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MULTIPACTOR STUDIES: SIMULATIONS AND MEASUREMENTS ON THE RF COAXIAL RESONATOR TEST BENCH*

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Abstract

Multipactor is an undesired phenomenon triggered by electromagnetic fields in accelerator components and more specifically in RF structures, such as accelerating cavities and power couplers, and may lead to Electron Cloud build up in beam tubes.

The accelerator group at LPSC has developed an experimental setup dedicated to multipactor studies. It consists in a coaxial resonator, tunable and operational between 100 MHz and 1 GHz. It allows to characterize under real conditions the efficiency of surface treatment mitigation processes (coatings, cleaning procedures) at room temperature.

This paper presents the experimental measurements performed with this setup confronted to simulations.

INTRODUCTION

Multipacting (MP) occurs under vacuum when an electron is accelerated by the electromagnetic field and hits the device's wall. Depending on the secondary electron yield of the surface, more than one electron can be emitted and, if accelerated by the electromagnetic field, a self-sustained electron avalanche can be created.

We define:

- The 1-point multipactor: The impacts sites are localised very close on the same surface. The time between two impacts is an integer number of a RF period (T_0). This integer number is called order of the 1-point multipactor.
- The 2-point multipactor: The impacts sites are localised on two distinct surfaces. The time between two impacts ($T_{2\text{-point}}$) is an odd number of a half RF period. The order of the 2-point multipacting (n) is given by the Eq. (1):

$$T_{2-point} = \frac{2n-1}{2} T_0 \quad (1)$$

The LPSC's experimental setup, based on a coaxial (1"5/8 EIA) copper resonator, can be used in a travelling wave configuration when the measurement vessel is loaded with 50 Ω. It can also be used as a cavity in a standing wave mode (Fig. 1). This configuration benefits from a voltage amplification (represented by a K factor) allowing measurements of multipacting barriers at higher field amplitude than injected. This allows the measurement of multipacting barriers at higher frequencies using the same RF amplifiers of 500 W.

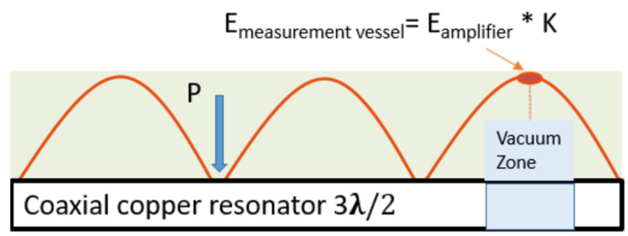

Figure 1: Schematic view of the electric fields in the measurement vessel as a cavity.

This paper presents the results of the multipacting simulations with the SPARK3D software, including MP barriers as well as the type of MP, and compares them to measurements on the experimental setup.

SPARK3D SIMULATIONS

SPARK3D (@Dassault Systemes) [1] is part of a commercial electromagnetics (EM) package. The main output of SPARK3D is the curve of the electron number (called in SPARK3D electron evolution) analysed in time for each RF power. For a given field level, if the electron number increases, multipacting occurs. For the same duration, the higher the electron number, the stronger the multipactor. At a given frequency, the simulation was stopped when the electron number reaches 10^{15}.

We define the electron growth rate (EGR) as the slope of the electron number curve (Eq. (2)). Two points (e_1/t_1 and e_2/t_2) have been chosen once the electron number curve become a straight line, (e_2/t_2) corresponds when the simulation stops.

$$Electron\ growth\ rate = \frac{e_2 - e_1}{t_2 - t_1} \quad (2)$$

The electron re-emission is given by the Secondary Emission Yield (SEY) as a function of the impact energy.

The SEY data used in the simulations in the Vaughan model is shown in Table 1. It corresponds to a clean surface where SEY_{max}, SEY_0, E_1 and E_{max} is defined as shown in Fig. 2.

Table 1: SEY of the Copper, Al_2O_3 and TiN Coating

Parameter	Copper	Al_2O_3	TiN
SEY_{max}	2,3	5,78	1,75
SEY_0	0,5	1	0,5
E_1(eV)	35	24	35
E_{max}(eV)	165	950	250

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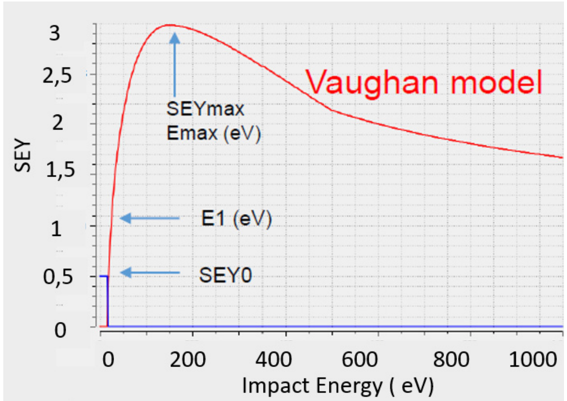

Figure 2: SEY_{max}, SEY_O, E_1 et E_{Max} of the Vaughan model.

