MULTIPACTING SUPPRESSION IN A SINGLE SPOKE CAVITY

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Abstract

Spoke cavities are good candidates for the low and medium β section of a high intensity proton or ion accelerator. For many high intensity accelerators, stability and reliability are the most important properties. Currently, one of the key issues of spoke cavity performance is multipacting (MP), which may cause instability during operation. Multipacting in a spoke cavity has a troublesome characteristic as it presents a continual barrier over a wide gradient range, usually in the range of operation from 3 MV/m to 15 MV/m. A good surface processing can improve the secondary electron emission yield. However, the complex 3D structure makes it not easily achievable as with the elliptical cavity variants. Suppressing multipacting in the design stage is clearly advantageous. This paper will present a multipacting study based on the PKU-I spoke cavity. A systematic correlation between geometric parameters and multipacting behaviors is obtained. Based on this study a new geometry of single spoke cavity called the 'balloon' variant is proposed.

INTRODUCTION

Spoke cavities are good candidates for the low and medium β section of a high intensity proton or ion accelerator. Currently, one of the key issues of spoke cavity is MP, which has a troublesome characteristic in a spoke cavity as it presents a continual barrier over a wide gradient range, usually in the range from 3 MV/m to 15 MV/m [1]. The usual operational gradient, from 6MV/m to 12 MV/m [2, 3], just falls into this range as well.

The PKU-I spoke cavity is a 450 MHz β=0.2 single spoke cavity [4]. The performance of this cavity is limited by strong MP at 3 MV/m [5]. The test result motivated the MP study, and the advantage of suppressing MP in the design stage is clear. This paper will present the MP study. A systematic correlation between geometric parameters and MP behaviors is obtained. Based on this study a new geometry of single spoke cavity called the 'balloon' variant is proposed.

MULTIPACTING STUDY OF PKU-I SPOKE CAVITY

Simulation results are shown in Fig. 1. There are wide MP barriers from 3 MV/m to 11 MV/m. The main MP modes are the 1st, 2nd and 4th orders. All of these resonances start around the gradient of 3 MV/m, as confirmed with cold test results.

Fig. 1 shows the MP positions and the relative surface electric field distribution of the PKU-I spoke cavity. The bottom four plots show different order MP at the different gradients and positions. MP happens at the minimal surface electric field region, as there are electric potential barriers, which will trap secondary electrons [6]. In a single spoke cavity, minimal surface electric field regions are the joint parts of the cavity body with the end walls and the spoke bar. Geometry optimization in these areas should help MP suppression.

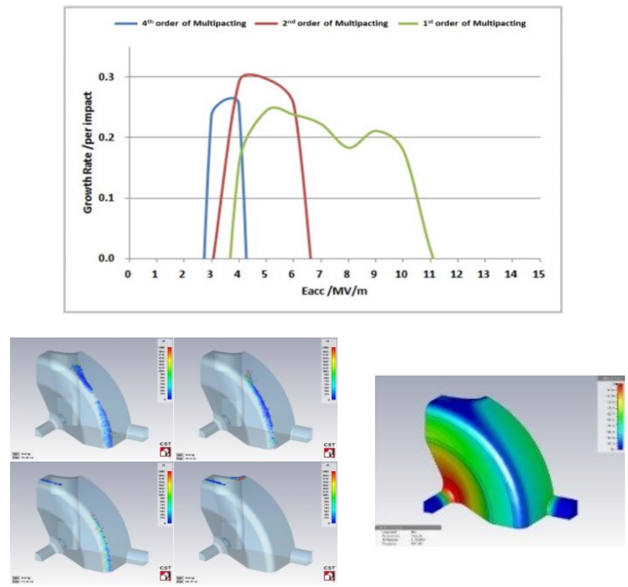

Figure 1: The simulation result of different orders of MP in the PKU-I spoke cavity. The growth rate of secondary electron vs. the gradient (top), and the MP positions (bottom left) with the surface electric field distribution (bottom right).

GEOMETRY OPTIMIZATION

MP suppression in TM mode cavities was achieved by moving from a pillbox to an elliptical geometry. Changing the fillet radius of joint areas appears to be a good choice for suppressing MP.

The first step is changing the fillet radius between the cavity body and the end walls, and keeping the other radius between the cavity body and the spoke bar a small constant, 5 mm. The simulation results are shown in Fig. 2. Increasing the radius makes the span of the 1st order MP barrier 33% narrower, but does not reduce the peak growth rate. It pushes the MP barrier to a lower field level. However, the suppression effect for the 2nd and higher order MP is strong. Increasing the radius pushes these MP barriers to the lower field level, which is similar with that of the 1st order. It not only makes the span 70% less, but also decreases the peak by 85%. Summarily, increasing fillet radius of outer conductor is very effective

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to suppress the higher order MP, but only pushes the 1st order barrier to a lower field level.

