Study of multipacting effect in superconducting cavity *

ZHANG Meng(张猛) ZHAO Ming-Hua(赵明华)1)

(Shanghai Institute of Applied Physics, CAS, Shanghai 201800, China)

Abstract A number of superconducting cavities of axis-symmetric geometry have been considered to study the effect in order to achieve the desired performance. It is shown that the multipacting effect is strongly dependent on the condition of the RF surface and can be suppressed with reconsideration of the geometry. The simulation result is compared with the result of the semi-analytical model in the end.

Key words multipacting, superconducting cavity, FishPact, geometry, enhanced counter function

PACS 29.20.-C

1 Introduction

Multipacting (MP) is an undesired, resonant build-up of electrons inside RF-structures operated under vacuum. Electrons can be released from an RF surface due to the surface electromagnetic field or other processes. If they return to the surface close to their origin in an integer number of RF-periods, with energies where the secondary emission yield of the RF-surface material is larger than unity, an electron cascade will build up that disrupts the operation of the structure. This disruption can be in the form of damage to the surface and/or due to absorption of an increasingly significant amount of RF power that becomes unavailable for its original purpose.

To study the multipacting effect, a number of superconducting cavities (SCs) of axis-symmetric geometry have been considered. It is shown that the multipacting effect is strongly dependent on the condition of the RF surface and reconsideration of the geometry can suppress this undesired effect. Finally, the predictions are compared with the results of the semi-analytical model. This study of the multipacting is based on 500 MHz π mode SCs and can also be applied to other frequencies[1].

2 Guidelines on simulation

The parameterization described in Ref. [2] allows us to finely control each aspect of the cavity performances in terms of one, or at most two, geometrical parameters, as shown in Fig. 1. The tuning of the cell to the right frequency is then performed by varying the cell radius D without changing any of the other independent parameters (namely, R, r, d, α, R_{iris} and L). The tuning program of the SUPERFISH is applied to accomplish this frequency adjustment[3].

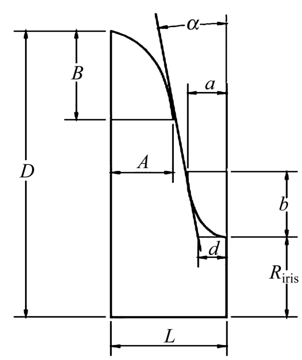

Fig. 1. Cavity shape parameterization.

To study the relationship between these parameters and the multipacting effect which happens in the cavity, a multipacting simulation code FishPact[4] developed by GenFa Wu is used to estimate the multipacting risk for the whole cavity. FishPact uses the established, well-maintained and widely available SUPERFISH code as the field solver to provide the electromagnetic fields in an RF cavity for electron trajectory tracking. The tracking code adopts the plain fourth order Runge-Kutta algorithm. For the multipacting part of the code, traditional counter functions

Received 18 December 2007
* Supported by SSRF Project
1) E-mail: zhaominghua@sinap.ac.cn

(CF) and enhanced counter functions (ECF) are calculated through the user-defined secondary electron yield coefficient for niobium, which depends on the impact momentum of electron.

Due to the axis-symmetric geometry of the cavity, we only need to calculate a quarter of the cavity length except for the beam tube. In FishPact, we set electron evenly distributed along the wall every 5 degrees in phase circle with constant energy 2 eV. If an electron is still alive after 10 processes, it is defined as a possible multipacting condition.

3 MP responses to surface material

The secondary emission yield (SEY) model is adopted from Ref. [5] and formula (1) is used for 90-degree impact.

$$\delta_{\rm s}=\delta_{\rm max}\frac{s\times\left(\dfrac{E_{\rm p}}{E_{\rm max}}\right)}{s-1+\left(\dfrac{E_{\rm p}}{E_{\rm max}}\right)^2}\ . \tag{1}$$

$\delta_{\rm max}$ is the maximum SEY. $E_{\rm max}$ is the impact energy corresponding to the maximum $\delta_{\rm max}$. $E_{\rm p}$ is electron impact energy in eV. s is a fitting parameter.

In the simulation, we keep the cavity geometry unchanged at first, and only vary the SEY.

