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MULTIPACTOR SIMULATIONS FOR MYRRHA SPOKE CAVITY: COMPARISON BETWEEN SPARK3D, MUSICC3D, CST PIC AND MEASUREMENT*

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Abstract

The multipactor effect can lead to thermal breakdown (quench), high field emission and limited accelerating gradient in superconducting accelerator devices. To determine the multipactor breakdown power level, multipactor simulations can be performed. The objective of this study is to compare the results given by different simulation codes with the results of vertical testing of SRF cavities. In this paper, Spark3D [1], MUSICC3D [2] and CST Studio PIC solver [3] have been used to simulate the multipactor effect in the single Spoke resonator developed within the framework of MYRRHA project [4]. Then, a benchmark of these three simulation codes has been made. The breakdown power level, the multipactor order and the most prominent location of multipactor are presented. Finally, the simulation results are compared with the measurements done during the vertical tests.

INTRODUCTION

Multipactor effect can lead to electron avalanche via secondary electron emission. In particular, for a superconducting cavity of accelerator, multipactor effect limits its accelerating gradient and increases significantly the time for conditioning.

Spoke Resonator of MYRRHA Project

The single Spoke resonator exhibits 3 symmetry planes. In order to reduce time of simulations, only 1 over 8 of the cavity is used in the simulation of RF field distribution and multipactor (Fig. 1). Boundaries at the planes of symmetry are open in multipactor simulation, which result in losses of electron and reduce the amplitude of multipactor.

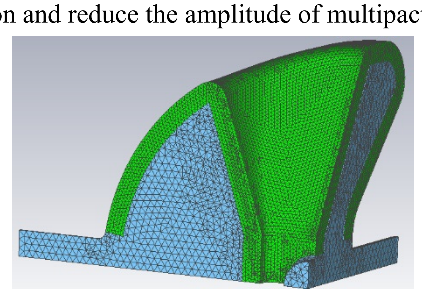

Figure 1: Double-layer mesh of 1/8 of the cavity.

Secondary Emission Yield (SEY)

The secondary emission yield is defined as the average number of re-emitted (secondary) electrons from the surface for one impinging (primary) electron. There are three types of secondary electrons:

- Elastic backscattered electrons.
- Inelastic re-diffused electrons.
- True secondary electrons.

Accordingly, Secondary Emission Yield (SEY) can be divided into three parts: Total SEY = Elastic SEY + Re-diffused SEY + True SEY. ONERA has measured the same piece of Niobium three times during conditioning: the first measurement is after buffered chemical polishing (BCP) and high pressure rinsing (HPR); the second is after bake-out at temperature 160 °C for duration up to 4 hours; the third is after electron bombardments at eV and 2.2 μA during 2 hours. Besides the SEY of Niobium, ONERA also measured the distribution of emission energy with fixed incident energy (Fig. 2). For each distribution, the peak near its incident energy is mostly contributed by elastic secondary electrons. According to this distribution, Elastic SEY can be separated from Total SEY (Fig. 3).

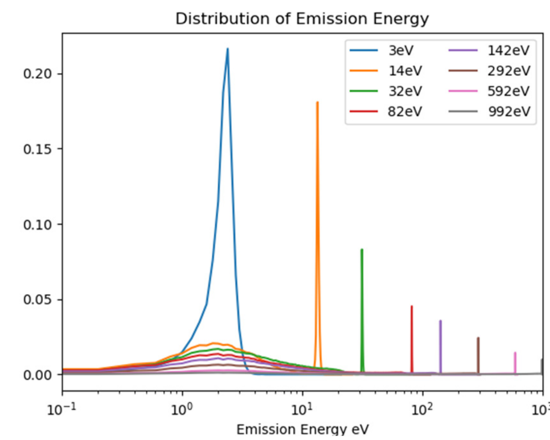

Figure 2: Energy distribution of secondary electrons for different primary electron energies.