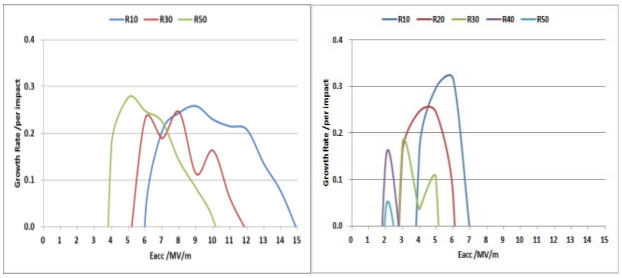

Figure 2: The growth rates of the 1st order (left) and the 2nd order (right) vary with the outer fillet radius changing.

The second step is changing the inner radius, and keeping the outer one as 5mm. The simulation results are shown in Fig. 3. Only the 1st order MP exists at this region. Decreasing radius makes the 1st order MP barrier 30% narrower and the peak growth rate 33% lower.

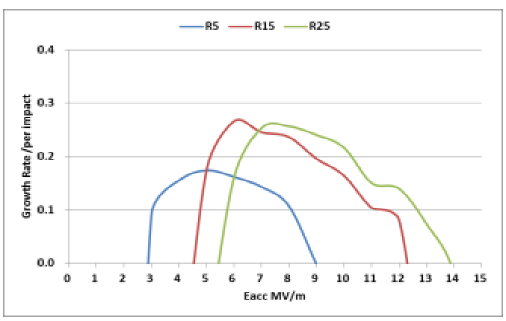

Figure 3: The growth rates of the 1st order as a function of the inner fillet radius.

Combining the preceding results, a short conclusion is obtained. Increasing the outer fillet radius while decreasing the inner radius will push the MP barriers to lower gradient regions, and result in MP suppression, especially for the higher order MPs. Naturally, the maximum radius for the outer fillet and zero radius for the inner one is considered to be the optimized geometry.

OPTIMIZED GEOMETRY

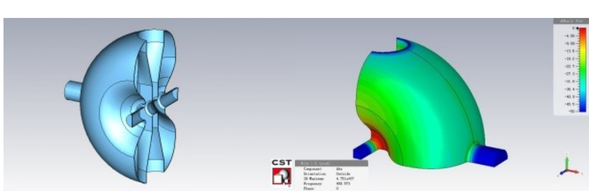

Figure 4: Cross section model of the balloon cavity and its surface electric field distribution.

Based on the above analysis, the optimized geometry is shown in Fig. 4, with the surface electric field distribution. In all cases the dimensions of the spoke bar and the accelerating gaps are the same as the PKU-I spoke cavity. The cavity body looks like an elliptical re-entrant cavity. All the curves of the balloon areas are chosen as circular arcs. The comparison of RF parameters between PKU-I spoke cavity and balloon cavity are listed in Table 1. Most parameters are comparable, but R/Q_0 of the balloon cavity is 10% higher.

Table 1: The Comparison of RF Parameters.

Parameters	Unit	PKU-I Spoke Cavity	Balloon Cavity
E_p/E_{acc}	1	4.1	4.2
B_p/E_{acc}	mT/(MV/m)	7.8	7.4
R/Q_0	Ω	179	200
G	Ω	73	73

The simulation results of MP of the balloon cavity of both CST and ACE3P codes are shown in Fig. 5. In the CST result, the span of MP barriers is 2 MV/m, at the accelerating gradient from 1 MV/m to 3 MV/m, which avoids the operational gradient. The peak of the growth rate is 30% lower than that of PKU-I cavity for the 1st order MP, and 70% lower for the higher orders. The balloon variant has a good suppression effect of MP. The result is cross checked with ACE3P code. The impacting energy of secondary electrons for a niobium cavity is from 50 eV to 2 keV. ACE3P gives the similar result with CST. All stable trajectories appear around the gradient from 1 MV/m to 3 MV/m. The lower order resonance has the broader impacting energy region in the plot. Around the typical operational gradient of spoke cavities, there is no MP barrier.

