ESTIMATION OF MULTIPACTING IN CDS STRUCTURE

I.V. Rybakov†, Institute for Nuclear Research of the RAS, Moscow, Russia
I.I. Isaev[1], DESY, Zeuthen, Germany

Abstract

Within the framework of the INR's linac upgrade the Cut Disk Structure (CDS) was recommended for the linac's main part first cavity replacement [1]. The stable cavity work in operation regime requires absence of multipactor discharge. The multipactor phenomenon in a CDS structure studies are presented in this paper.

INTRODUCTION

CDS structure was first applied as a booster cavity in DESY PITZ test facility in Zeuthen [2]. For this cavity according to our analytical estimation multipaction should appear at the operating power level in coupling cells, but it was not confirmed by the numerical simulation with both accelerating and coupling modes excitation for RF energy transfer along the cavity. The multipactor appears only with the Secondary Emission Yield (SEY) growth which could happen if the inner surface of the cavity is polluted. The results of multipactor investigation in CDS PITZ were used as the reference for the CDS structure in the first cavity of the main part of INR linac. The analytical estimation and numerical simulation of multipactor in CDS INR structure shows the appearance of the discharge in coupling cells with the OFC copper SEY for the operating regime of the cavity. An option for the multipactor damping with the forced excitation of oscillations in coupling cell with voltage higher than upper multipactor limit was considered.

METHODICS OF ESTIMATION

The multipactor discharge in CDS cavity could appear in the coupling cell, which is geometrically like a flat capacitor (see Fig. 1).

The field level in the coupling cell depends on the accelerating field rate and position of the cell relative to the RF coupler.

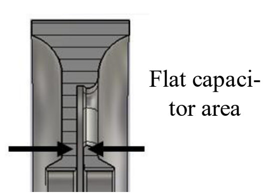

Figure 1: The design of CDS cavity.

For the power transfer through the cavity the coupling mode should be excited additionally [3]. This is the operating regime of compensated structure. The coupling mode is excited with the attenuation coefficient per period *d*:

$$\alpha d = \left(1+\frac{I_b U_a}{P_a}\right)\frac{\pi\beta}{2\beta_g Q_a}\ , \qquad (1)$$

$$\frac{\beta_g}{\beta} = \frac{\pi k_c}{4}\ , \qquad (2)$$

where I_b is the beam current, β_g is the group velocity, β is relative phase velocity, U_a, P_a and Q_a are the accelerating voltage, power and quality factor, k_c is the coupling coefficient. For each cavity cell the αd value multiplies by coefficient N, which depends on the cell position relative to feeding waveguide.

Analytical Estimation

For the coupling cell of the CDS structure the analytical estimation of multipactor voltage level could be obtained using the flat gap approximation [4]:

$$U=4\pi^2 (fs)^2 \frac{m}{e}\left(\frac{1+K_v}{1-K_v}\pi n\cos\psi+2\sin\psi\right)^{-1} \qquad (3)$$

Where f is the cavity operating frequency, s is the gap length, K_v is the relation between secondary and primary electrons velocity, ψ is the secondary electron yield phase and n is the multipactor order. The multipactor voltage levels for different f*s parameters and discharge orders could be represented by a diagram (see Fig. 2).

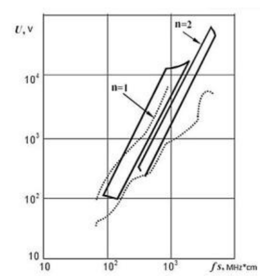

Figure 2: Multipactor voltage levels.

The analytical estimation shows the voltage levels in the gap when the multipaction is possible. We considered only 1st order discharge in case of low current in high order multipactor.

Numerical Simulations

For the numerical simulation of multipacting, the CDS structure was tuned to the secondary electron emission parameters corresponding to pure OFC copper [5]. The secondary emission yield (SEY) graph is shown at Fig. 3. All the simulations were made using the CST studio software [6], the simulation procedure is presented in [7].

† irybakov@inr.ru
[1] on leave from NRNU MEPHi, Moscow, Russia

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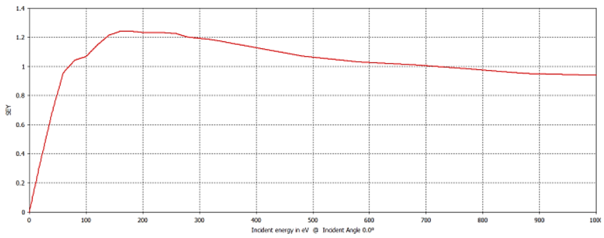


Figure 3: Secondary emission yield for pure OFC copper.

Injection of primary electrons was performed during the first RF field period of simulation. The injector of primary electrons was placed on the total inner surface of the structure.

The output of numerical simulation consists of secondary electrons counter graph, electrons number over time graph, electrons position in the structure over time and electrons energy distribution along transverse axis plots.

PITZ CDS BOOSTER

PITZ CDS booster is designed for electrons acceleration with β=1, k_c=0.08. The designed operational acceleration gradient is up to 14 MV/m [2].

The multipaction in CDS PITZ cavity was observed experimentally at 3.5 – 6.5 MV/m accelerating field rates. The analytical estimation shows the multipactor possibility in CDS PITZ structure at accelerating field rate 6 – 12 MV/m, which corresponds to the operating regime of the cavity but doesn't match the experimental results.

At the first stage of numerical investigation we performed a simulation using structure's accelerating and coupling modes separately. The acceleration rate levels were set from 0 – 14 MV/m. This simulation shows that electrons number is decaying over time at all considered accelerating voltage levels, as it is shown at Fig. 4.

