MULTIPACTING IN A RECTANGULAR WAVEGUIDE*

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Abstract

Multipacting in the reduced-height waveguide coupler used in CESR III superconducting RF system is studied through numerical and simplified analytical calculations. An improved model for secondary electron emission is developed for numerical calculations. We present in this paper a new method to counter against multipacting by opening slots on broad walls along the center plane of a rectangular waveguide. The simplified analytical approach provides a fast survey of multipacting characteristics for various VSWR's in the waveguide.

1 INTRODUCTION

The rectangular waveguide coupler has been adopted in the normal conducting RF system of PEP-II and superconducting RF system (SRF) of CEBAF and CESR-III (for an excellent review on RF couplers, see Champion [1]). These couplers have been performing well to deliver desired power into charged particle beams. However, when higher power regimes are explored, great care must be exercised to avoid some performance limiting mechanism, among which multipacting is a main culprit.

2 A COMPARATIVE REVIEW

Multipacting in rectangular waveguides emerges as a problem when over 100 kW CW power is required to transfer in high current colliding beam machines at the frequency range of 300-500 MHz [2]. This problem is particularly pronounced in an SRF system because of the enhanced secondary emission coefficient of the cryosorbed gas layers on the coupler inner surface. Other types of waveguides like coaxial lines adopted in RF couplers of LEP-II and KEK-B SRF systems have also been baffled by multipacting. Numerical calculations by Somersalo et. al. [3] have provided tremendous insights for multipacting in coaxial lines. Increasing the line impedance was found very helpful. A DC electric bias technique was developed by Tückmantel et. al. [4]. Coaxial RF couplers in LEP-II and KEK-B have both benefited from this technique and achieved excellent performance [5][6].

Multipacting in hollow rectangular waveguides has not received much attention in the accelerator community. This is not surprise because couplers with rectangular waveguides had been operating far away from multipacting regimes until the installation of the CESR-III SRF system with a reduced-height waveguide in its coupler. The $5'' \times 1''$ waveguide used in CEBAF input coupler operates at a power level of only 5 kW at 1500 MHz. Extrapolating the 100 kW barrier for CESR-III, CEBAF waveguide should be free of multipacting harassment up to a power level of 50 kW, according to the simplified scaling rule[1] $P \propto (f \times d)^4$ by Hatch and Williams [7]. By the same token, the $16'' \times 9''$ waveguide used in PEP-II 476 MHz RF system will not suffer from multipacting until a power level of above 460 kW. The room temperature environment provides further safety enforcement against multipacting for the PEP-II waveguide.

In the CESR-III SRF system, a reduced-height waveguide ($17'' \times 4''$), instead of a full height WR1800 waveguide, is used between the ceramic window and coupler tongue. Moreover, this section is cooled by cryogens, resulting in an enhanced secondary emission coefficient for inner waveguide surfaces. These two factors, the *reduced height* and *enhanced secondary emission coefficient*, are responsible for making this waveguide more prone to multipacting. As remedy measures, RF processing of the coupler and sometimes warming-up of the whole system were resorted to keep a low RF trip rate.

Pursuing more active counter measures, Geng and Padamsee [8] proposed a DC magnetic bias technique. This technique has been implemented in the spare RF modules for CESR-III (see Fig.1). It will be tested after the installation of the spare moudle in 2001. Chojnacki [9] proposed

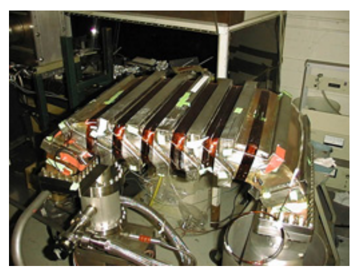

Figure 1: Solenoid coils are installed on the reduced-height elbow waveguide to provide bias magnetic field for suppressing multipacting in the spare RF system for CESR-III.

the wedge-guide concept which is revisited in section 4.3. In this paper, we present a new method to counter against multipacting by opening a slot on broad walls along the center plane of a rectangular waveguide.

3 IMPROVED SIMULATION CODE

The multipacting code developed in [8] is used in this paper with improvement in the following two aspects.

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[1] P is the multipacting onset threshold, f is RF frequency, and d is the narrow dimension of the waveguide.

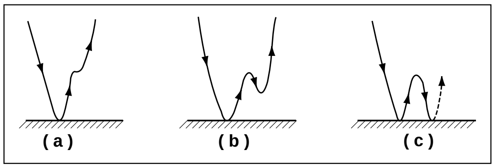

Figure 2: Improved model for secondary electron emission. (a)Emission with an accelerating field. (b)Emission with a decelerating field. (c)A secondary electron experiences an extended period of deceleration after emission. It is driven back to the emission surface and be absorbed there.

