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MULTIPACTING SIMULATION ON HALF-WAVE RESONATOR FOR 200 MeV ENERGY UPGRADE OF KOMAC PROTON LINAC*

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Abstract

A superconducting radio frequency cavity has been developed for proton beam energy upgrade from 100 MeV to more than 200 MeV at KOrea Multi-purpose Accelerator Complex (KOMAC). The half-wave resonator (HWR) is designed for the SRF linac. 350 MHz, beta = 0.56 HWR is designed to provide 3.6 MV accelerating voltage. After the electromagnetic design study and the electromagnetic – mechanical coupled analysis, an analysis on a multipacting (MP) of the HWR was carried out. The MP simulation was performed by using the CST Particle Studio. To understand a feature of the MP occurrence in the HWR, a particle-in-cell (PIC) simulation was conducted while changing various conditions such as an RF amplitude, an RF phase, and a primary electron emission surface.

INTRODUCTION

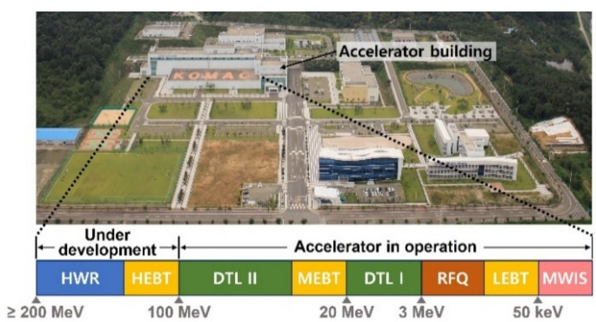

Figure 1: Layout of the 100 MeV proton linac at KOMAC and upgrade plan.

The linac at KOMAC has provided a 100 MeV beam for the proton irradiation research since 2013. Although the proton linac is stably operated, the upgrade of the linac is continuously requested to expand the application field including a spallation neutron source. Various proposals for enhancing the performance of the proton accelerator are discussed, and basic research is conducted. One such basic study is the study on the superconducting RF (SRF) linac that accelerate the 100 MeV proton beam as shown in Fig. 1. The RF design study and electromagnetic (EM) - mechanical coupled analysis on the HWR were conducted and presented [1]. The driving RF frequency of the HWR is 350 MHz which is RF frequency of the 100 MeV linac. The optimum beta and the accelerating voltage of the cavity are 0.56 and 3.6 MV. The HWR is depicted in Figure 2., and it consists of an inner conductor, an outer conductor, short plates connecting conductors, and ports for a RF power coupler, beam transport, and rinsing.

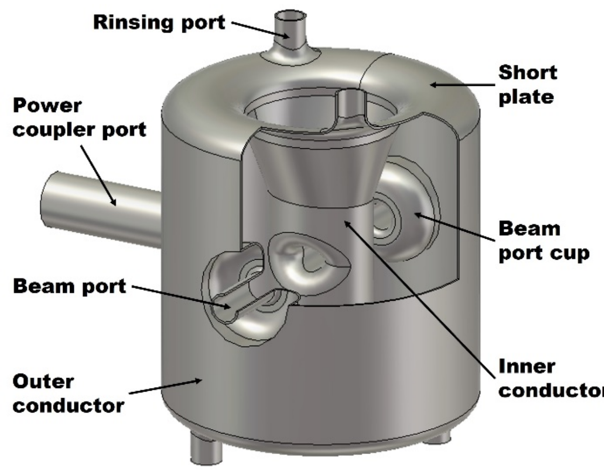

Figure 2: Cutaway drawing of the HWR designed by KOMAC.

After EM and mechanical analysis, the multipacting simulation was carried out using this design. The MP is a phenomenon that is an exponential growth of the electron by a secondary electron emitted at the surface impacted by an electron accelerated by the RF field. The MP causes problems such as unnecessary RF power consumption and limiting accelerating voltage. In the SRF cavity, the MP leads to additional heat load on the cavity surface, even causes loss of superconductivity [2]. Therefore, the characterization of the MP is required to improve cavity design or perform cavity processing. Thus, the MP simulation was conducted, and the simulation set up and result are presented in this paper.