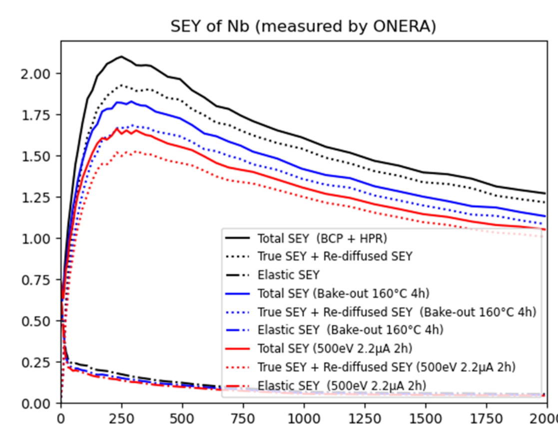

Figure 3: SEY of Niobium measured by ONERA.

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Multipactor Codes

In order to determine the multipactor breakdown power level, a number of 3D multipactor simulation codes have been developed.

- SPARK3D

SPARK3D is a tool to identify multipactor discharges, and it is included in CST Studio Suite. It can read the mesh and EM field map generated by CST, FEST3D and HFSS. Vaughan emission model and an imported SEY model can be used in SPARK3D. Vaughan emission model is a heuristic emission model, which only considers the true secondary electrons [5]. Meanwhile its imported SEY model contains both True SEY and Elastic SEY. Initial electrons are emitted at the beginning of simulation. Apart from particles number, it shows average SEY, impact energy and emission density of the surface.

- MUSICC3D

MUSICC3D is a 3D multipactor code developed in IJCLab [6]. Before the simulation, external EM field map and tetrahedral mesh needs to be transformed into a predefined format. It only considers true secondary electron in the simulation. Initial particles are emitted at the beginning of simulation, and its virtual charge is the indicator of multipactor. So, there is no exponential growth of particle number in MUSICC3D.

- CST Particle in Cell (PIC) Solver

The PIC solver is a self-consistent simulation method for particle tracking. It has the most complete model, and in the meantime it is very time-consuming and needs a large amount of computing power. It supports space charges effect, which leads to a non-exponential growth of number of particles in multipactor simulation [7]. Apart from an imported SEY model, it contains inner-built Vaughan and Furman emission SEY models. Furman emission model considers all three types of secondary electrons above. It is the most sophisticated emission model, but a lot of parameter is needed to set up the emission model properly [8]. It also has continuous initial emission.

MULTIPACTOR OF THE CAVITY

SPARK3D

In order to evaluate the intensity of multipactor, we use ‘Growth Rate α’, which is the factor in exponential approximation function of the particle number [9],

$$N(t) = N_0 e^{\alpha t}. \quad (1)$$

If α is positive, there is multipactor. Conversely, when α is negative, the emission of secondary electron cannot sustain and there is no multipactor (Fig. 4). From the average SEY of surface, we can locate the position of multipactor. There are two peaks in Growth Rate. The first ($0.6\ MV \leq V_{acc} \leq 1.6\ MV$) is a mixture of one-side multipactor of different orders which occupies very broad area (Fig. 5). The second ($2\ MV \leq V_{acc} \leq 6\ MV$) is a two-side multipactor that migrates along corner (Fig. 6).

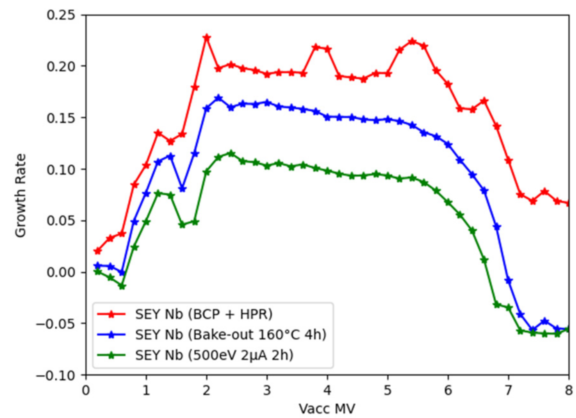

Figure 4: Multipactor growth rate in MYRRHA Spoke cavity simulated with SPARK3D.

