A NOVEL TECHNIQUE FOR MITIGATING MULTIPACTOR BY MEANS OF MAGNETIC SURFACE ROUGHNESS

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Abstract

Multipactor phenomena which are closely linked to the SEY (secondary electron yield) can be mitigated by many different methods, e.g. including grooves in the metal surface as well as using electric or magnetic bias fields. However, the application of global magnetic or electric bias field is not frequently practicable or applicable. On the other hand, surface grooves may degrade the RF performance. Here we present some preliminary results of a novel approach, which is based on a magnetostatic field pattern present on the metallic surface with fast spatial modulation. This field pattern can be produced by proper magnetization of an underlying ferromagnetic layer such as nickel, or by adding small permanent magnets. Results of simulations and preliminary experimental findings are presented and discussed.

INTRODUCTION

The mitigation of multipactor problems related to excessive SEY values of the metallic surfaces is of growing interest. One strategy is to apply coatings (e.g. carbon coatings) and surface treatments like chemical polishing or cleaning of the surface by vacuum glow discharges. In particular, the scrubbing method has turned out to be rather efficient for accelerator applications. This method takes essentially advantage of a beam induced surface bombardment of the vacuum chamber which removes or reduces oxide layers. As it is an *in situ* method, it is usually applied in particle accelerators after a shut down or some other intervention, i.e. when the surface conditions of the beam pipes are degraded due to venting. A similar approach is the conditioning of power RF cavities which show certain multipactor levels as a function of the RF power present in the cavity. However, for certain cavities not all multipactor related problems can be controlled by the usual conditioning method and, in particular, in the vicinity of power couplers additional measures are required. Such measures include the application of a DC electrostatic field to the inner conductor of such a coaxial power coupler in order to shift the multipactor bands outside the region of interest for practical operation. Alternatively, or in addition, static magnetic field can be applied provided that they return a reliable and significant improvement.

PLANNED ALTERNATING MAGNETIC FIELD TEST ON THE LHC CAVITY MAIN POWER COUPLER AT CERN

The LHC power coupler is a 400 MHz mobile RF power coupler with very high power requirements: 250 kW CW for several hours, and in pulse mode, in the worst case, 300 kW forward + 670 kW reverse, including beam loading, i.e. 1.85 MW local peak power.

The different requirements at injection and collision with the heavy beam loading have imposed the use of a variable power coupler. The general layout of the latter can be seen in Figure 1 below and has already been described with details in [1] and [2].

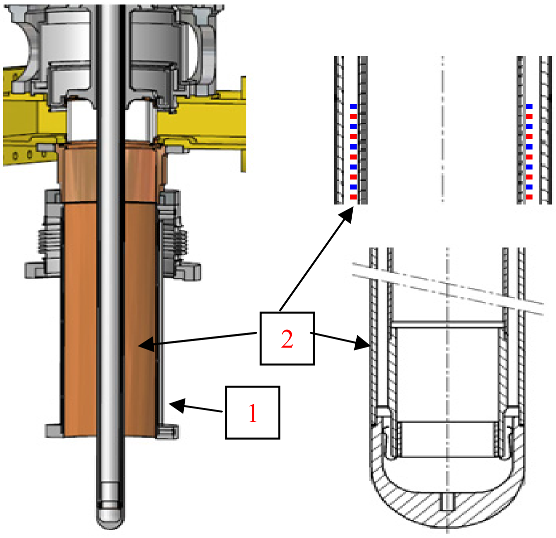

Figure 1: Part of the LHC Main Coupler design. The open ended 75 Ω coaxial line under vacuum is shown. 1 is the outer conductor double walled and 2 the inner conductor copper antenna.

An RF power conditioning is necessary before increasing the power applied to a high power RF component. The design of the ceramics to be used in an RF power coupler to apply DC polarisation is very delicate [2]. We propose to implement the "surface roughness magnetisation" on the LHC coupler antenna, which could replace the usual DC polarisation.

As shown in Figure 1, we prepared a double coil (similar to a bifilar coil) on the inner rod of the air cooling antenna. Then, we will apply a magnetostatic field pattern in order to try to modify the multipactor conditions.

