 80 mm gap of a warm magnet, with an additional solenoid.

2 EXPERIMENTAL SETUP AND MULTIPACTING DETECTION

The 1 m long coaxial structure consists of two circular stainless steel tubes, an outer one with 39 mm inner diameter, and an inner one of outer diameter 4.5 mm. Both tubes are copper coated with 50 μm thickness. The inner tube is held by three teflon supports, placed at the nodes of the E-field in third harmonic standing-wave operation. The inner tube is capacitively coupled to two ports at both ends, one of which is operated close to critical coupling. The experimental setup is schematically shown in Fig. 1.

The advantage of the resonant setup is that we can reach high electric fields and RF-voltages between the inner and outer conductor, in spite of the limited power of the amplifier: for a Q of 1000 and a characteristic impedance of about 100 Ω, a power of 100 W corresponds to a peak voltage of $\sqrt{100\ \mathrm{W} \times 100\,\Omega \times 1000 \times 2} \simeq 4.5$ kV. According to simulations, the minimum voltage required to reach a significant multipacting level is around 1.5 kV: Fig. 2 shows the power deposition on the outer conductor due to

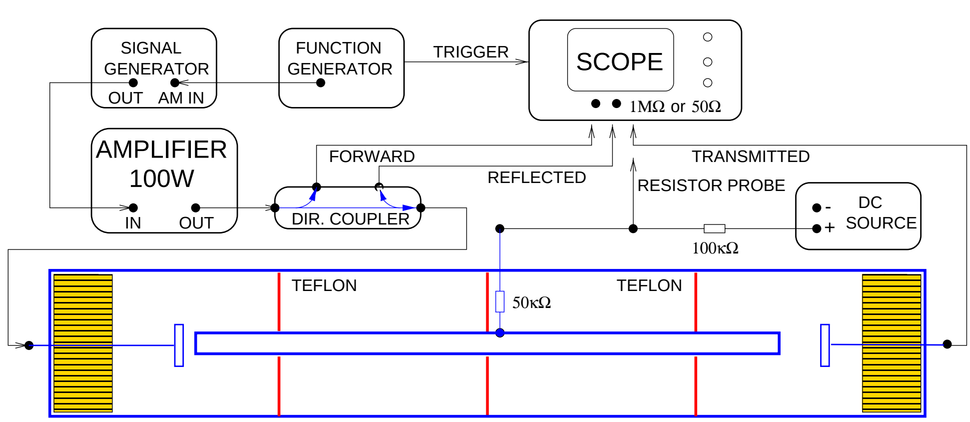


Figure 1: Experimental setup for multipacting tests.

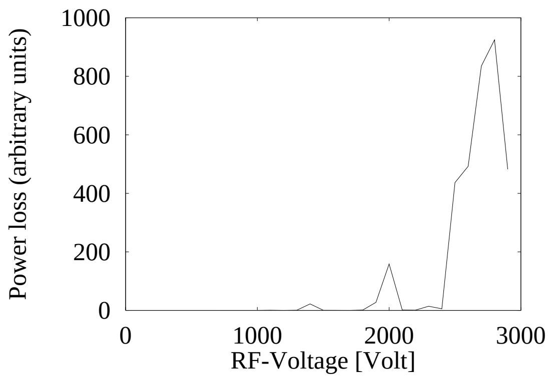


Figure 2: Simulation results for multipacting tests in a coaxial structure: power deposition (arbitrary units) versus peak RF voltage for a fixed RF frequency of 500 MHz.

multipacting electrons as a function of the RF voltage, for a fixed RF frequency of 500 MHz. One nicely recognises the resonance behaviour of the multipacting. The largest peak on the right corresponds to electrons moving from the outer conductor towards the inner and back again to the outer conductor during one RF period. The two smaller peaks correspond to resonances where the electrons oscillate more than once between the inner and outer conductor. Resonant electrons never touch the inner conductor.

We have developed a simple and reliable technique, based on amplitude modulation of the input signal, to detect electronically the onset of multipacting and to monitor the field level in the resonator. An example of multipacting signature is shown in Fig. 3a: no reflected signal (upper trace) is present until the amplitude modulated input signal reaches a threshold value. Meanwhile the transmitted signal (lower trace) increases and then becomes flat in the multipacting range, corresponding to a constant value of the peak electric field inside the resonant setup. This is often accompanied by a low-frequency signal superimposed on the transmitted or on the 'resistor probe' signal from the inner conductor (see lower traces in Fig. 3b-c), when measured with a 1 MΩ termination on the scope. The high termination impedance enhances the measurable low-frequency voltage and avoids fast discharge; we estimate a capacitance of about 30 pF for the coaxial structure, corresponding to a time constant around 30 μs for the resistor probe signal.

