HOM DAMPING AND MULTIPACTING ANALYSIS OF THE QUARTER-WAVE CRAB CAVITY*

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Abstract

The quarter-wave crab cavity design has been analyzed further to accommodate LHC requirements. The goal for the design is to provide strong deflecting voltage to the proton bunches at the IP, while keeping the effective length as short as possible. We will evaluate the higher order mode damping with two or four magnetic coupling dampers installed in different configuration. In this paper, we also show possible multipacting locations which are simulated by 2D and 3D codes.

INTRODUCTION

Quarter wave crab cavity (QWCC) has been proposed for the LHC upgrade in 2010 [1]. The quarter wave resonators have the merits of compactness and big separation between fundamental (operating) mode and 1st higher order mode. Both aspects are highly desirable and will benefit the design of the crab cavity. In order to meet the constrains of the installation in the LHC beamlines as well as maintain high performance and low peak fields, the cavity has been optimized into an elliptical shaped geometry with small taper angles for both inner and outer conductor [2]. The optimized cavity is as shown in Figure 1. The Higher Order Modes (HOMs) of the cavity have also been carefully studied to fully understand the strength and type of effect each one the mode will apply to the beam [2]. These studies give useful guidelines to the damping scheme of the HOMs.

In the mean time, multipacting analyses using 2D and 3D code have been carried out to give preliminary results.

HOM DAMPING

The HOM damping scheme selection depends strongly on the field distribution in the cavity. A 3D code, MicroWave Studio is used for simulations of the cavity field and HOM damping [4]. The HOM field distributions of the QWCC are simular to all quarter wave structures, and some typical HOM magenetic fields are shown in Figure 2. From the experience with other quarter wave resonators [3], small loops for magnetic coupling are inserted at the shorted end of the quarter wave structure. Due to the spatial limitation of the adjacent beam pipe, the extended ports for HOM couplers must be located appropriately to avoid the beam pipes.

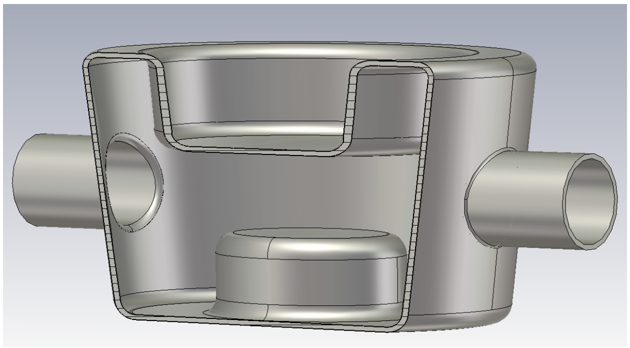

Figure 1: Optimized quarter wave crab cavity.

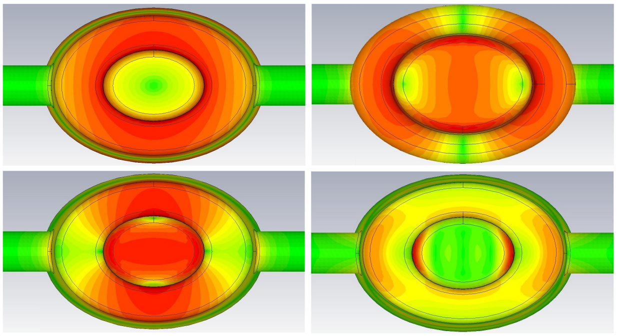

Figure 2: Magnetic field distribution of 4 different HOMs of QWCC. Top-left: 0.657 GHz; Top-right: 0.690 GHz; Bottom-left: 0.893 GHz; Bottom-right: 1.856GHz.

For simplicity, we designed the two damping schemes with either two small loops located 45 degrees on the different sides of one beam pipe (scheme I) or 180 degrees diagonally from each other (scheme II), as shown in Figure 3. For stronger HOM coupling, we also can use 4-coupler damping schemes as shown in Figure 4. In the scheme on the top of the picture, the four couplers are all on the same side of the beam pipe and 90 degrees apart (scheme III), while the scheme on the bottom has two on each side with 90 degrees separation (scheme IV). Scheme IV is designed for fair coupling to all the HOMs including those with magnetic field focused on either shorted end of the cavity. Since the cavity is assymetrical, the size of the couplers are designed differently to accommondate the size of the port opening. In all schemes, the couplers inserted from the end

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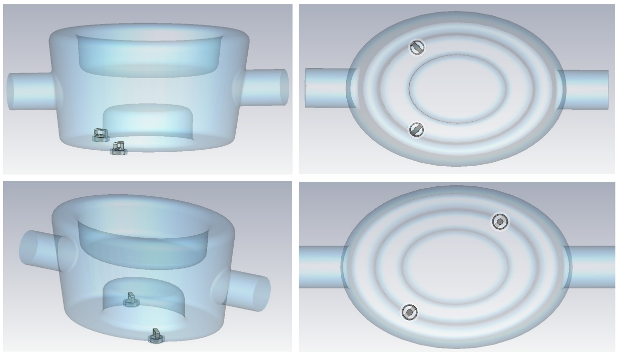

Figure 3: Two 2-coupler damping schemes. Scheme I (top): 45 degrees on different side of one beam pipe; Scheme II (bottom): diagonally from each other.

