THE MULTIPACTION ANALYSIS OF THE HWR AT RISP*

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Abstract

The half wave resonator (HWR) has been developed for the low-medium energy acceleration in RAON, the proposed heavy ion accelerator at rare isotope science project (RISP). This paper reports the progress on the multipaction study and the related issues. The simulation result by 3D solver CST-PS (PIC) is presented: the multipaction of the cavity, the effects of the rinsing ports, the effect of the coupler.

INTRODUCTION

A parasitic electron loading caused by the multipacting discharge of the electron in the superconducting cavities can spoil the high quality factor as well as collision-induced heating, followed by the thermal breakdown. Although the multipacting (MP) can be usually processed in RF conditioning, the processing time could take long and there are MP's that survive the processing near the operating voltage of the cavities. Thus the cavity must be designed to avoid the MP's.

In this paper, we report the study on the multipaction of the $\beta = 0.12$ HWR (see Fig.1) and the related issues such as the effects of the rinsing ports and the couplers. The relevant specification of the HWR for the MP simulation is given in Table. 1. We simulate the MP's using CST-PS (PIC solver) to identify the location and the bandwidth of the accelerating voltage where the multipactions take place. If any, the multipaction must be away far from the operating accelerating voltage.

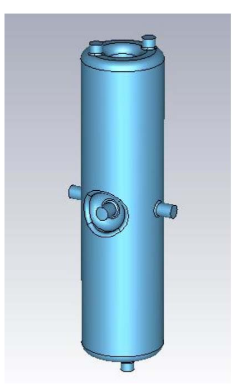

Figure 1: 3D view of the HWR.

In the simulation, the HWR is assumed to be made of the the niobium baked out at 300C, whose SEY curve is shown in Fig.2

Table 1: Specifications of the HWR

Figures of merit	Unit	Value
V_{acc}	MV	1.21
L_{eff}	m	0.22
E_{acc}	MV/m	5.47
f	MHz	162.5

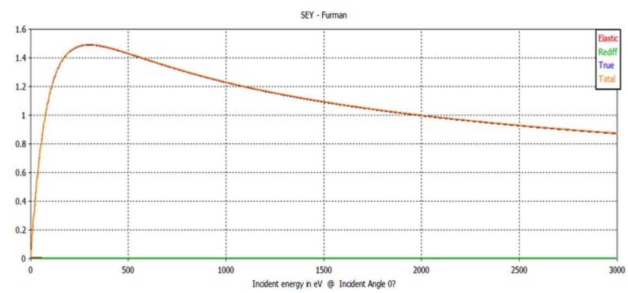

Figure 2: SEY curve of the niobium baked out at 300 C. More emittant electrons than incident ones between 100 $\sim$ 2000 eV.

The MP simulations were done in three steps. First, we used the cavity geometry without the coupling ports (rinsing ports and the coupler ports). Secondly, we included the rinsing ports. The rinsing ports with the blending is known to change the magnetic field [1] and subsequently the trajectories of the electrons near the short plates. Thus we inspect the MP in the presence of the rinsing port with the optimized blending radius. Finally, we added the coupler to the cavity to see the effects of MP's in the coupler on the cavity, i.e., the electrons multipacted from the coupler migrate into the cavity for further multipaction.

MULTIPACTION OF THE CAVITY

The Global Multipaction in the HWR

The geometry of the HWR suggests that the dangerous regions for the multipaction are capacitor region for the two-point MP, the short plates for the two-point MP, the stem region for the one-point MP and two-pont MP's. Due to the limit on the CPU memory and simulation time, we simulate the MP for the entire region of the HWR with smaller number of electrons, coarser mesh, and the larger step for ramping the accelerating voltage, while as more detailed, separate simulation is done for the aforementioned dangerous region.

The simulation with the initial design showed the strong

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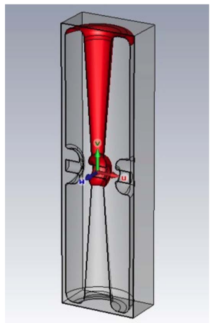
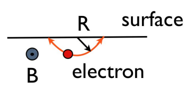
multipaction near the operating accelerating voltage only at the short plates, which agrees with the previous studies on the similar HWR's. [2, 3]



(a) Particle sources of the simulation in the HWR.

(b) Multipacting electrons near the short plate.



(c) Schematic view of the multipaction.