MULTIPACTING SIMULATION MODEL AND SET UP

Simulation Tool

The MP simulation was conducted using the CST Studio Suite [3] because the CST provides integrated system for the analysis on the RF field and the particle behavior. Also, the CST material library supports an advanced secondary electron emission model called as Furman-Pivi model [4]. The CST includes the particle-in-cell (PIC) solver and tracking solver for particle simulation. In this study, the particle-in-cell (PIC) solver was utilized for the MP simulation. Although requires more computing resource and computational time compared to the TRK solver, it provides detailed data such as the number of electrons over

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time and 3 D position monitor for the MP analysis. Thus, instead of using the PIC solver, calculation time could be reduced using GPU acceleration and a symmetric model.

Model, Meshing and Set Up

The KOMAC HWR has no symmetry due to the rinsing and the power coupler port, but a symmetric model in which the corresponding ports were removed was introduced to simplify the problem. However, since the CST particle solver does not offer the symmetric boundary condition for the particle, a reflection wall that reflects all incident electrons was used to implement the symmetry. This configuration of the symmetric model was developed refer other work [4]. The 1/8 symmetry model is shown in Fig. 3. The 300°C bakeout niobium (Nb) which is one of the materials provided by the CST was assigned to the HWR cavity.

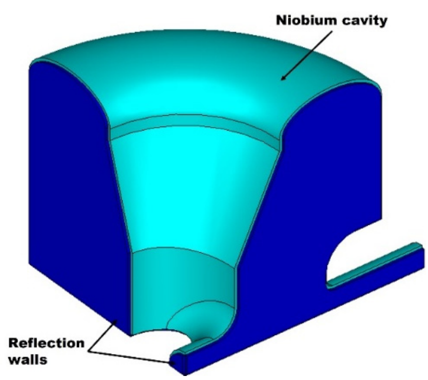
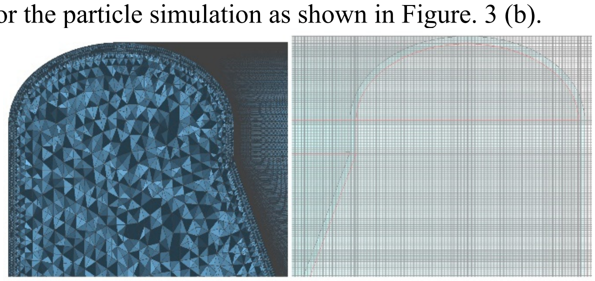


Figure 3: 1/8 symmetric HWR cavity model and reflection walls for MP simulation.

The 350 MHz RF field calculated by the eigenmode solver was imported into the PIC solver for the MP simulation. An additional thin layer vacuum model adjoining the cavity wall was made because the multipacting is affected by the EM field near the surface. A local mesh option limiting maximum cell size to less than 1 mm was assigned on the outer layer to enhance mesh density. More than 6 million tetrahedral mesh cells were used for the EM field analysis, and it can be confirmed that two different mesh density options were applied as shown in Fig. 4 (a). Meanwhile, a hexahedral mesh is only allowed in the PIC solver. Approximately 62 million hexahedrons were used for the particle simulation as shown in Figure. 3 (b).



(a) (b)

Figure 4: (a) Tetrahedral mesh used for the EM analysis and (b) hexahedral mesh used for the particle simulation.

The MP simulation should be conducted under various conditions such as RF amplitude, RF phase, and primary electron emission surface. The simulation was performed on four RF phases with a difference of 90 degrees from 10 degrees to 280 degrees, and on the accelerating gradients in the range of 0.5 to 10 MV/m. Also, the PIC simulation time duration was ten RF periods (28.6 nanoseconds).