The so prepared couplers will be used in the upcoming LHC coupler tests, and, once the first outgasing levels have been exceeded, we will check if this new method has the desired or at least any effect. As with the DC polarisation, we expect neither more vacuum activity nor electron measurements while using the new anti-multipactor system. As the couplers will be equipped with either DC polarisation or “surface roughness magnetisation”, we will compare the effectiveness of the two methods.

EXPERIMENT AT ESA-ESTEC

At the ESA's TEC-ET laboratories a state-of-the-art test bed in L-band has been set up. A signal generator delivers an RF signal at about 1.1 GHz which is amplified via a TWTA to achieve a maximum of 1750 Watts peak with a duty cycle of 2 % (pulse width 20 µs, PRF 1kHz).

The amplified signal enters into the actual test bed along a circulator to prevent any reflected power to damage the TWTA. Adequate filtering ensures a clean signal into the device under test (DUT), and two bidirectional couplers monitor the input and reflected power.

At the output section, another coupler monitors the transmitted power, and a dedicated coupling structure splits the harmonics generated into a low noise amplifier (LNA) that sends the signal to a spectrum analyzer.

Several methods for detecting multipactor have been studied and are available; these are classified as global or local detection methods. Local detection methods are used close to the point of the actual discharge, while global detection methods are used to indicate that a discharge is present somewhere in the assembly. The used methods have been the following ones:

- Optical Detection (local)
- Electron Probe Detector (local)
- Third Harmonic Detection (global)
- Nulling of Forward/Reverse Power Method (global)

A high power flexible RF cable with vented TNC connectors is used as interface for the DUT test sample. This sample is tested on the main RF path, and the power is increased until a discharge appears. This procedure has been repeated with and without magnetic field.

The results of the tests show no change in the RF power level at which multipactor occurs but they show a decrease in the intensity of the discharges when a solenoid-type field is applied (both wires with the same current sign). Figure 2 below shows the DUT test sample and the wires used.

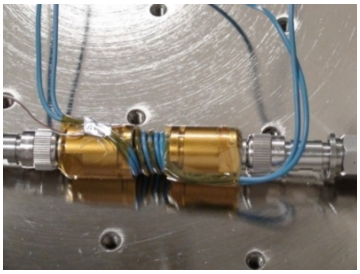

Figure 2: ESA coaxial test setup at 1.1 GHz.

SIMULATIONS

Simulations with Computer Code Faktor2

For the case of a rectangular beam pipe with full width of 2 × 7.6 cm, full height of 2 × 1.7 cm and a magnetic field in the top and bottom plane we have performed simulations for the evolution of the electron cloud density. A train of 72 bunches with 7.48 m bunch spacing has been considered. The magnetic field was generated by assuming virtual wires embedded in the top and bottom of the beam pipe and extending parallel to the beam.

In Figure 3, we can even observe an increase of the electron cloud density for the weak field case (0.05 T). However, a clear reduction can be identified in Figure 4 for the moderate field case (0.1 T). The important message of these results is that a mechanism to control the electron cloud parameters with a *local* field could be found. Additionally, such local magnetostatic field variation can be implemented without significantly modifying the beam dynamics, since the field modulation is strictly confined to the surface and not "felt" by the beam.

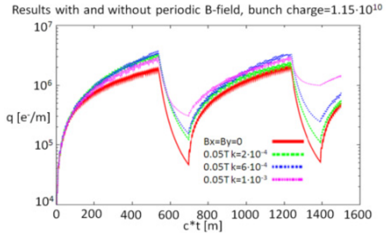

Figure 3: E-cloud evolution for a weak field (0.05 T, SEY = 1.5 at 200 eV).

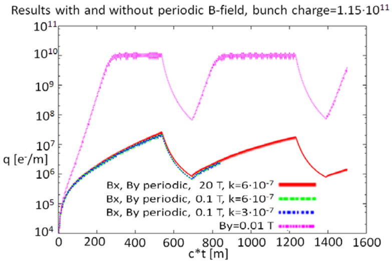

Figure 4: E-cloud evolution for moderate field (0.1 T, SEY = 1.5 at 200 eV).