Figure 3: The multipaction simulation. In (c), electrons are in cyclotronic motion due to magnetic field.

More specifically, the 1st order two-point MP took place at the short plates as shown in Fig. 3 (b). The dominant motion of the electrons is determined by the magnetic field, which leads to cyclotronic motion with the radius R given as

$$R = \frac{\sqrt{mK}}{B_0 e}. \tag{1}$$

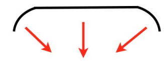
Here B_0 is the approximately uniform magnetic field near the short plate, K is kinetic energy of the electron, and m, e are the mass and the electric charge of the electron respectively. Thus the resonant condition is given by

$$B_0 = \frac{\sqrt{2}m\omega}{en}. \tag{2}$$

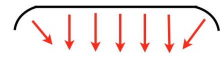
Here n is the order of the multipaction, ω is the RF frequency.

In general, the multipaction in the region where E field is small (such as near the short plates) can be sensitive to the convexity of the surface. While the resonant condition is mostly determined by B field, the small E field also can perturb the trajectories of the electrons causing the resonant trajectories move elsewhere (Fig.4).

Once moving around with the different geometry, it becomes more difficult to maintain the resonant condition. Thus, concave(convex) surface with the E field (normal to the surface), can (de)stabilize the migration of the multipacting trajectories. Therefore, the easiest solution to our



(a) short plate with less flat region.



(b) short plate with more flat region.

Figure 4: The electric fields in different geometry. Red arrows are the electric fields while black lines are short plate surface.

problem was either to reduce the blending radius of the short plates or to increase the flat region in the short plate by reducing the inner conductor radius. The first option was discarded since it gives less mechanical strength to the cavity. But the second option means the less tapering, which was introduced to reduce the peak magnetic field. We made some parameter study for the radius of the inner conductor to find the maximum radius that eliminates the multipaction, which turns out to be $r = 45$ mm (Fig.5).

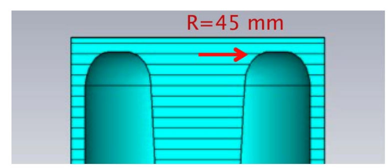


Figure 5: The multipactor as a function of the accelerator voltage(multiplying factor).

In Fig.6, the resulting multipaction is shown. With the smaller radius (and the more flat region), the multipaction except for the very low accelerating voltage vanished.

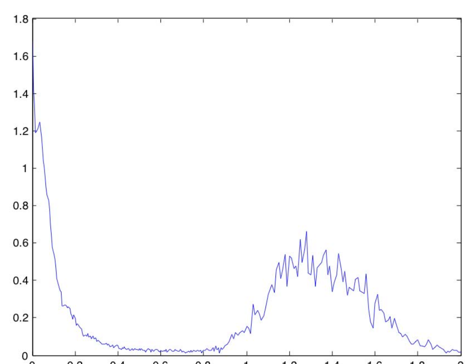


Figure 6: The multipactor as a function of the accelerator voltage(multiplying factor).

Mutipaction with the Coupling Ports

To get a more realistic model, we included the rinsing ports, which in general enhances the peak magnetic field.

The peak field is reduced as well when the blending radius of the ports are increased [1]. In case of the HWR at RISP, the effect of the blending radius turns out to be negligible as shown in Fig.7. The reason for this small effect comes from the fact that the peak magnetic field is located (slightly) below the short plates unlike in [1]. For engineering convenience, the radius was determined to be 5 mm.

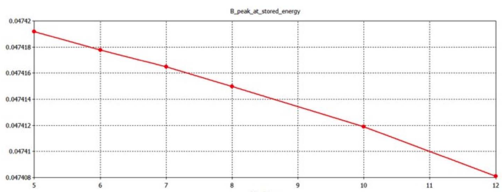


Figure 7: The peak magnetic field (T) vs. blending radius (mm) of the coupling ports.

According to (1), with the rinsing ports the radius of the cyclotronic orbit is reduced leading to the different resonant condition. The simulation study on the MP was done (Fig.8). Compared to Fig.6, the weak yet genuine multipaction (with multipaction level∼1.5) is prevalent in proximity of the operating range of the accelerating voltage. Since this is not a strong MP, we expect that it will be processed straightforwardly.

