MULTIPACTING SIMULATION IN ISAC-II SUPERCONDUCTING CAVITIES

M.A. Gusarova, M.V. Lalayan, N.P. Sobenin, Moscow Engineering Physics Institute (State University), Moscow, Russia
V.L. Zvyagintsev, TRIUMF Canada's National Laboratory for Particle and Nuclear Physics

Abstract

The results of 3D multipacting simulation in coaxial superconducting quarter wave cavities of the heavy ion linear accelerator ISAC-II are presented. The multipacting simulation was done using MultP-M code. Dangerous areas of structure and levels of an accelerating field are revealed. Examples of electrons resonant trajectories are presented. Simulation results are compared with experimental data obtained during several superconducting cavities processing.

INTRODUCTION

Multipactor discharge must be considered while developing new accelerating cavities.

Once appeared it could spoil cavity performance and limit accelerating gradient achieved. Multipactor in superconducting cavities causes surface heating by electron bombardment and finally result in quench, i.e. cavity part falls out of superconducting mode and becomes normal conducting one.

The results of multipactor discharge studies carried out for ISAC-II high beta section superconducting quarter wave cavities are presented.

ANALYTICAL CONSIDERATIONS

Researches were carried out for superconducting (SC) quarter wave cavity developed for ISAC-II accelerator. Cavity is designed for heavy ions at β=0.11. Operational frequency is 141.4 MHz. Accelerating gradient goal is 6 MV/m [1].

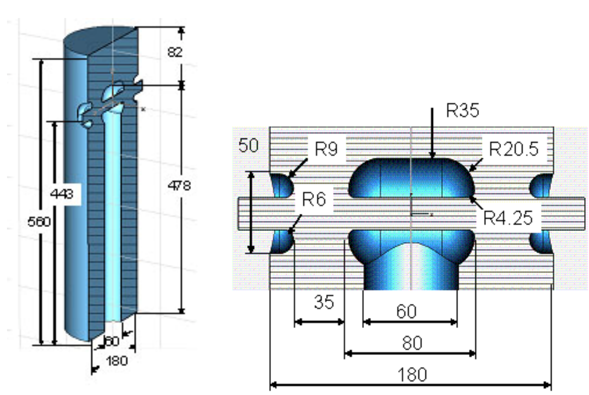


Figure 1: Quarter wave superconducting cavity for ISAC-II ("donut cavity"-type).

First approach to multipactor studies was made using analytical equations obtained for discharge between two planes case [2]:

$$fd = \frac{1}{2\sqrt{\pi}}\sqrt{\frac{qV}{m}} \quad (1) \qquad E_a = \frac{V_a T_o}{D} \quad (2)$$

where f – frequency, q and m – electron charge and mass, d – gap between planes, V – peak gap voltage, Va – peak RF voltage across the cavity acceleration gaps, Ea – acceleration gradient, To=0.936 – transient time factor for optimum velocity β=0.11, D=0.18 m – conventional accelerating length, which is the cavity diameter.

Using these formulas the E_a values providing resonant conditions for multipactor were defined. The following cavity areas were considered: region between outer conductor and donut, coaxial line and space between donut and cavity end cap. Data obtained for these regions of the cavity are presented in Table 1. The simplified model is applicable as the initial approximation for these regions because magnetic field strength is negligible compared to electric one.

Table 1: Multipactor Discharge Parameters for Superconducting ISAC-II High Beta Cavity

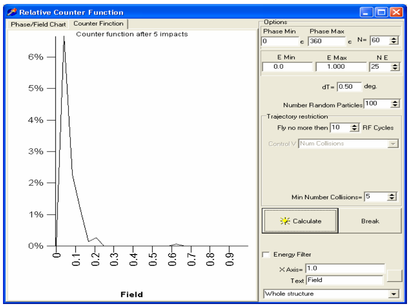
Analytical Calculations		Simulation by MultP-M code		Meas-ured
E_a, kV/m	**Cavity region**	**E_a, Kv/m**	**Cavity region**	**E_a, kV/m**
18. 2	accelerating gap	12.0 – 26.0	accelerating gap, donut – coax outer conductor	10 – 24
45.0	donut – coax outer conductor	27.0 – 33.0	donut – coax outer conductor	28 – 33
53.6	coax line	35.0 – 54.0	coax line donut – end cap	42 – 50
107.5	donut – end cap	58.0 – 193.0	donut – end cap	77 – 80

NUMERIC SIMULATION

Numeric simulation of multipactor in the accelerating cavity was made using MultP-M code [3]. The cavity model was created with secondary electron emission dependence for niobium and imported from CST Microwave Studio electromagnetic field distribution.