SPARK3D simulations were performed with five different coaxial copper cavities working at 88 MHz, 100 MHz, 350 MHz, 650 MHz and 852 MHz. The cavities have the same geometry and they are fit to the different frequencies by homothetie. The analyzed region was reduced to the electric peak field area.

For each frequency, the multipacting barriers have been plotted for each type of multipacting found. At each frequency, the electron growth rate is plotted versus the maximal electric field (Fig. 3).

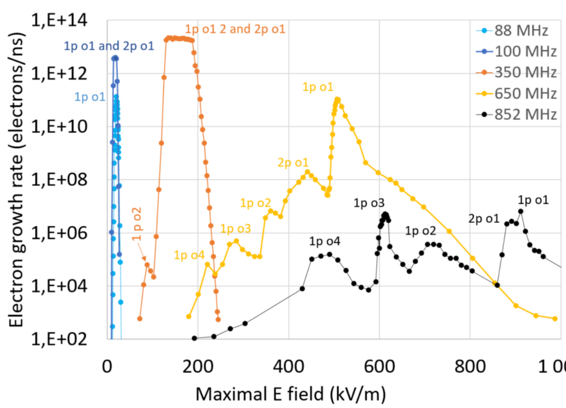

Figure 3: Electron growth rate and type of multipacting for 88 MHz (light blue), 100 MHz (dark blue), 350 MHz (orange), 650 MHz (yellow) and 852 MHz (black). Multipacting x point y order is indicated xp oy.

At 88MHz, only one narrow multipacting barrier has been found. This barrier corresponds to 1-point 1st order multipacting. Neither multipacting barrier 1-point 2nd order nor 2-point 1st order have been found.

At 100 MHz, as at 88 MHz only one narrow multipacting barrier has been found but here, this barrier corresponds to a mix of 1-point and 2-point 1st order multipacting. As the peak of 1-point 1st order and 2-point 1st order multipacting are very close, they are not distinguishable.

At 350 MHz, a large multipacting barrier to a mix of 1-point and 2-point 1st order multipacting has been found. This barrier is saturated because the electron number has reached its maximal, 10^{15}. On the other hand, one barrier of 1-point 2nd order has been found.

At 650 MHz and at 852 MHz, the multipacting barriers of 1- point and 2- point 1st order become differentiable. Multipacting barriers up to the 4th order have been also found.

For all frequencies, the lower the frequency, the lower the electric field level of multipacting, as the Sommersalo theory predicted [2].

For each frequency, the greatest EGR corresponds to a multipacting 1-point 1st order. For all the 1-point 1st order, the greatest EGR is reached at 350 MHz, and it decreases steadily as frequencies increases or decreases. The lowest EGR is found at 852 MHz.

The lower the order of the multipacting, the lower the EGR with the exception of the MP 1- point 3rd order at 850 MHz.

For each frequency the electric field boundary values where multipacting was present have been plotted (Fig. 4). These electrical field boundary values plotted corresponds to an electron growth rate of 10^3. The hatched area (MP zone) represents the electric field and the frequency ranges where multipacting might appear.

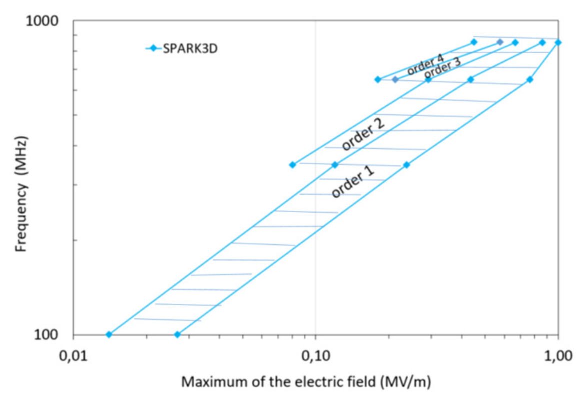

Figure 4: Electric field and frequency ranges where MP might appear in the coaxial cavity calculated by SPARK3D.

These results have been crosschecked with MUSICC3D (@IJC Lab/ France) [3] simulations [4]: similarities have been found as shown in Fig. 5, even if SPARK3D predicts larger multipacting barriers than MUSICC3D.