For a direct measurement of the power deposited in the cavity we use two diode rectifiers, operating in the parabolic region of their characteristic curve, and a DC differential amplifier to obtain a signal proportional to the difference between forward and reflected power.

3 COLD TESTS WITH STRONG FIELD

Typically multipacting starts for the first time at an RF power level around 10 W. Then, after switching off the power, the minimum level required to start multipacting again is about 1 W. However, if we short the inner and outer conductors, the minimum required power is again 10 W. This 'memory' effect, presently not fully understood, seems to indicate that the inner conductor acquires an electric charge during multipacting: after removing this charge, it is more difficult to start multipacting again.

A related observation is that during multipacting without magnetic field the low-frequency resistor probe signal is negative, as in the lower trace of Fig. 3b. It becomes positive with a strong dipole magnetic field, as shown in Fig. 3c. Therefore the electric potential of the inner conductor tends to become negative (without magnetic field) or positive (with magnetic field) relative to the outer tube; we have measured typical differences between -30 and $+5$ V. Simulations can only account for a negative potential due to the effect of image charges. A DC-voltage applied to the inner conductor shifts the onset of multipacting and the threshold for higher multipacting levels, sometimes observed. This is in qualitative agreement with simulations.

The multipacting levels at room temperature are very similar to those measured during cold tests, with a dipole magnetic field up to about 7.5 T. This seems to exclude any significant reduction of the secondary electron yield by a strong magnetic field over most of the outer tube surface, i.e., away from the region where the field is parallel to the metal surface.

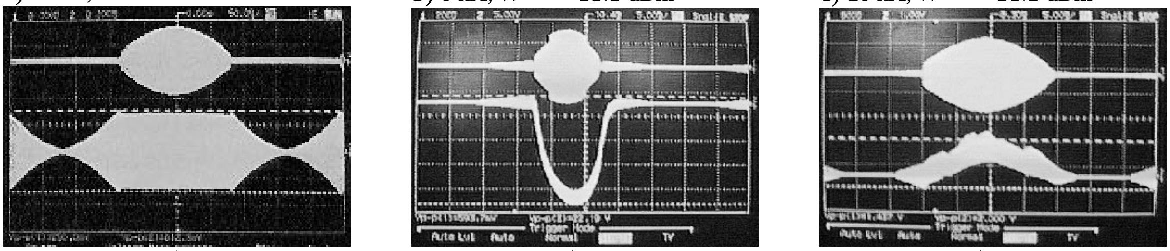
4 TESTS IN A WARM DIPOLE MAGNET WITH SOLENOID FIELD

We have performed further warm multipacting tests in presence of a solenoid and a dipole magnetic field, the latter being either in the vertical direction or tilted by an angle of up to $1.2°$. The results show that a solenoid field of about 50 Gauss is usually sufficient to stop the multipacting, but that the same longitudinal field is ineffective in presence of a strong dipole field (up to about 1.5 T). When the dipole field is tilted from the vertical direction by an angle of up to $1.2°$, corresponding to a longitudinal component of more than 300 Gauss, we observe no suppression of the multipacting. For a total magnetic field intensity below 100 Gauss, the maximum tilt angle still compatible with suppression of the multipacting is about $30°$ from the longitudinal direction.

We have also measured the rise time of the resistor probe signal at the onset of multipacting as a function of the solenoid field intensity, from 0 to about 60 Gauss, both without dipole field and with several dipole field intensities. The resistor probe is connected to an external 500 MΩ resistor, the signal is amplified 10 times with an additional 1 MΩ load and a 1 MHz bandwidth amplifier. The filling time of the cavity in the absence of multipacting is estimated to a few μs. With a dipole magnetic field of 5000 Gauss, the rise time is practically independent of the solenoid field and equal to 20 μs. With a (residual) dipole field of 20 Gauss the rise time is around 30 μs, although the shape of the resistor probe signal is rather irregular. The rise time measured without dipole field is shown in Fig. 4.