First the dangerous field strength levels were defined by making series of simulations for different field strength ranges.

Simulation made for acceleration gradient Ea in the range from 0 to 3866 kV/m showed that the electron resonant trajectories could be found at Ea from 2.7 to 2320 kV/m (as shown on Fig.2).



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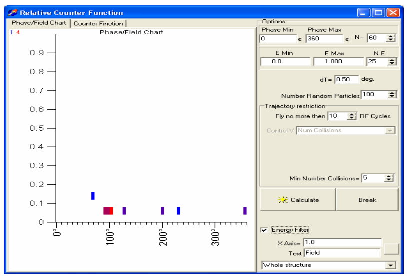

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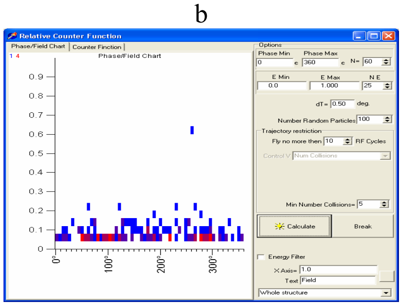

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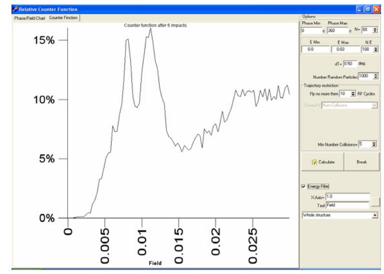
Figure 2: Numeric simulation results for ISAC-II cavity. Broad field strength band. a – Electron Counter Function; b – Phase/field diagram; c – Phase/field diagram+ Energy Filter.

It should be noted that acceleration gradient Ea on diagrams is given in relative units: 1 unit corresponds to accelerating gradient Ea of 3866 kV/m. Gradient and phase step intervals were 81 kV/m and 6^o correspondingly. The simulation was made for 100 initial particles randomly distributed on cavity walls. Peaks seen on Electron Counter function indicate the field strengths providing electron trajectories having more than 5 impacts. Phase/field diagram has the highlighted area where the conditions for resonant trajectories existence are fulfilled.

Multipactor discharge could occur only in case secondary electron emission yield (SEY) exceeds 1. Electron hitting the cavity wall energy range providing SEY>1 for niobium is 50 to 1500 eV. Therefore the phase/field + Energy Filter diagram shows only the trajectories with this criterion satisfied.

More detailed study with lower field step and narrow Ea range 7.73 – 116.00 kV/m showed that there are two distinct peaks and several not so apparent ones found on counter function diagram as seen on Fig.3.



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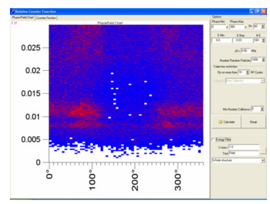

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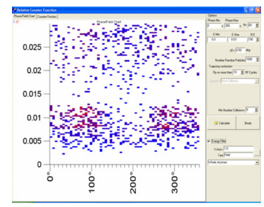

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Figure 3: Numeric simulation results for ISAC-II cavity. Narrow field strength band. a – Electron Counter Function; b – Phase/field diagram; c – Phase/field diagram+ Energy Filter.

Thus the following field levels being dangerous for the sake of multipactor were defined: 12 – 26 kV/m, 27 – 33 kV/m, 35 – 54 kV/m and 58 – 193 kV/m. More thorough study indicated areas where multipactor occurs (Table 1). Several trajectories at high field strength (0.2 to 2 MV/m) were found in coaxial line and drift tube, however they are not so stable.

All the trajectories provide impacting electron energy in 50 to 1500 eV range. Several resonant trajectories for different field strength values are shown on Fig. 4.