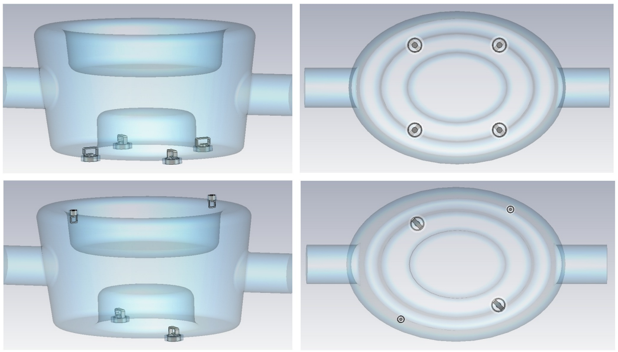

Figure 4: Two 4-coupler damping schemes. Scheme III (top): 45 degrees all on one side of the beam pipes; Scheme IV (bottom): two couplers located on each side of the beam pipes.

with larger ports, e.g. scheme I, II, III, are designed with loop area of 26mm × 11mm, and the couplers inserted from the other end have a loop area of 13mmx11mm. The results of all four damping schemes are shown in Table 1.

From the results of the four damping schemes, the 2-couplers schemes in Figure 3 are sufficient for only some of the HOMs, e.g. 0.656 GHz. Differences in the external Q are also shown for modes having magnetic field focused close to the beam pipe area. Obviously, further coupling can be achieved by adding two more couplers in scheme III. But in order to have sufficient coupling for all HOM modes, couplers must be placed on both shorted ends of the cavity. As an example from the table, the mode with frequency of 0.690 GHz can be very efficiently damped with the two small couplers on the opposed side in scheme IV. However, further studies are ongoing to determine the exact location and orientation of the loops for efficient damping.

Table 1: Qext for all Four HOM Damping Schemes

Freq. [GHz]	R/Q [Ω]	Qext I	Qext II	Qext III	Qext IV
0.656	82.7	6.6e2	6.8e2	3.4e2	4.8e2
0.690	39.3	2.7e6	4.1e6	1.8e6	2.0e3
0.702	29.1	2.2e3	2.2e3	1.1e3	8.5e2
0.812	14.0	5.8e2	6.1e2	3.1e2	5.2e2
0.893	3.5	4.0e2	6.1e2	3.1e2	5.6e2
0.896	40.8	2.9e3	2.2e3	1.2e3	7.2e2
0.922	2.6	2.7e4	2.5e4	1.4e4	1.4e4
1.132	11.6	8.5e4	7.5e4	4.1e4	6.2e3
1.136	2.0	2.6e3	2.4e3	1.9e3	2.1e3

MULTIPACTING

Quarter wave resonators are well known to have several multipacting bands at low fields, but were also easily processed in several operational SC resonators around the world.

The special topology of the deflecting cavity and its deviation from a pure quarter wave does however require some investigation. Durding optimization of the QWCC, it was first designed as a round structure, type I in [2]. This design without beam pipes has 2D symmetry, and 2D code MultiPac [5] was used to simulate multipacting. Although the final geometries deviate from the symmetric structure, a first idea of the different types of trajectories and their relative strengths is useful.

Figure 5 shows the total number of electrons after a given number of impacts normalized to the average secondary emission coefficient corresponding to the specific impact energy (enhanced counter function) as a function of surface electric field. Two different types of SEY curves were used to distinguish between a good surface compared to that of an untreated one.

There are primarily four types of trajectories as labeled in Figure 5 and the corresponding trajectory is plotted in Figure 6. Case I (top-left) around 0.7 MV/m is the typical two point multipacting that one might expect in coaxial lines. The number of surviving secondary electrons is very small and the wall angles on the final design should suppress this further. Case II (top-right) around 1.4 MV/m corresponds to 2-point low order multipacting between the parallel plates of the inner conductors which also doesn't sustain due to the low yield. Case III (bottom-left) and IV (bottom-right) correspond to a reasonably strong barriers where the electrons multiply at the top ceiling or the bottom trough of the resonator.

