MUSICC3D: A CODE FOR MODELING THE MULTIPACTING

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Abstract

Most of the facilities that are under design or in construction for proton and electron acceleration are using superconductivity cavities. Like "hot" RF structures but reinforced, Multipacting is then of major importance. Therefore, during the design of these new cavities, Multipacting studies should be undertaken so that it does not become problematic while these cavities are running. Modelisation tools for Multipacting are now essential. If 2D calculations are sometimes relevant, for example in coaxial lines, modern cavities are complex 3D structures often without axial symmetry. For that reasons, IPNO have conducted an effort to develop a 3D code for modeling Multipacting in RF structures, MUSICC3D. This code has been compared to 1D analytical calculations, to a 2D code and experimental results for a real Spiral 2 cavity. Now, the code permits to predict Multipacting zones for various RF structures, such as the Spoke cavity for ESS.

INTRODUCTION

Multipacting is a parasite phenomenon, described by Farnsworth in the 1930's [1], in vacuum devices in which a hyper frequency wave is transmitted. It is encountered especially in vacuum tubes [2], particle accelerators structures [3,4] and in microwave circuits on satellites [5].
This phenomenon generates on avalanche of electrons in a vacuum hyper frequency device. It results in energy loss, electronic noise and frequency disorder, heating and alteration of the HF device. All this can lead to the disruption of the functioning the HF structure and even its destruction.

To eliminate or limit Multipacting, there are three main techniques:

1. Improve the surfaces conditions of materials used. I.e., minimize the Secondary Emission Yield (SEY) [6] to reduce the creation of secondary electrons. The SEY is the most important parameter in Multipacting. This is possible by using materials with low SEY or by modifying the surface geometry (for example by producing sawtooth [7]).

2. Adapting the geometry to the RF device (hardly feasible on accelerating cavity geometries already very complex).

3. Polarisation of the RF device. This technique involves sending an electric or magnetic field in the RF device to disrupt the resonance frequency of the electrons created [8,9] (impossible in superconducting accelerating cavities).

Several theories have been developed to model Multipacting discharge (Gill and von Engel [10], Hatch and Williams [11], Vaughan) for simple 1D geometries. Few calculations exist for 2D geometries [2,12].
These theories and calculations are limited to simple geometries. Today, the accelerator cavities or HF structures have 3D geometries more and more complex, this is why it is now essential to simulate Multipacting in 3D.

CODE MUSICC3D

The MUSICC3D program is being developed at IPNO. It enables the study of Multipacting for any 3D geometries including one or more materials. It uses particles in the cell method. Based on the Runge Kutta method and using the relativistic equation of motion, it solves the trajectory of a particle (e-) in the RF field imported from an external field solver (any solver using a tetrahedal mesh). The integrations over the multi differential SEY, with electron incident energy (E_{in}), electron incident angle (α_{in}), electron emission energy (E_{out}) and electron emission angle (α_{out}), is done with the Montecarlo method.

The MUSICC3D program is presently using a model of virtual particle (i.e. the charge of a unique particle "rebounding" in the interior of the cavity is created by the product of SEYs occurring at each interaction with the walls). Main inputs are given in Table 1.

Benchmarking calculations have been done with analytical calculations in 1D [11] and with the MULTIPAC [13] 2D program. Precision of calculation with MUSICC3D has been then estimated. For reasonable calculation times, maximum error found ,between the calculations 1D, 2D and results obtained with MUSICC3D, is less than 0.5 percent.

SIMULATION OF SPIRAL 2 CAVITY

In the framework of Spiral 2, an intense program of R & D was launched at the IPNO to study and design the superconducting accelerating cavities to be used in the high-energy part accelerator (12-40 MeV). The IPNO has designed a new quarter-wave cavity (QWR) at the frequency of 88 MHz and a beta of 0.12. The conditioning of this type of cavity has identified various Multipacting zones. These zones were then measured experimentally.