Post-processing

An exponential growth rate coefficient (α) and averaged secondary emission yield (<SEY>) are representative values to evaluate intensity of the MP and defined as

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

$$\langle SEY \rangle = \frac{\mathrm{I_{emission}}}{\mathrm{I_{collision}}} = e^{\alpha T} \tag{2}$$

where the t is time, T is RF period and N is number of electrons [4]. These values can be obtained from results of the PIC solver. The PIC solver returns results such as the number of electrons over time data, collision and emission current data. A Matlab-based post-processing program was created to quickly and consistently process many results calculated by combinations of various simulation conditions. This post-processing program reads the result files and calculates α and <SEY> according to the above equations. The α is determined by exponential fitting of the number of electrons over time data. The <SEY> is the average value obtained by dividing the emission current by the collision current for about 5 RF periods. An example of the Matlab-based post-processing result is shown in Fig. 5.

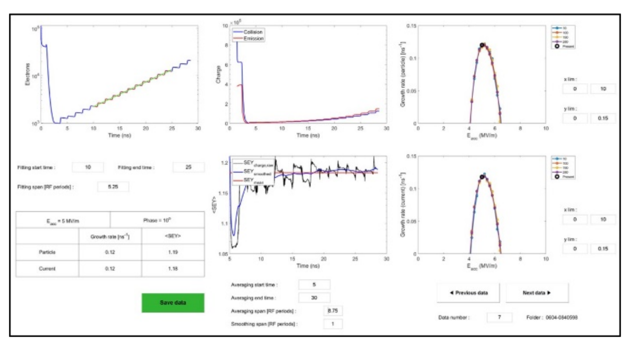


Figure 5: Matlab-based post-processing program.

CHARACTERISTICS OF MULTIPACTING IN 350 MHz HWR

Figure 6 shows the exponential growth rate coefficient calculated for the accelerating gradients in the range of 0.5 to 10 MV/m. There are narrow MP barrier near low electric field of 1 MV/m and wide MP barrier between 4 and 6.5 MV/m. This MP characteristics is similar to those reported in other work [5-9]. The MP of the first barrier occurs between the inner and the outer conductor. The MP of the second barrier is generated near the short plate. It is a typical two-point first-order MP in the HWR. Also, according to the reference 5, this MP depends on a height of ellipse in

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the short plate cross section [6]. Therefore, it is expected that the wide MP barrier can be mitigated by design optimization.

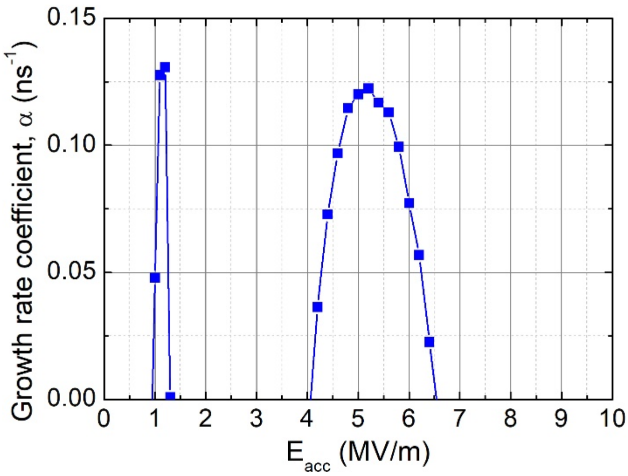

Figure 6: Calculated exponential growth rate coefficient over accelerating gradient.

SUMMARY

The HWR type superconducting RF cavity has been developed at KOMAC to increase the proton energy from 100 MeV to more than 200 MeV. The study on the multipacting, one of the key issues of the SRF cavity design, was conducted using the PIC solver of the CST Studio Suite. To simplify the model and enhance mesh density, the symmetric HWR model without the rinsing and the coupler port was introduced for the MP simulation. The simulations were performed on the various RF phase, accelerating gradient and primary electron emitting surface. The MP barriers were confirmed at low and medium accelerating gradient. The MP at the low accelerating gradient occurs between the inner and outer conductors. The MP at the medium accelerating gradient is the two-point first-order MP called as a horseshoe.

FUTURE WORK

The simulation and study on the multipacting will be conducted continuously. The effect of the short plate height, the rinsing port and the coupler port on the MP will be researched. Also, based on the MP simulation result, the design improvement of the HWR is carried out.

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