A preliminary 3D multipacting simulation has been carried out using the ACE3P package [6]. A coarse scan of the surface electric field level from 4 MV/m to 18 MV/m with 0.04 MV/m step size was performed, and we found more field levels for possible multipacting. Figure 8 shows four typical trajectories of the resonant elelctrons at various field levels. The trajectories are mostly two point multipacting with particles resonant between the edge of the center conductor and the outer conductor. Some trajectories are also found focused around the beam pipe opening. The 2D simulation results did not show these trajectories due to the lack of ellipticity of the cavity and

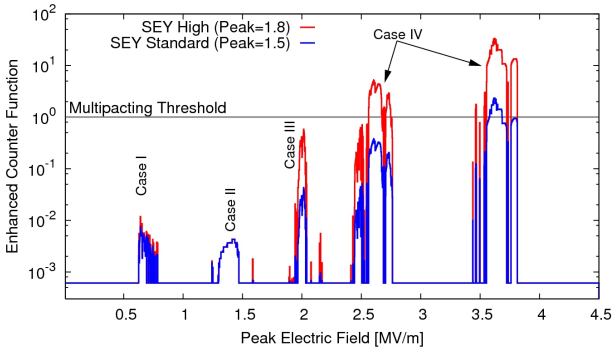

Figure 5: The number of secondary electrons after 40 impacts normalized to the SEY corresponding to the impact energies plotted as a function of surface electric field.

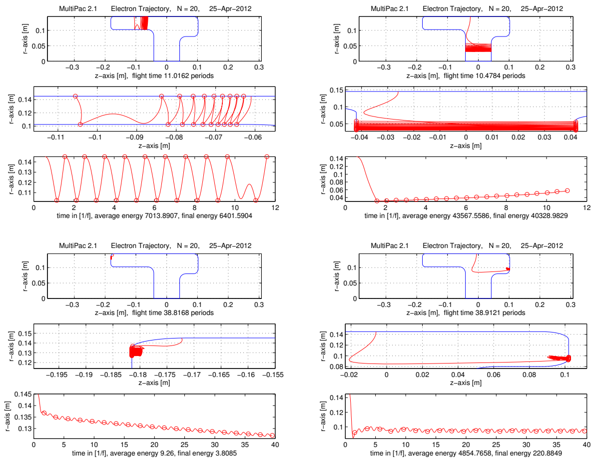

Figure 6: 4 types of multipacting trajectories from MultiPac results. Top-left: case I; Top-right: case II; Bottom-left: case III; Bottom-right: case IV.

the beam pipes. The 3D simulation allows us to perform a detailed analysis on the final geometry of the QWCC. Further fine scanning of the field level is in progress, and the results will provide guideline for the multipacting suppression. Future simulation will include HOM couplers once the exact damping scheme is finalized.

CONCLUSION

A variety of HOM damping schemes are studied, and the efficiency was compared by damping of the high shunt impedance modes. Because the HOMs may have EM fields only focused in either shorted ends of the cavity, the eventual design must have couplers that can couple to field on both side of the beam pipe.

Multipacting simulations indicate several field levels at which may have resonant electrons. 3D simulations with beam pipes and ellipticities revealed trajectories not present in the 2D symmetric round cavity. More detailed 3D multipacting simulation is required for the cavity and for the couplers in the future.

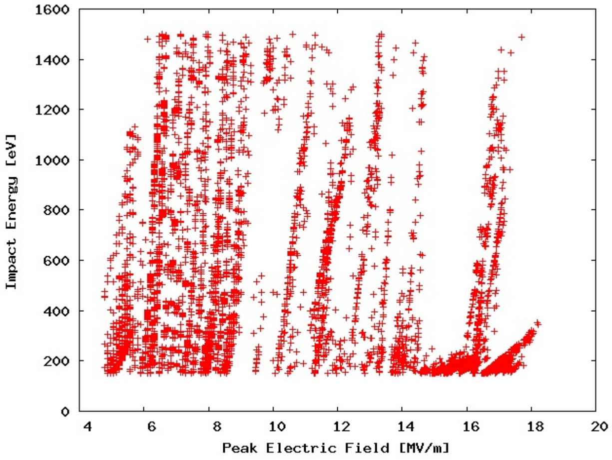

Figure 7: Multipacting simulation for QWCC from 4.5 MV/m to 18 MV/m surface electric field with impact number set to 20 or above.

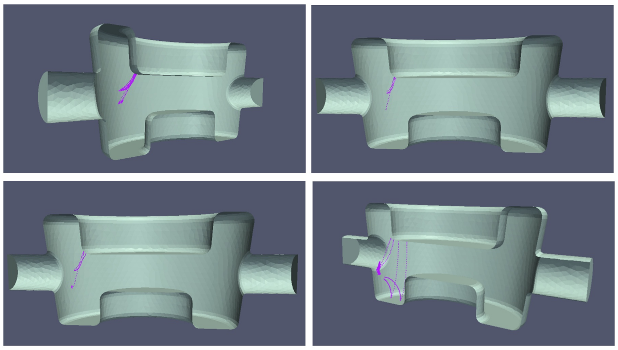

Figure 8: Multipacting trajectories from 3D multipacting simulation. Top-left: 7 MV/m; Top-right: 11.8 MV/m; Bottom-left: 13.2 MV/m; Bottom-right: 17 MV/m.

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