Thereafter, in order to benchmark the MUSICC3D program with a real cavity and a complete 3D structure, simulations of the cavity Spiral 2 were performed using the software MUSICC3D. These simulations have identified the Multipacting that were zones measured experimentally.

Table 1: List of the Main Inputs of MUSICC3D Program

Input
Frequency (fixed)
Electric field (fixed or sampled in a range)
Phase (fixed or sampled in a range)
Electron parameter - SEY calculated in the program for the main materials in RF structures (copper, niobium) or imported by a file. - Electron emission perpendicular to surfaces or with angular emission (Gaussian distribution). - Electron emission energy fixed or according to Gaussian distribution. - Collision parameter (number of collision for which the calculation stops). - Trajectory parameter (number of electrons emitted per site, number of points stored for visualisation and recording trajectories). - Emissions sites.

The Figure 1 gives the comparison between experimental measures and MUSICC3D simulations. Taking into account the experimental error bias, correspondence is very satisfactory, which may be important especially at low field value.
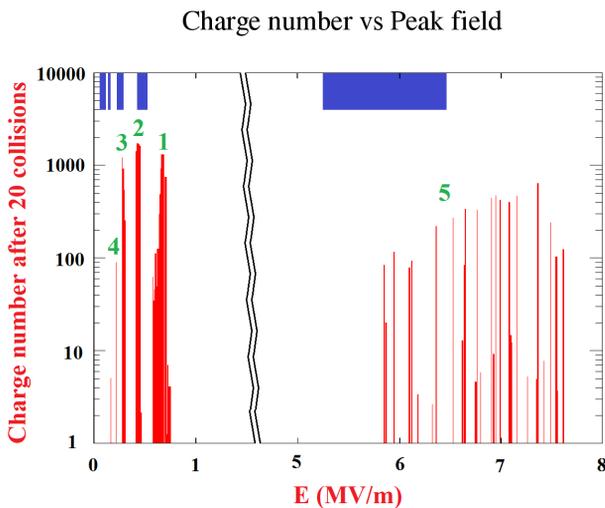

Figure 1: Multipacting barriers for the Spiral 2 cavity. In red : MUSICC3D simulations. In blue : experimental measures. The green numbers are used to identify Multipacting zones. E (MV/m) representing the peak electric field ($E = 4.78 * E_{acc}$ with E_{acc} the accelerator electric field).

The zones marked 1 to 4 on the Figure 1 correspond to the 4 orders of Multipacting located at the corner of the cavity bottom. The simulations reveal that the 2nd order

(zone 2) is the most important Multipacting zone both to its maximum height and amount of charges. This is found experimentally, since this zone is the most difficult to pass. Moreover, the electrons so-called primary initiating the Multipacting can be emitted from the nuts of the cavity. The higher electric fields of the cavity being present on this nut, the chances to emit the primary electrons are maximums. These 2nd order is represented on the Figure 2.
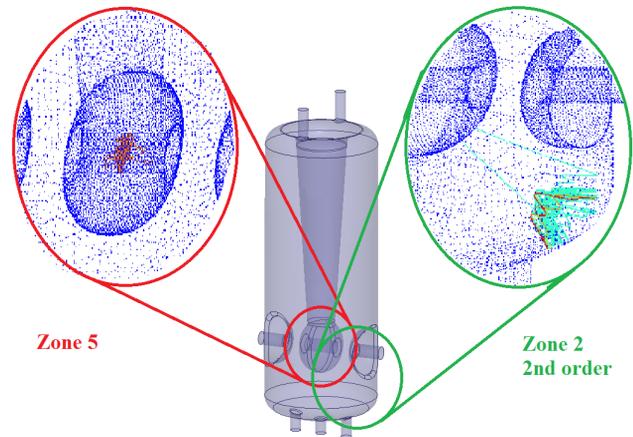

Figure 2: Visualisation of the electron trajectories for 2 and 5 Multipacting zones in the Spiral 2 cavity (MUSICC3D).