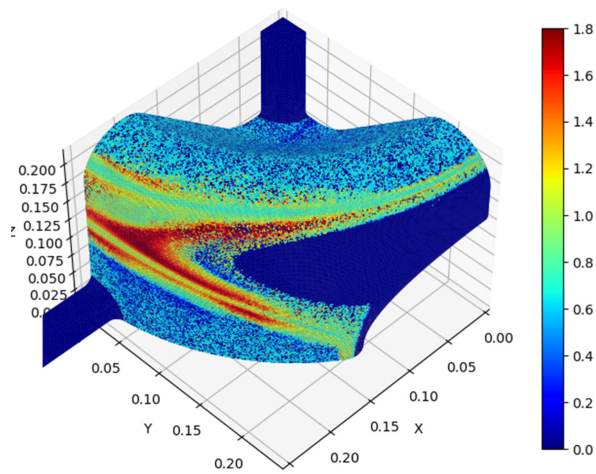

Figure 5: Average SEY of one side multipactor at 1.2 MV simulated with SPARK3D.

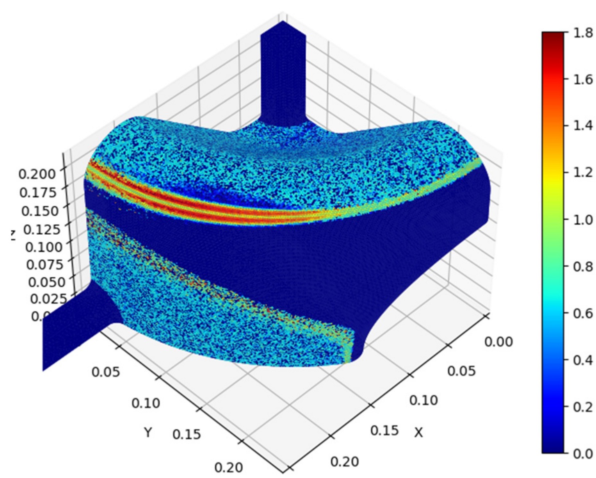

Figure 6: Average SEY of two side multipactor at 4 MV simulated with SPARK3D.

With an imported SEY model, SPARK3D considers both True SEY and Elastic SEY, while MUSICC3D and CST PIC solver only support True SEY. In order to compare their results, another simulation has been performed by considering Elastic SEY as part of True SEY in SPARK3D (Fig. 7). It shows that the second multipacting band is

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weakened whereas first band is reinforced. This is because the electro-magnetic field at the corner of Spoke cavity is low. Therefore, secondary electrons are mainly elastically reflected electrons. Due to different emission energy distribution, elastically reflected electrons can enter regions of phase space unavailable to true secondary electrons or the initial primary electrons [10].

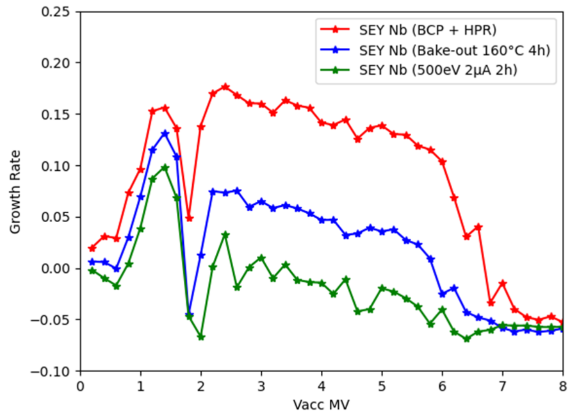

Figure 7: Multipactor growth rate without considering Elastic SEY simulated with SPARK3D.

MUSICC3D

With Bake-out Nb SEY, MUSSIC3D detected the two peaks of multipactor. With Electron Bombardment Nb SEY, MUSSIC3D can only find the first peak (Fig. 8). This is the same as the simulation without independent Elastic SEY in SPARK3D, because MUSICC3D doesn't consider elastically reflected electrons.