First, a more realistic model for secondary electron emission is implemented. In previous models, secondary electron emission is prohibited if the electric field has a decelerating polarization at the time of emission. In the improved model, secondary electrons are allowed to emit regardless of the electric field polarization. Because secondary electrons are born with a finite amount of kinetic energy (2-5 eV), even those emitted with a decelerating field have a chance to run away from the surface (see Fig.2). However, if a secondary electron experiences an extended period of deceleration after emission, it will be driven back to the emission surface and be absorbed there.

Secondly, new secondary electron emission coefficient data by Bojko, Hilleret, and Scheuerlein [10] are incorporated to reflect the nature of the waveguide surface, which is Copper plated Stainless Steel with vacuum baking at 200 °C. The new secondary emission coefficient values are noticeably higher.

With these two improvements, the multipacting bands become broader and stronger (band positions are the same as that predicted by the previous model [8]). Fig.3 shows the multipacting bands for the CESR-III reduced-height waveguide operated in the traveling wave mode.

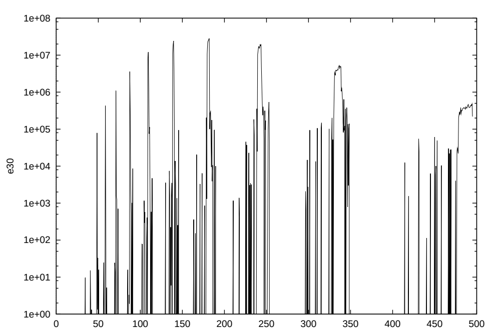

Figure 3: Multipacting bands of the CESR-III reduced-height waveguide in the traveling wave mode. The order of the band near 100 kW is 21.

4 COUNTER MEASURES

To fight against multipacting in the waveguide, more active counter measures than *in situ* RF processing are needed. Here are a few examples for this purpose.

4.1 DC Magnetic Bias

The DC magnetic field bias technique was proposed by Geng and Padamsee [8] and has been implemented in the spare RF module for CESR-III. The effectiveness of this concept is borne out again from the repeated simulations with the improved numerical code.

4.2 Opening Slot on Broad Walls

Here we present a new concept - a waveguide structure that is free of multipacting by design. The idea is to open a slot on the broad wall along the center plane of the waveguide. The slot is narrow enough that no RF field is leaking into it. Fig.4 shows the multipacting bands of a reduced-height waveguide with a slot opened up on its top wall. The slot has a dimension of 5mm in width and 5 mm in depth. As we can see, multipacting is suppressed to a great extent. This concept works by letting electrons drift in a field free region and hence provides a perturbation to resonance.

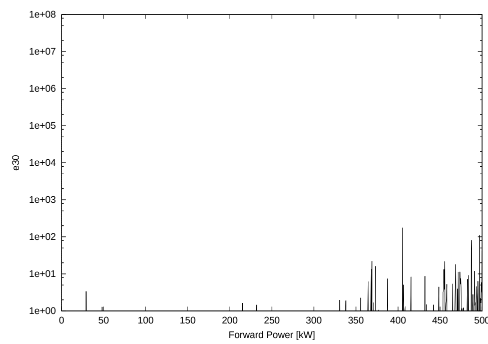

Figure 4: Multipacting bands of a slotted CESR-III reduced-height waveguide in the traveling wave mode.

The slot can be further made to have a 45° tilted ceiling as illustrated in Fig.5. According to the cosine law for secondary electron emission, those excited by residual mul-

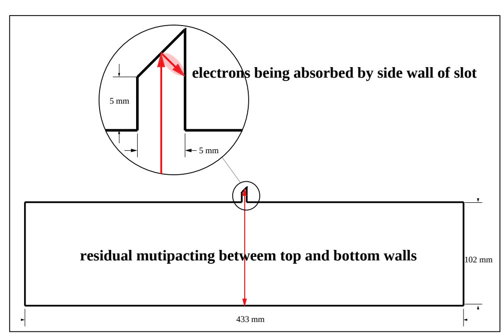

Figure 5: Suppressing multipacting by opening a slot on the top wall along the center plane. Titling the ceiling of the slot by 45° provides further suppression by deviating the residual secondary electrons to the side wall of the slot.

tipacting electrons will be deviated to the side wall of the slot and then be absorbed there, thus providing further multipacting suppression. In practice, cleaning the slot may be difficult, but can be taken care of by new cleaning techniques, such as High Pressure Water Rinsing.