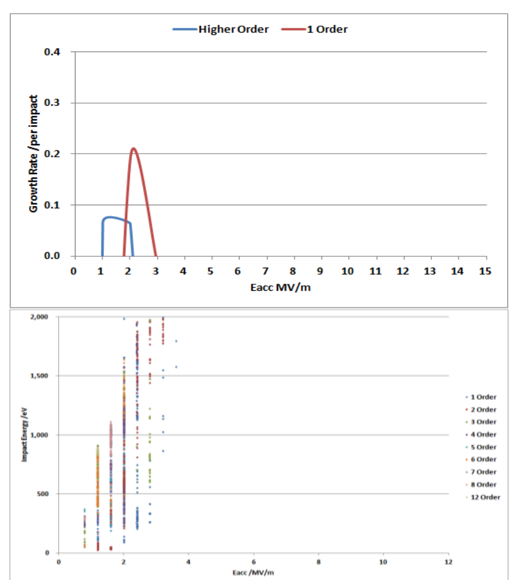

Figure 5: MP results of the balloon cavity with CST (top) and ACE3P (bottom) codes

DISCUSSION

The 1st order MPs appear at the high magnetic field region and Fig. 1 shows it is close to the end wall in the beam direction and nearby the spoke base in the coupler direction, both corresponding to the local minimal electric field region. The amplitude of electric field in these regions is characteristically low and provides suitable energy for the secondary electron resonance. For each electron energy, there is a magnetic field condition to bend the electron and support resonant discharge. The particular cavity geometry will determine the local magnetic field. Therefor changing the fillet radius (the surface magnetic field) will affect the multipacting strength. Fig. 6 shows that modifying the fillet radius will change the position of the minimal electric field point, and the local magnetic field of MP position will also change. So increasing the fillet radius of the outer conductor will push the MP position to a higher magnetic field region. On the growth rate and gradient plot, the MP barriers will be pushed to lower field levels. Correspondingly decreasing the fillet radius of the inner conductor will push MP to a lower gradient. This will also explain why the spoke cavity usually has wide MP barriers. If the maximal outer radius and minimal inner radius is chosen, the green dot curve in the left plot of Fig. 6, the MP position will be at the highest magnetic field region and MP will be pushed to the lowest gradient level. On the other hand, in this condition, the right angle will change the phase conditions of resonance. Both of them will suppress MPs.

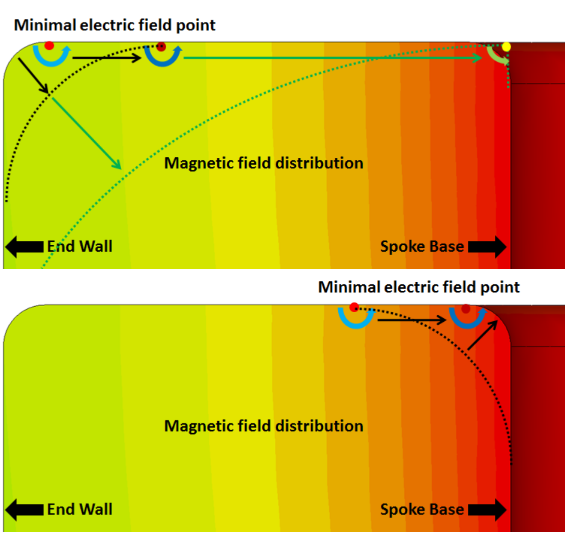

Figure 6: The 1st order MP position with various fillet radius and local magnetic field. The Cross section of beam direction (top) and coupler direction (bottom).

Considering the higher order MP, it occurs at the joint area between the end wall and the cavity body. Fig. 7 shows that increasing the fillet radius of this region will remove the zero surface electric field area in this region. If secondary electrons come out of the inner surface of cavity, they will go towards the zero surface electric field areas around the spoke base, which has different field and phase conditions for higher order MP. The higher order MP can't maintain the resonance or switch to the 1st order MP. It is similar to the MP suppression in elliptical cavities.

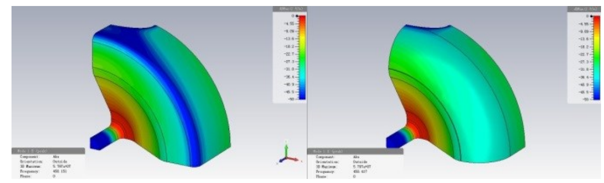

Figure 7: The surface electric field distributions depend on the fillet radius. The field scale is same.

CONCLUSION

This paper systematically studied the relationship between the geometry and the multipacting performance of a single spoke cavity based on the PKU-I cavity. It shows the fillet radius of the joint area will change the multipacting performance. A brief explanation is discussed. The variations of the local RF field magnitude and the phase condition of the secondary electron resonance cause the differences in multipacting performance. Finally, a new variant of single spoke cavity, the balloon cavity, is proposed. It has good multipacting properties, and comparable RF parameters with traditional spoke cavities.

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