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MULTIPACTING STUDIES FOR THE JAEA-ADS FIVE-CELL ELLIPTICAL SUPERCONDUCTING RF CAVITIES*

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Abstract

The Five-cell Elliptical Superconducting Radio-Frequency Cavities (SRFC) provide the final acceleration in the JAEA-ADS linac (from 208 MeV to 1.5 GeV); thus, their performance is essential for the success of the JAEA-ADS project. After their optimization of the cavity geometry to achieve a high acceleration gradient with lower electromagnetic peaks, the next step in the R&D strategy is the accurate estimation of beam-cavity effects which can affect the performance of the cavities. To this end, multipacting studies were developed to investigate its effect in the cavity operation regimen and find countermeasures. The results of this study will help in the development of the SRFC models and in the consolidation of the JAEA-ADS project.

INTRODUCTION

Multipacting is an undesired resonant effect, where a fast electron build-up occurs inside the Radio-Frequency Cavity (RFC) [1]. As a result, multipacting limits the accelerating gradient E_{acc} of the RFC, and for Superconducting Radio-Frequency Cavity (SRFC) can result in the loss of its superconducting state. The Accelerator Driven Subcritical System (ADS) designed by Japan Atomic Energy Agency (JAEA) employs SRFC to accelerate a proton beam from 2.5 MeV to 1.5 GeV; thus, multipacting could be a potential risk for the SRFC performance. To this end, we started with the analysis of multipacting for the Five-cell Elliptical SRFC, known as EllipR. Table 1 presents the general parameters of the EllipR cavities for the JAEA-ADS linac.

Table 1: Parameters of the EllipR SRFC

Parameter	EllipR1	EllipR2
Frequency (MHz)	648	648
β_g	0.68	0.89
E_{acc} range (MV/m)	2.3 - 13.8	10 - 14.2
Energy range (MeV)	208.8-583.4	583.4-1500

The study exploited the EllipR symmetry to simulate a fraction of the total cavities; thus, the computational time is reduced. In addition, the simulations took into account the space-charge effects of the electron in the multipacting formation. Finally, we explored different cavity profiles around the equator to mitigate the multipacting.

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SIMULATIONS

The multipacting studies were developed using two CST Studio (CST) [2] solvers: MicroWave Studio (MS) with eigenmode and Particle Studio (PS). First, MS was used to design the cavity geometry and compute the electromagnetic fields [3]. Second, PS exported the electromagnetic fields and geometry from MS solver to simulate the multipacting formation. The PS simulations used different Niobium surface conditions: wet treatment, discharge cleaned, and 300 deg baked. In the end, 300 deg baked was selected because its secondary emission yield (SEY) is close to the one obtained in the measurements [4]. In the beginning, the electron source was in all the inner surfaces of the cavity. However, the studies show that only multipacting appears around the cavity equator; thus, we set the electron source in the cavity equator. The multipacting formation was simulated over 10 RF periods, and we computed the average emission current I_{Emis} over the last 3 RF periods as a figure of merit.

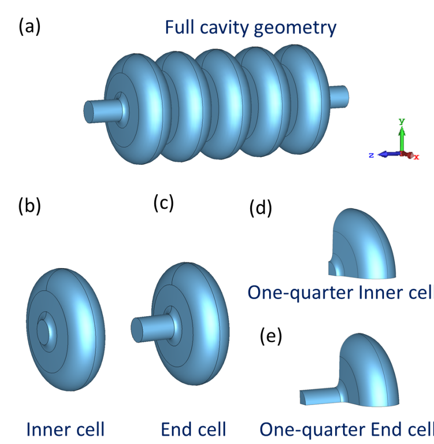

Figure 1: The full cavity geometry of the EllipR1 (a), Inner cell (b), End cell (c), one-quarter Inner cell (d) and one-quarter End cell (e).

