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Multipacting Simulation of 350 MHz HWR Cavity at KOMAC

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1. Introduction

A 350 MHz half-wave resonator (HWR) has been designed for energy upgrade of the proton linac at KOrea Multi-purpose Accelerator Complex (KOMAC). The electromagnetic (EM) analysis and the design optimization of the HWR were conducted [1]. The HWR consists of a conical inner conductor, a cylindrical outer conductor, rounded short plates connecting these conductors, and ports for a power coupler, beam transport, and rinsing, as depicted in Fig. 1. In this paper, a multipacting (MP) simulation using the CST Particle Studio (PS) [2] and its result are described. The MP is a phenomenon that is an exponential growth of the electron by the secondary electron emitted at the cavity wall impacted by the electron accelerated by the RF field. The MP can cause problems such as unnecessary RF power consumption, insufficient accelerating field, wall heat load increase, and quenching the cavity [3]. Therefore, the MP characteristic should be analyzed to improve cavity design or perform the MP conditioning.

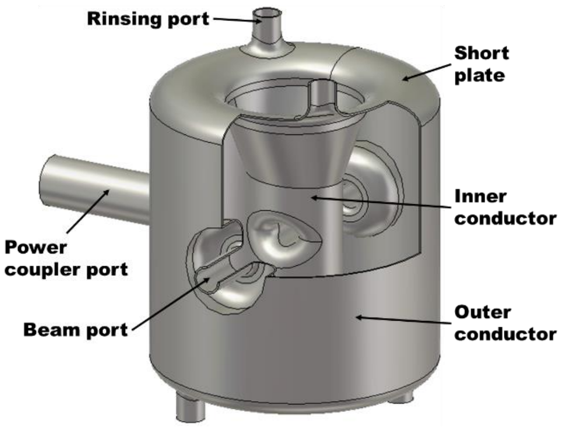

Fig. 1. Cutaway drawing of 350 MHz HWR designed for energy upgrade of the proton linac at KOMAC.

2. MP Simulation by CST Particle Studio

The MP in the HWR was simulated using the CST PS because the CST utilizes the existing cavity model with the EM field simulation result and provides an advanced secondary electron emission model called as Furman-Pivi model [4]. Two solvers, the Particle-in-Cell (PIC) and the particle tracking (TRK), evaluating the motion of the particle are available in the CST PS. The PIC solver was used in this work.

2.1 Simulation Model and Set up

Due to the nature of the particle simulation, the MP simulation requires strong computing power. The smaller mesh size and more mesh cells are requested for a more accurate simulation of the behavior of the electron. However, a longer computing time also is required depending on the number of mesh cells of the model. Therefore, a 1/8 symmetric model was introduced to reduce the consumption of computing power while maintaining the mesh density. By the way, symmetric boundary condition for the particle is not served in CST PS. Therefore, instead of mirror reflection boundary condition, solid walls made of a material that reflects all incident electrons was established as shown in Fig 2. Although these walls do not act as real mirror reflectors because they reflect electrons to random angle according to the secondary electron emission model, they preserve the number of electron and its energy. The concept of the symmetric model with the mirror wall was introduced in another study [4].

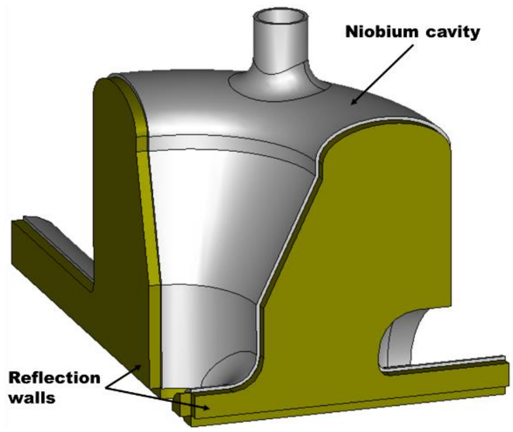

Fig. 2. 1/8 symmetric HWR cavity model and reflection walls for MP simulation.

Another important material property is the secondary electron emission yield (SEY) of the niobium (Nb) HWR cavity. In CST PS, three SEY libraries are provided depending on the Nb surface treatment status. The SEY of wet treatment Nb is the highest, that of the 300°C bakeout Nb is intermediate, and that of the argon discharge cleaned Nb is the lowest. In this study, the 300ºC bakeout Nb surface data was utilized for conservative calculation, and the SEY curves are depicted in Fig. 3.