Simulations with Computer Code FEST3D[3]

Simulations performed with the software code FEST3D for a waveguide structure with a vertical gap of 0.1 mm operating at 10 GHz, and a gap of 2 mm operating at 0.5 GHz, show the validity of the scaling law: the increase in breakdown voltage is proportional to the product frequency times gap distance (f*d). Here we show the case of a homogeneous static magnetic field in the direction of propagation of the wave. It is evident that from a certain threshold value onwards, the breakdown voltage is significantly increased; but it also becomes evident that for lower B-fields the breakdown voltage is even decreased.

It should be noted that the case of alternate static field for this configuration has also been simulated and that this significant effect on the breakdown threshold was found up to very high field strength.

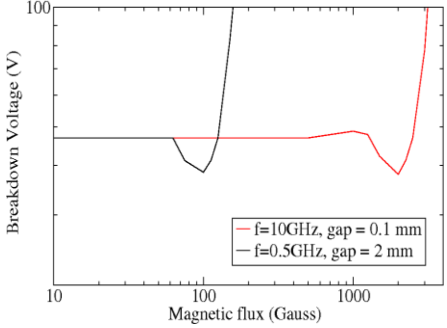

Figure 5: FEST3D results for breakdown levels as a function of a constant magnetic field.

FERROMAGNETIC LAYER RESULTS

In order to test the hypothesis experimentally on a possible impact of ferromagnetic layer underneath some conducting layer with field strength about 0.005 T a number of tests were carried out on different flat samples. In the following, the notation Ni-Ag indicates that there was a 10 micron silver layer on 20 micron nickel deposited on a 2 mm thick aluminium substrate 50 × 50 mm, and correspondingly for the notation Ni-Cu. The Ni reference sample was a non magnetized Ni foil. SEY characteristics of the different sample materials have been measured in the range 5 to 2000 eV at different e-beam incidence angles using a beam diameter of about 3 mm.

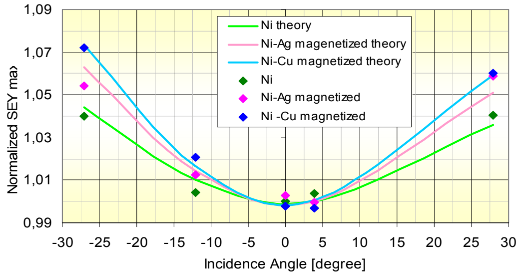

Figure 6: Measured SEY as a function angle of incidence and magnetization.

The magnetic domains are smaller than the e-beam spot size. Figure 6 shows the variation of the SEY coefficient with the incidence angle. For normal incidence, we did not find a significant effect of the magnetic pattern on the SEY as a function of primary electron energy curves. However, a small change of about 2 degrees in the position of the minimum of the SEY coefficient as a function of nominal incidence angle was found.

CONCLUSIONS

According to Faktor2 simulations, we can have significant effects on the electron cloud build-up and final density due to a periodic magnetostatic field pattern in the beam pipe situated in a drift region. However, those effects are not always beneficial, i.e. both an enhancement and a decrement of the electron cloud density can be caused depending on the parameters. However it was clearly shown that local magnetic fields have very significant impact on the growth rate and steady state density of electron clouds, even for moderate fields of the order of 0.01 T. On the other hand, according to FEST 3D simulations, mitigation of multipacting in satellite application (several GHz) appears much more demanding, since there, and due to the high frequency and small gap size, magnet field intensities in the order of at least 0.1 T are required. This cannot certainly be achieved by just giving a magnetic pattern to existing nickel layers but would rather require the installation of tiny, yet very strong permanent magnets.

Measurements of the SEY on several magnetized samples with field strength around 0.005 T and field periods of 100 micron have not shown any significant effects, apart from a very faint shift (a few degrees) of the SEY minimum vs. incident beam angle. Also, measurements with an alternating DC magnetic field on an RF connector have not revealed any change in multipacting (power) threshold as predicted by simulations, but the multipacting intensity went significantly down in the non-alternating case. The foreseen tests on a RF coupler would not be carried out by the deadline of this paper but results are due very soon.

REFERENCES

[1] H.-P. Kindermann, M. Stirbet, The variable power coupler for the LHC superconducting cavity, Proc. 9th Workshop on RF superconducting cavity, Santa Fe, New Mexico, USA, 1999.

[2] E. Montesinos, Status and RF power tests of the LHC variable main couplers for the LHC superconducting cavity, CERN, Genève, Switzerland, 2004.

[3] www.fest3d.com.