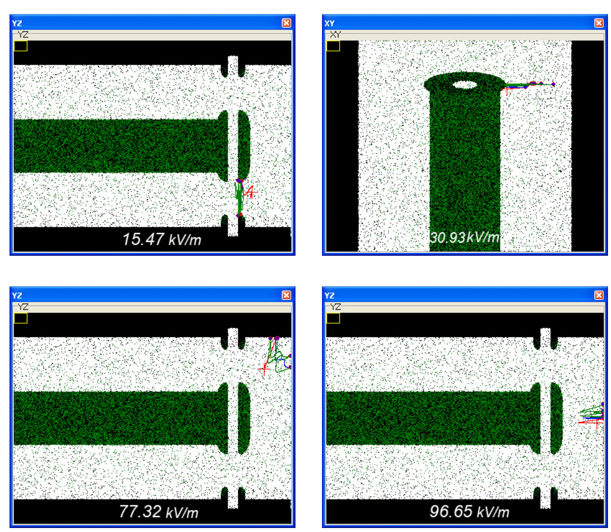

Figure 4: Examples of multipactor electrons resonant trajectories.

Multipactor simulation clearly detected two peaks on Counter Function diagram for field strengths 0.008 (30.93 kV/m) and 0.02 (77.32 kV/m) corresponding to electrons number exponential growth.

For the less distinct peaks at 0.0065 (25.13 kV/m) and 0.012 (46.40 kV/m) there was no such rise detected, however it could be caused by insufficient initial particles number. Fig.5 illustrates the direct modeling results discussed above.

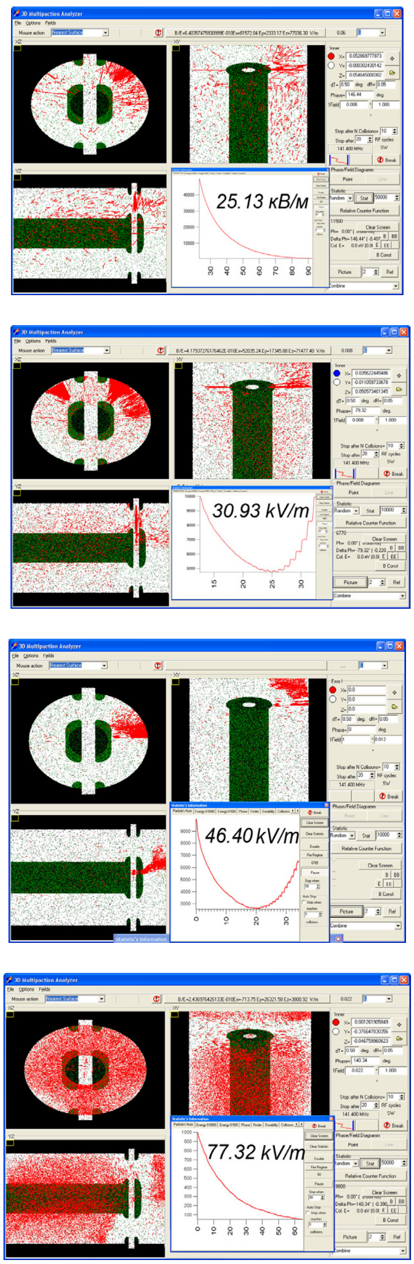

Figure 5: Multipactor direct modeling examples for different field strengths.

EXPERIMENTAL STUDY RESULTS

During ISAC-II High Beta production cavities testing and conditioning at TRIUMF [4], multipactor discharge occurred at field strengths: 10...24 kV/m, 28...33 kV/m, 42...50 kV/m, 77...80 kV/m. It was also noted that the conditioning time for 28...33 and 42...50 kV/m levels exceeded one for 10...24 и 77...80 kV/m. Sometimes we could see some unstable multipactoring events higher 100 kV/m. Cavity was conditioned during cooldown from 300K to 200K. In superconducting state some multipactor levels reappeared creating difficulties for cavity power-on. RF pulse power conditioning vanish multipactor events. It doesn't take long and is relatively easy. It was observed that in ISAC-II high beta QWR cavity multipactor events occur at acceleration gradients much lower than operational one, therefore it doesn't affect on cavity performance. Cavity multipactor conditioning is relatively easy procedure.

CONCLUSIONS

Multipactor discharge numeric simulation results for ISAC-II QWR accelerating cavity are in good concordance with experimental ones. Some deviations are caused by SEY values for especial cavities depending on individual surface features. Results obtained show that multipactor discharge occurs in this cavity at the filed levels significantly lower than 6 MV/m at cavity operation and could not limit the cavity operation. Multipactor hampers the cavity power-on but conditioning eliminates this problem.

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