Since the PIC solver requires a process of defining an EM field for the MP simulation, the 350 MHz RF electromagnetic field map calculated by the eigenmode solver was imported into the PIC solver. The multipacting is the phenomenon that occurs near the surface. Thus, an additional thin layer vacuum model adjoining the cavity wall was made and a local mesh option was applied to enhance mesh density. More than 4.4 million tetrahedral mesh cells were used for the EM analysis, and it can be confirmed that two different mesh density options were applied as shown in Fig. 3 (a). Meanwhile, a hexahedral mesh is only allowed in the PIC solver. More than 11 million cells were used for MP particle simulation as shown in Fig. 3 (b).

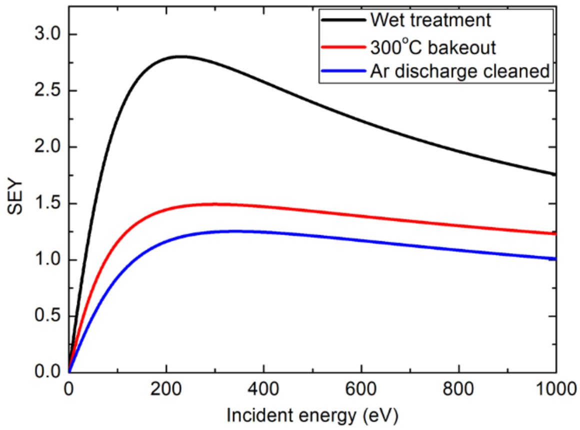

Fig. 3. Three SEY curves depending on Nb surface treatment status provided in CST PS.

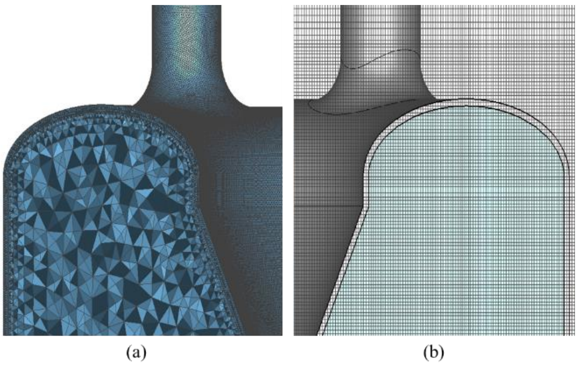

Fig. 4. (a) Tetrahedral mesh used in eigenmode solver for EM analysis and (b) hexahedral mesh used in PIC solver for MP simulation.

For the effective MP analysis, the simulation should be conducted under various conditions such as RF field level, RF phase, and primary electron emission surface. The simulations were performed for four RF phases that differed by 90 degrees and various accelerating gradients from 0.2 to 10 MV/m. Also, the PIC simulation time was 28.6 nanoseconds, which is ten RF periods.

2.2 Simulation Result

The CST PS returns the information for the MP analysis such as the total number of the electron with time, collision current and power, and emission current and power. Since various simulations were performed and the result files were generated, an analyzing application based on the Matlab was developed for easy post-processing. This application calculates exponential growth rate coefficient, α, and averaged secondary electron emission yield, <SEY> which defined as follows:

$$\langle SEY \rangle = \frac{I_{\text{emission}}}{I_{\text{collision}}}$$

$$N(t) = N_0 \exp(\alpha t).$$

Among the simulation results for all RF phase and primary electron emission surfaces, the maximum values of the growth rate coefficients at each acceleration gradient are shown in Fig 5. The strongest MP occurred near short plate at 5 MV/m accelerating field and the <SEY> is 1.41.

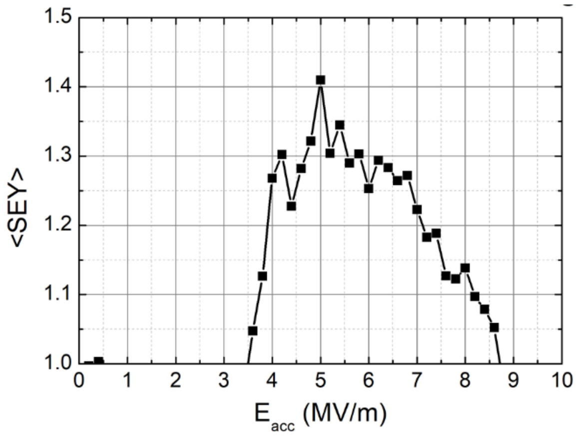

Fig. 5. Averaged secondary electron emission yield estimated by the MP simulation of the 350 MHz HWR.

3. Conclusions

The simulations of multipacting in 350 MHz HWR designed by the KOMAC were conducted using the CST PS PIC solver. It was confirmed that the MP occurred near the short plate. Also, as shown in Fig. 5, it is estimated that there is the wide MP barrier in the range of 3.5 to 8.5 MV/m. Therefore, it will be followed that the HWR design improvement to mitigate the risk of the MP through further studies such as analyzing MP characteristics depending on the curvature of the short plate.

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