The analysis requires good accuracy in terms of electromagnetic fields and the mesh cell for its correct estimation. Consequently, the computational time increases considerably. A standard approach is to exploit the cell symmetries by simulating the so-called Inner cell and End cell instead of the entire cavity, as shown in Fig. 1. Moreover, we simulated one-quarter of the cell with an elastic scattering wall to reduce the simulation time [5,6]. Figure 2 shows the I_{Emis} against E_{acc} for the one cell and one-quarter cell. The two models present a good agreement.

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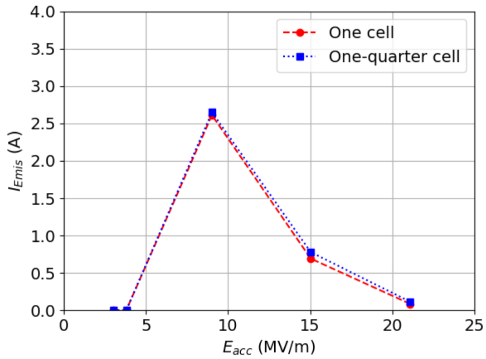

Figure 2: The comparison between one cell and one-quarter model of the Inner cell of EllipR1.

Space-charge affects the secondary emission electron; therefore, it also affects the multipacting [7, 8]. Typically, multipacting studies present an exponential electron growth when the space-charge is omitted; on the contrary, the electron growth reaches saturation. At the saturation regime, the effective $SEY = I_{Emis}/I_{Ecoll}$, where I_{Ecoll} is the electron collision current, is not a clear indicator of multipacting; thus, we used the I_{Emis}. Figure 3 shows the I_{Emis} for the cases with and without space-charge. The space-charge reduces the I_{Emis} amplitude, but the location of the multipacting zone, 8 to 15 MV/m, is unchanged.

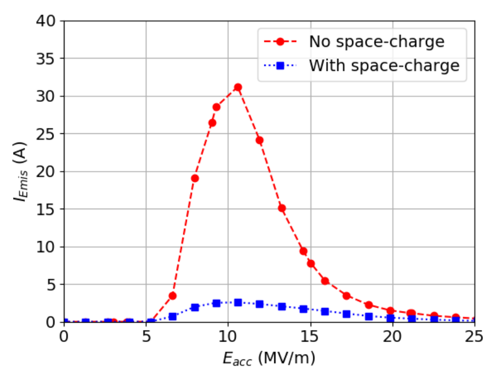

Figure 3: The space-charge effect in the multipacting studies for the Inner cell of EllipR1.

Figure 4 shows that the multipacting occurs around the equator. Therefore, we slightly modified the cavity geometry near the equator. Figure 5 presents the different cavity profiles tested to reduce the mitigation in the EllipRs. The cavity geometry was changed 5 mm around the equator to keep the electromagnetic performance of the original model [3]. However, we required a small adjustment of the cavity length to operate at the design frequency, 648 MHz.

RESULTS

The summary of I_{Emis} versus E_{acc} curves from the EllipRs is shown in Fig. 6. The larger values for the EllipR2 cells are because the multipacting areas of EllipR2 are larger than EllipR1. This behavior agrees with the reported by another project with similar cavity parameters [4, 7]. Because the Elliptical cavities will operate in that E_{acc} range, it is important to explore possible countermeasures to mitigate the multipacting.

To this end, we implemented different geometries around the equator, as shown in Fig. 5. Figure 7 presents the I_{Emis} curves for the different geometries. The results show a remarkable increase for the concave case. This is because the convex geometry enhances the two-point multipacting near the equator. In contrast, the convex case presents a reduction

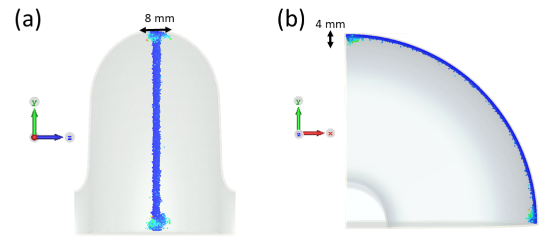

Figure 4: The multipacting location in the cell on the *yz*-plane (a) and on *xy*-plane (b).