As shown in Fig. 2, smaller values of $\delta_{\rm max}$ achieve better multipacting suppression. In practice, however, the adsorbates of the cavity surface may have much larger $\delta_{\rm max}$. Meanwhile, from the formula (1), the larger $\delta_{\rm max}$ implies larger scale corresponding the SEY which larger than unity. These factors may induce the multipacting effect even worse.

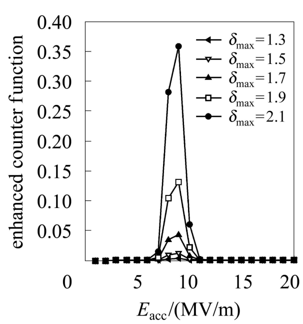

Fig. 2. ECF as a function of the field to different $\delta_{\rm max}$.

4 MP dependences on geometry of the cavity

As a free parameter for the electromagnetic π mode design, the equator aspect ratio $R=A/B$ is a critical factor to suppress the multipacting effect. It indicates that applying bigger R can be beneficial to suppress the multipacting effect, as shown in Fig. 3. However, R has an impact on the mechanical performances of the cavity[2] and we must strike a balance when we make a decision.

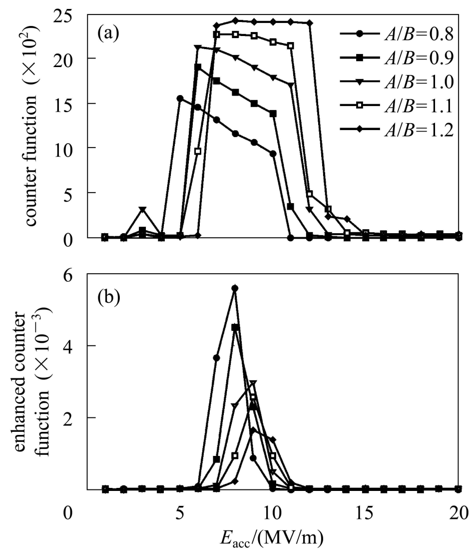

Fig. 3. CF and ECF as a function of the field to different equator aspect ratio, $R=A/B$.

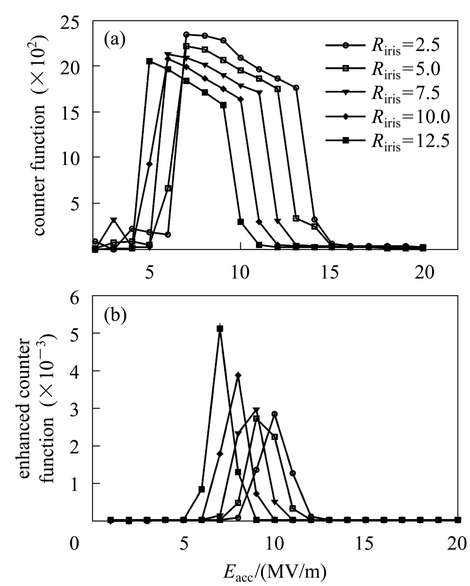

Fig. 4. CF and ECF as a function of the field to different $R_{\rm iris}$.

Smaller values of $R_{\rm iris}$ achieve better multipacting performance, Fig. 4 gives this relationship. In practice, however, the choice of the $R_{\rm iris}$ needs to be balanced with the cell-to-cell coupling and the beam line aperture requirement.

No obvious changes can be seen from Fig. 5, in which ECF is given as a function of the field to different wall inclination angle α and different iris aspect ratio, $r=a/b$. As the wall angle α constrains to the fabrication and cavity treatment and iris aspect ratio is used to minimize the peak electric field, we can look over the influence of this small effect over the multipacting effect.