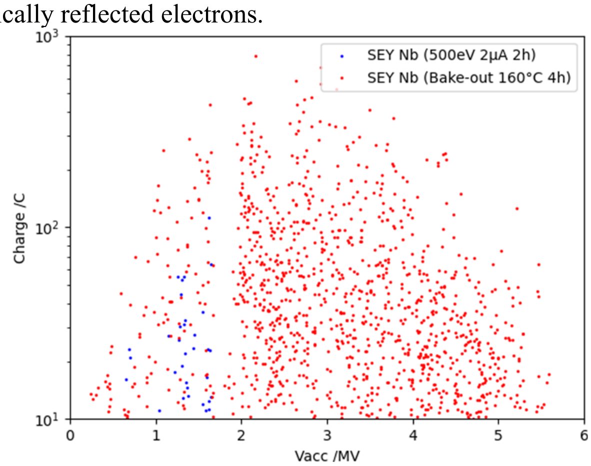

Figure 8: Virtual charge vs. V_{acc} simulated with MUSICC3D.

CST Particle in Cell Solver

Without considering space charge effects, the growth of number of particles is exponential. So, only the case with the weakest Nb SEY has been simulated. Its Growth Rate is bigger than that of SPARK3D (Fig. 9), because CST PIC solver has continuous initial emission, which means secondary electrons can enter all phase space. So even without independent Elastic SEY, CST PIC solver can find the two-side multipactor at the corner of the cavity.

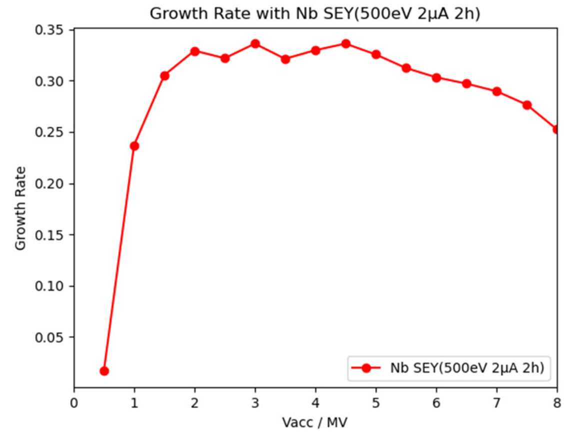

Figure 9: Multipactor growth rate simulated with CST PIC solver.

Comparison with the Experimental Data

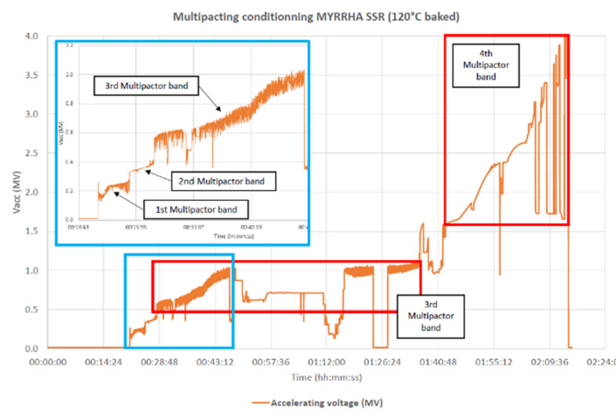

Figure 10: Multipactor conditioning of MYRRHA Single Spoke Resonator in vertical cryostat.

The experimental measurements achieved during vertical test show fours barriers of multipactor (Fig. 10). The 1st, 2nd and 3rd barriers are unstable higher order multipactor on the walls of the cavity (Fig. 5), and the 3rd barriers corresponds to the first peak in simulation. The 4th barrier is a stable two-side multipactor barrier at the corner of the cavity (Fig. 6), which causes a strong Q_0 degradation versus accelerating voltage. It corresponds to the second peak found in simulation.

CONCLUSION

In this paper, three codes have been used to simulate the multipactor effect in Spoke cavity of MYRRHA project. With the SEY of Niobium measured by ONERA, two kinds of multipactor have been found: the first is higher order multipactor in a large area of the cavity and the second is two-side multipactor at the corner of the cavity. Then, the comparison between the three codes shows that elastically reflected electrons can help to find the multipactor in low energy areas, by allowing secondary electrons to enter different phase space. Finally, the simulation results are compared with the measurements achieved during vertical test. It can be observed that the multipactor bands found by simulation are in good agreement with experimental observation during vertical testing.

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