4.3 Revisit the Wedge-Guide Concept

The wedge-guide concept proposed by Chojnacki [9] is revisited in this paper. Fig.6 shows the multipacting bands of a wedge-guide with a 5° tilting angle of the top wall with respect to the bottom wall. As we can see, multipacting is still quite appreciable. We found that even the tilting angle is increased to 13.2°, the wedge-guide concept is still less effective in suppressing multipacting than the DC magnetic bias technique.

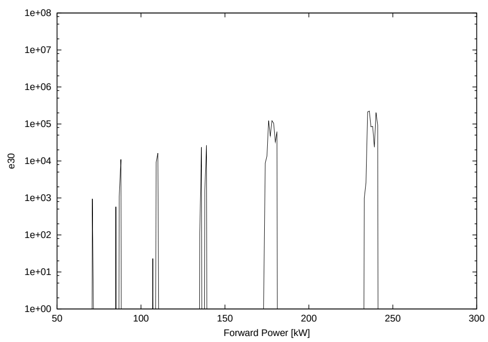

Figure 6: Multipacting bands of a wedge-shaped waveguide with a tilting angle of 5° of its top wall.

5 MULTIPACTING MAPS

For operational purposes, RF input couplers usually work in a mode that part of the input power is reflected. Multipacting bands will shift as a result of reflected power. For diagnostic purposes, a multipacting map, multipacting susceptibility as a function of input power and power reflection ratio, is usually very helpful. Fig.7 shows such a map for the CESR-III reduced-height waveguide for the input power range from 250 kW to 350 kW. Both simulations and the past experience from CESR-III indicated that the multipacting susceptible region shown in Fig.7 is a rather hard barrier.

Neglecting the effect of RF magnetic fields, a simplified analytical approach has been developed, which gives results agreeing well with numerical results (for more details see Shemelin [11]). The analytical approach is very efficient in drawing a multipacting map, as shown in Fig.8.

6 CONCLUDING REMARKS

Multipacting in a rectangular waveguide can be an annoying or even limiting problem when multi-hundred kW power is required. Great care should be exercised in order

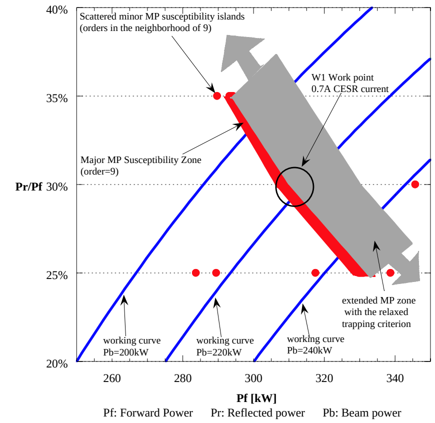

Figure 7: Multipacting susceptibility of the reduced-height waveguide for input power range from 250kW to 350kW.

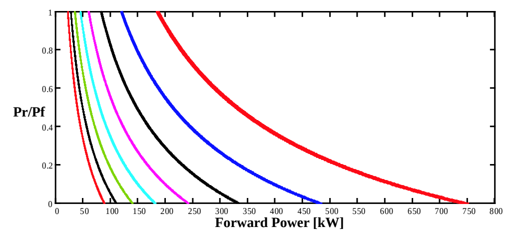

Figure 8: Multipacting susceptibility for an extended input power range, provided by the analytical approach.

to have a waveguide structure that is free of multipacting by design. In this paper, the slotted waveguide concept is presented for this purpose. In case multipacting is encountered in the post-design stage, active counter measures, such as the DC magnetic bias technique, should be implemented to fight against this problem. A better designed waveguide geometry and effective multipacting suppression measure will not only reduce the time for excessive RF processing but also guarantee better coupler performance at higher power levels.

7 REFERENCES

[1] M.S. Champion, 7^{th} RFSC [12], 1995, P. 195.

[2] S. Belmoestnykh, PAC [13], 1999, P. 272.

[3] E. Somersalo et. al., PAC [13], 1995, P. 1500.

[4] J. Tückmantel et. al., PAC [13], 1995, P. 1642.

[5] P. Brown et. al., 9^{th} RFSC [12], 1999, P.1.

[6] T. Furuya et. al., 9^{th} RFSC [12], 1999, P.31.

[7] A.J. Hatch and H.B. Williams, Phys. Rev., 112(3), 681(1958).

[8] R.L. Geng and H. Padasmee, PAC [13], 1999, P. 429.

[9] E. Chojnacki, Phys. Rev. ST Accel. Beams 3, 032001 (2000).

[10] I. Bojko, N. Hilleret, and C. Scheuerlein, J. Vac. Sci. Technol. A 18(3), 972(2000).

[11] V. Shemelin, LNS Report, SRF-010322-03, Cornell Univ..

[12] Workshop on RF Superconductivity Proceedings.

[13] Proceedings of Particle Accelerator Conference.