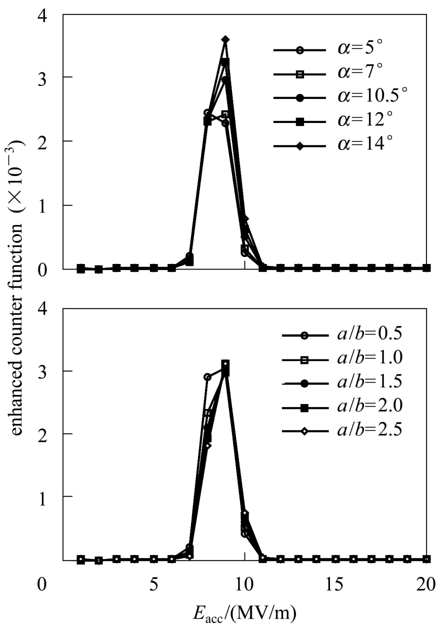

Fig. 5. ECF as a function of the field to different wall inclination angle α and different iris aspect ratio, $r=a/b$.

In conclusion, the multipacting effect in superconducting cavities can be well suppressed by changing the geometry. However, the electromagnetic and mechanical performances should also be taken into account when we choose to optimize the multipacting effect.

5 Comparison with semi-analytical method

During the multipacting process, the typical electron trajectory is constrained to very small size compared with the cavity dimensions, as shown in the left column of Fig. 6. So the semi-analytical method[6] can also be applied to describe this process. In our computation, the distance between the equator and the initial point is 74 μm and the electron emitted from this point at 70° when the accelerating field is 9 MV/m. Using numerical approach to solving the equations of motion, we can get the trajectory of the electron shown in the right column of Fig. 6.

The simulated result of the electron from FishPact is in good agreement with the semi-analytical result and the so-called two-point multipacting happens at this condition. The small differences during the process may be introduced by the inaccuracy when we judge the impact position.

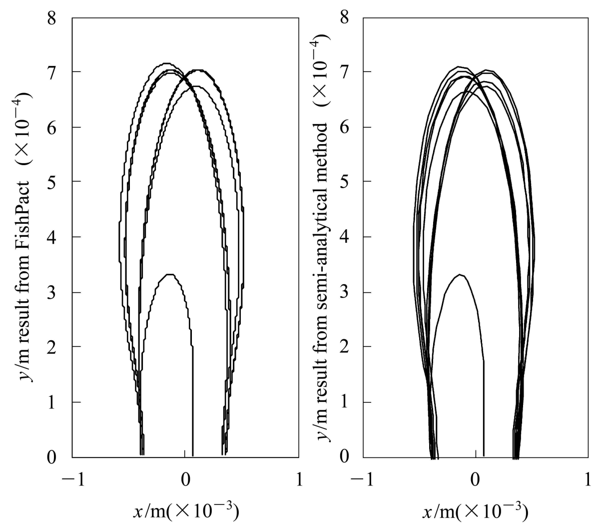

Fig. 6. Comparison of the simulated result with semi-analytical method and result from FishPact.

6 Summary

Multipacting is strongly dependent on the condition of the RF surface, so the cleanness during the fabrication is crucial and effective chemical methods can be useful to get the desired performance. The modification of the geometry is very beneficial to suppress the multipacting effect. Flatter equator ellipse and larger bore radius can get a better multipacting performance. The simulated result is compared with the results of the semi-analytical model in the end and the results agree well with each other.

The authors want to thank Genfa Wu for his kind help during the application of his code FishPact. We are also grateful to our colleagues, Chen Jian-hui and Deng Hai-xiao, for their wonderful suggestions.

References

1 Tückmantel J. One Point Multipacting Levels Determined Without Particle Tracking. In: Proceedings of the 4th Workshop on RF Superconductivity. Japan: Tsukuba, 1989. 569—581

2 Pagani C, Barni D, Bosotti A et al. Design Criteria for Elliptical Cavities. In: Proceedings of the 10th Workshop on RF Superconductivity. Japan: Tsukuba, 2001

3 James H B, Lloyd M Y. Poission Superfish, LA-UR-96-1834. Los Alamos: Los Alamos National Laboratory, 2004

4 http://www.jlab.org/~genfa/fishpact

5 Henrist B, Hilleret N, Jimenez M et al. Secondary Electron Emission Data for the Simulation of Electron Cloud. In: proceedings of ECLOUD'02 Workshop. CERN, 2002

6 Valery Shemelin. Multipacting in Crossed RF Fields near Equator. In: Proceedings of EPAC04. Lucerne, Switzerland, 2004, 1075—1077