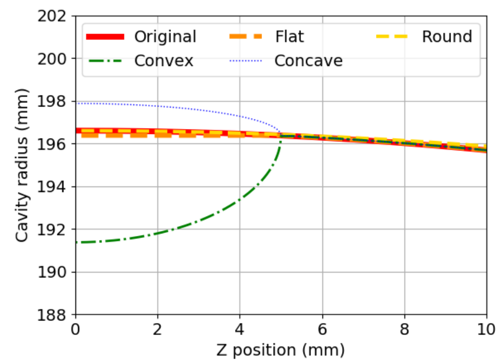

Figure 5: A close up of the cavity profile, *yz*-plane, around the equator for the different geometries used to analysis the multipacting effects.

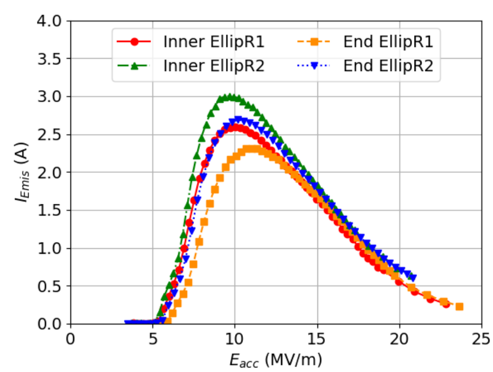

Figure 6: The average I_{Emis} for the Inner and End cells of the EllipRs cavities.

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of 48%. Others reported similar results [9, 10]. The other profiles produce similar results as the original shape.

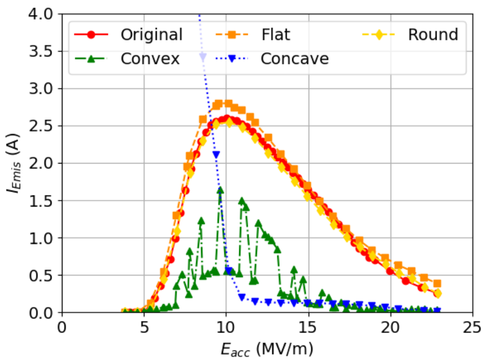

Figure 7: The average I_{Emis} of the inner EllipR1 for the different geometries.

The geometry effect in the electric field was evaluated by using the geometrical parameter p defined as

$$p = (dE_n/dr)/\omega B_0 \tag{1}$$

where E_n is the electric field normal to the multipacting area, r is the transverse direction, B_0 is the magnetic field in the area [11]. The p values were computed for the E_{acc} = 8 MV/m from a region between 2 to 6 mm from the equator. Figure 8 shows that convex geometry has the lowest value and the concave, the highest. In addition, the others geometries showed superposition of the curves. These results indicated that lower p values resulted in lower multipacting. This is, in such a way, supported by the multipacting zone presented in reference [11], which showed multipacting zone became smaller for lower p values.

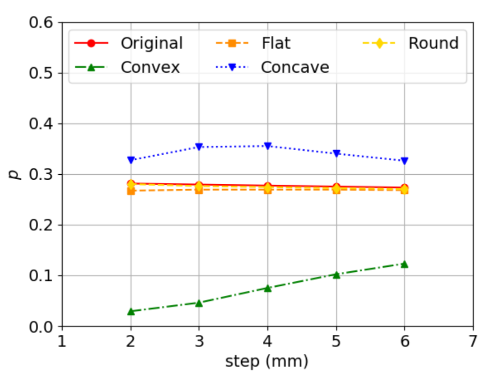

Figure 8: p values of the Inner EllipR1 for the different geometries. The steps indicate the position, with respect to the top part of the equator, where the electromagnetic fields were computed.

CONCLUSION

The studies showed multipacting in the E_{acc} operational range of the Elliptical cavities. To overcome this effect, we adopted a convex geometry around the cavity equator. As a result, the I_{Emis} peak was reduced by 48% of the original profile peak. This is related to the decreasing of the p value obtained by using a convex profile. Convex geometry around the equator reduces the multipacting effect in the cavities; however, we require to evaluate the challenge for cavity machining before adopting this option.

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