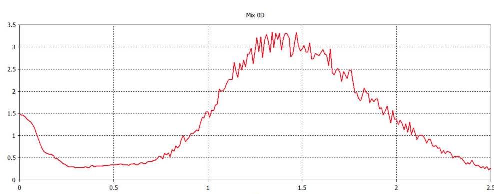


Figure 8: The multipaction of the HWR with the rinsing ports.

THE EFFECTS OF THE COUPLER

Specification of the Coupler

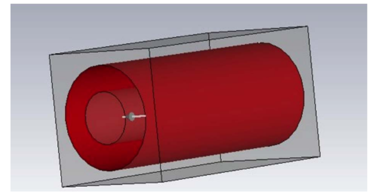
The power coupler for the HWR is supposed to deliver $5 \sim 6$ kW. Its characteristic impedance Z for the coaxial coupler is determined as

$$Z = \frac{1}{2\pi}\sqrt{\frac{\mu_0}{\varepsilon_0}}\ln{(b/a)}, \tag{3}$$

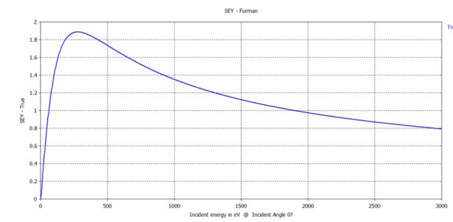
where a is inner radius and b is outer radius. In turn, a, b would be determined by considering as low peak electric field E_p and the power loss α_c as possible. The initial choice was $50\,\Omega$, which is connected to the RF power line without any modification.

Multipaction with the Coupler

The coaxial power coupler has its own multipaction, which could serve as an ample electron source for further multipaction in the cavity. Thus we study the multipaction of the coupler and its effect on the cavity (Fig.9).



(a) Particle source of the coupler.



(b) SEY curve of the copper. SEY is bigger than 1 between 100 and 2000 eV.

Figure 9: Schematic view of the coupler and SEY curve for the copper.

The empirical formula for the n-point multipaction was given in [4]

$$P_m \sim f^4 d^4 Z^n, \tag{4}$$

where P_m is resonance peak, $d = b - a$ and this suggests that the reducing the distance d will shift the resonance peak to the left (smaller). The simulation for the initial design is done with $a = 8.7$ mm, $b = 20$ mm ($Z = 50\,\Omega$) and showed a strong multipaction near the operation range of the cavity, i.e., $0.7 \sim 1.2$ MV. We changed the inner radius a to 10 mm while keeping the outer radius the same for the engineering reason. This implies $Z = 42.1\,\Omega$ but the peak of the resonance band is shifted lower and the mulipaction level in the operating range is now significantly down (Fig.10).

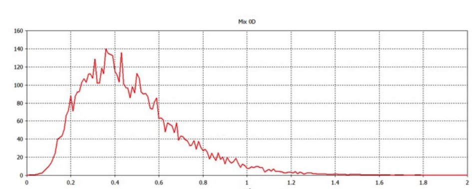


Figure 10: The multipaction of the coupler.

Multipaction of the Cavity with the Coupler

Since the multipaction that did not show up in the successful vertical test could appear in the cryomodule test after the power coupler in full capacity is installed, one needs to simulate the multipaction including the coupler (Fig.11).

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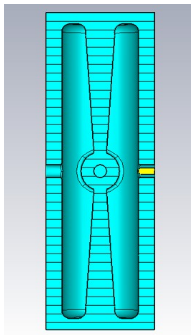

Figure 11: The cavity with the coupler. Yellow bar is the antenna of the coupler.

The simulation result is shown in Fig. 12. As shown, there is no strong multipaction over the entire accelerating voltage range.

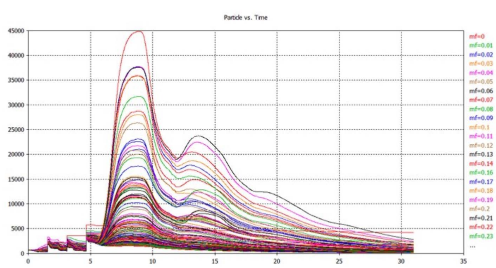

Figure 12: The multipaction of the cavity with the coupler. Shown is the number of the electrons vs. time for various accelerating voltage between 0 and 1.2 MV.

SUMMARY

- With the modified geometrical design in the short plate, we have the HWR free from the multipaction near the operational range of the accelerating voltage.
- The coupler partially has the multipaction, but the work is in progress toward the complete reduction of the multipaction in the operational range.

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