The zone marked 5 is located in the middle of the beam tube. Despite its large width, it is relatively easy to go through it. This can be explained because of the low charge and its emission rate of primary electrons is fairly low as they are emitted inside the beam tube where the electric fields are very low.

SIMULATION OF SPOKE CAVITY FOR ESS

IPNO is in charge of the design of news Spoke cavities [14] for the ESS project. These cavities will resonate at a frequency of 352.21 MHz for a beta of 0.5, and are maintained at a temperature of 2 K by a cryomodule supplied by the ESS cryogenic system.

Thanks to the MUSICC3D program, a Multipacting study is in progress. Figure 3 shows the first results of simulations in the Spoke ESS cavity.

Two distinct Multipacting zones were revealed as shown in Figure 4:

1. The first zone is located in the corners at the bottom and at the top of the cavity.

2. The second zone is located towards an intersection point between the central bar and the edge of the cavity. This zone is composed of 4 Multipacting orders.
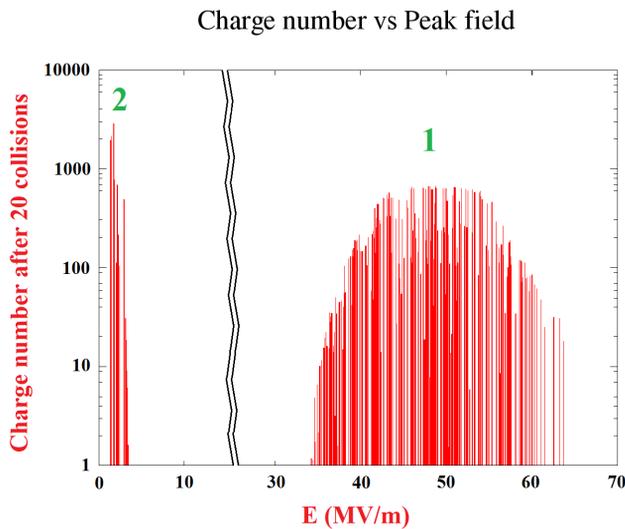
Charge number vs Peak field

Figure 3: Multipacting barriers in the Spoke cavity for ESS obtained by MUSICC3D simulations ($E = 4.98 * E_{acc}$).
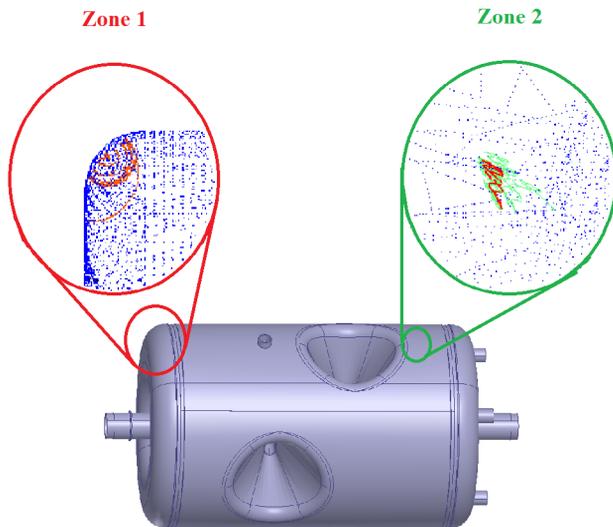

Figure 4: Visualisation of the electrons trajectories in the Spoke cavity for ESS (MUSICC3D).

CONCLUSIONS

The new RF structures being increasingly more complex, it is now necessary to study them using 3D tools. Multipacting is a very annoying phenomenon, especially in the accelerating cavities, IPNO has undertaken the design of a 3D program studying this phenomenon, MUSICC3D.

This program allows to predict and locate spatially the Multipacting zones. It has been compared and validated by crosscalculations using 1D analytical calculations, 2D MULTIPAC calculations. Moreover, it has been benchmarked by measures on Spiral 2 cavity.

With MUSICC3D, a first Multipacting study was carried out on the Spoke cavity while under development, for ESS. Two Multipacting zones were revealed during this study.

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