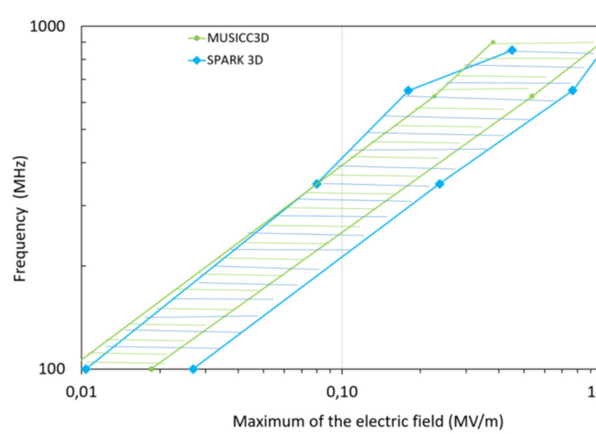

Figure 5: Electric field and frequency ranges where MP might appear in the coaxial cavity calculated by MUSICC3D (green) and SPARK3D (blue).

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EXPERIMENTAL MEASUREMENTS

Measurements with the test bench in a standing wave configuration at 352 MHz, 604 MHz and 855 MHz were realized.

For this initial campaign, no particular cleaning protocol of the surface has been applied in order to induce a bad SEY. This aims to generate large multipacting barriers to ease the detection on the test bench.

At each frequency, the power is steadily increased from 0 to about 500 W (the maximal power delivered by the amplifier) and then decreased down to 0 W. Pulsed RF mode is used with a 1 second period and a 200 ms power pulse in order to avoid fast conditioning and disappearance of the multipacting barriers.

In Fig. 6, the largest multipacting barriers measured in a standing wave configuration at 352 MHz, 604 MHz and 855 MHz are plotted. The measurements in a travelling wave configuration at 120 MHz, 140 MHz, 160 MHz and 180 MHz (made previously [4]) are also plotted. Both SPARK3D and MUSICC3D simulations of all the types of multipacting found are also indicated.

At 855 MHz, the maximal electrical field reached on the test bench was 0,7 MV/m. This field is not sufficient to go over the MP barrier, as indicated on Fig. 6.

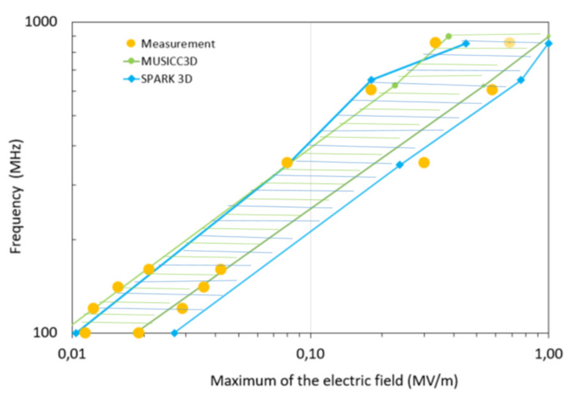

Figure 6: Electric field and frequency ranges where MP might appear in the coaxial cavity: experimental measurements (yellow dots) confronted to MUSICC3D (green) and SPARK3D result (blue) simulations.

In SPARK3D simulations, the SEY used corresponds to a clean surface. Measurements were done without cleaning the surface. Yet the MP barrier measured is not larger than the simulated one. This leads us to believe that the electron growth rate threshold of 10^3, used to indicate the presence of multipacting, is too low and that we overestimate MP barriers with simulations.

CONCLUSIONS

Multipacting (MP) studies were performed both with simulation codes and experimental measurements on a dedicated coaxial resonator test bench [5]. MP simulations and measurements are similar from 100 MHz to 855 MHz.

It has been verified that the higher the frequency, the higher the electrical field required for multipactor.

The higher the frequency, larger the zone of the electrical field where multipacting might appear and the higher the order of the MP can exist.

Multipacting 1-point order 1 shows the strongest electron growth rate over all frequencies.

On the other hand, the strongest multipacting barrier (highest EGR) is found at 350 MHz and not at the highest frequency.

In SPARK3D, an electron growth rate threshold of 10^3 indicates multipacting barriers slightly larger than the measurements. An analysis will be performed to study and optimize this parameter to refine the simulations.

The next step will be to compare the multipacting barriers in travelling wave configurations with the electrical and magnetical MP barriers in standing wave configuration at identical frequencies.

In addition, the experimental program will be pursued. It is planned to characterize multipactor with different cleaning protocols of the surface of the samples. The goal is to develop protocols minimizing the multipactor with better surface preparation, including surface coatings and RF conditioning processes.

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