Moreover, as shown in Fig. 5, we have observed a sub-

a) 100 V, $W = -28.2$ dBm | b) 0 kA, $W = -21.2$ dBm | c) 10 kA, $W = -21.2$ dBm



H: 50 ms/div, V^{top}_{bot}: 0.1-0.2 V/div | H: 5 ms/div, V^{top}_{bot}: 0.2-5 V/div | H: 5 ms/div, V^{top}_{bot}: 0.5-1 V/div

Figure 3: Multipacting tests in a resonant coaxial setup: with 100 V DC-bias and no magnetic field (a), in a cryostat at 1.8 K without magnetic field (b) and with a dipole field of 7.3 T (c). The generator signal, with frequency around 480 MHz and power W, is amplitude modulated at 3 Hz (a) or at 30 Hz (b)-(c) and amplified at maximum gain (~ 60 dB). The upper trace is the reflected signal attenuated by 40 dB and measured with a 50 Ω load, the lower trace is the transmitted signal (a) or the 'resistor probe' signal (b)-(c) measured with a 1 MΩ load.

stantial decrease of the multipacting threshold when the dipole magnetic field has an intensity (170 Gauss) such that the electron cyclotron frequency is equal to the resonant frequency of the coaxial cavity (480 MHz), thus confirming that our multipacting tests involve electrons, rather than ions, and that there can be a 'magnetron effect' under special resonance conditions, though unlikely for the LHC. The dip visible in Fig. 5 is caused by the cavity impedance mismatch, related to the refraction index of the electron plasma, leading to a large reflected signal. The sign inversion of the low frequency resistor probe signal happens for a dipole field around 340 Gauss, i.e. at about twice the resonant intensity.

5 CONCLUSIONS

Multipacting tests indicate no significant reduction of the secondary electron yield over most of the beam screen surface in the LHC dipole magnets, with or without solenoid field. However a 50 Gauss solenoid field can be effectively used to lower the secondary yield in the drift spaces. Further analysis of our multipacting rise time measurements versus solenoid field intensity may provide direct information on the secondary electron yield and possibly on the energy distribution of secondary electrons.

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7 REFERENCES

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[2] F. Caspers, J.-M. Laurent, M. Morvillo, and F. Ruggiero, "Multipacting tests with a resonant coaxial setup", CERN LHC Project Note 110 (September 1997).

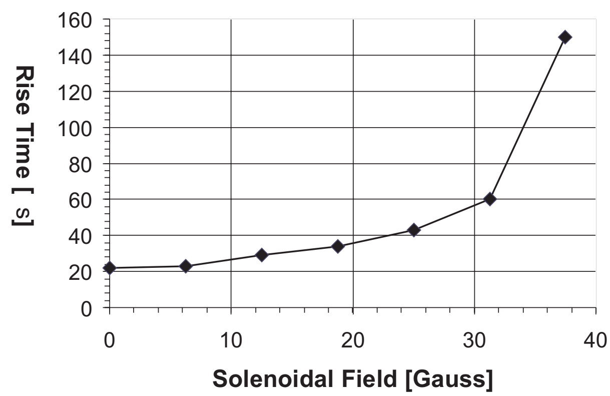

Figure 4: Measured risetime of the resistor probe signal at the onset of multipacting vs solenoid magnetic field intensity: RF frequency 480 MHz, RF forward power 50 W, 1 Hz square wave AM modulation with 10% duty cycle. The rise time measured by the oscilloscope, independent of a possible signal overshoot sometime observed, is defined as the delay required to pass from 10 to 90% of the saturation level.

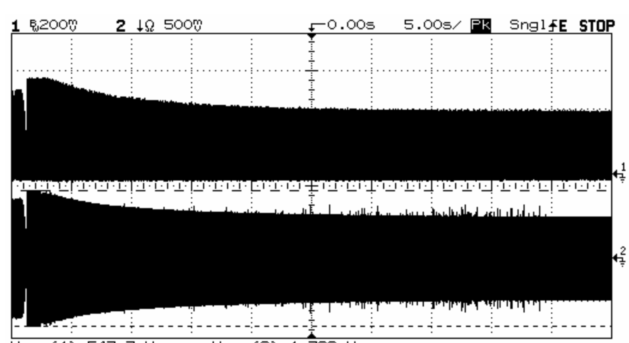

Figure 5: Multipacting tests in a warm dipole magnet: deposited power (top, 2.5 W peak) and transmitted signal (bottom) measured during a 50 s ramp of the dipole field from 100 up to 7800 Gauss. The dip on the left corresponds to a magnetic field of 170 Gauss, when the cyclotron frequency of the electrons becomes equal to the RF frequency of 480 MHz. AM modulation frequency 20 Hz, DC-bias 100 V, RF forward power 4 W.