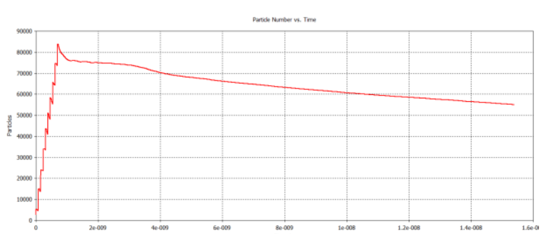
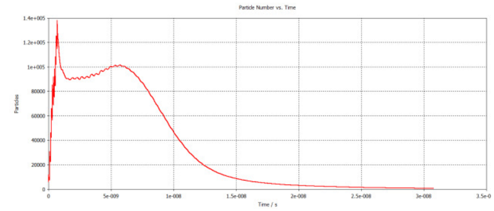
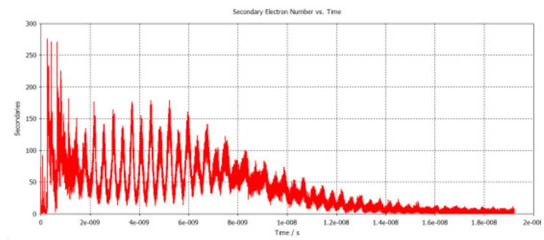


Figure 4: Total particles number over time at acceleration gradient 12 MV/m.

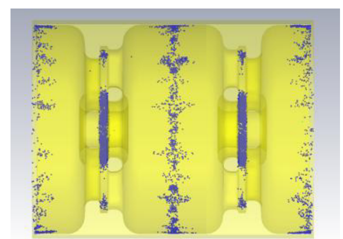
A simulation using the operating regime with accelerating and coupling modes both excited shows that electrons number at accelerating voltage levels 6 - 12 MV/m is growing in the first half-time of simulation with subsequent decaying. Results of this simulation for accelerating rate 12 MV/m are presented at Fig. 5.



a) Total particles number over time.



b) Secondary electrons number over time.



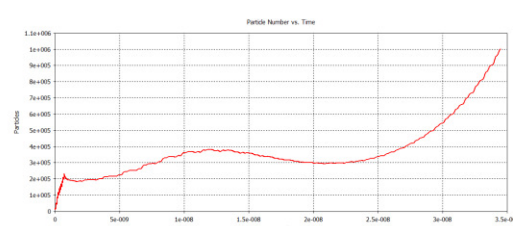
c) Remaining electrons after 25 RF cycles.

Figure 5: Results for accelerating field rate 12 MV/m.

As we can see most of secondary electrons are concentrated in coupling cells. The time distance between secondary emission pikes is ½ of RF period.

CDS PITZ booster operation has shown significant dark current (DC) [8] in the structure. The highest DC intensity has been registered in the three cells near the RF coupler. The numerical simulation shows the multipactor presence in the same cells on accelerating gradients 3.5 – 6.5 MV/m (see Fig. 6). It is a strong indication that both DC and multipactor discharge appearance could be explained as the result of cell's inner surface pollution.

For the numerical simulation with higher SEY the graph of OFC copper was point with factor 1.3.



a) Total particles number over time.

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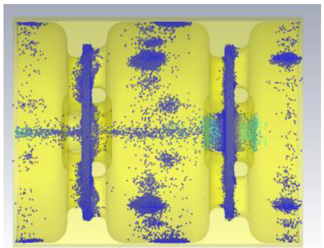


b) Remaining electrons after 25 RF cycles.

Figure 6: Results for accelerating field rate 4.5 MV/m

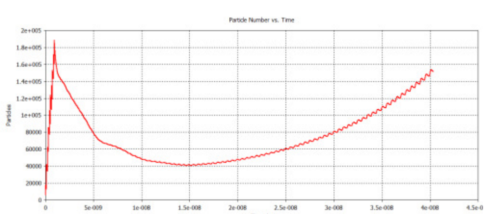
As we can see from Fig. 6b, simulation shows that multipacting electrons reach the acceleration axis. These electrons could provide significant contribution to DC, which is confirmed by the DC increase in the presence of multipactor during the operation of PITZ CDS booster.

INR CDS CAVITY

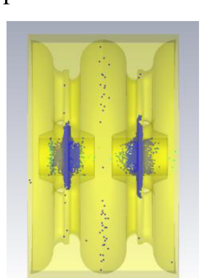
The first cavity of the main part of INR linac is designed for proton acceleration, β=0.4313 – 0.4489 and with significantly lower acceleration gradient 2 – 2.5 MV/m, which causes the shift of multipactor appearance levels.

Results of simulations in CDS PITZ structure were taken as reference for perspective in development structure for INR linac. The analytical estimation predicts the multipactor on accelerating field rates 2 – 2.5 MV/m, which are operating for INR linac. The first cavity of the main part consists of 4 sections with 18 – 21 CDS periods in each. The feeding waveguide is placed in sections 2 and 3. In this case the coupling mode field level in sections 1 and 4 is lower in operating regime and may produce conditions for multipactor discharge.

The results of numerical simulation for this structure are matching with analytical estimation. Multipaction appears on accelerating field levels 2 – 2.5 MV/m in coupling cells with 10*αd – 15*αd attenuation coefficient, which corresponds to cavity sections 1 and 4 (see Fig. 7).



a) Total particles number over time



b) Remaining electrons after 25 RF cycles.

Figure 7: Results for 2.5 MV/m accelerating voltage.

In case of multipaction appearance on operating field levels an option of its damping was considered [9]. It is based on forced excitation of oscillations in coupling cell with voltage higher than upper multipactor limit. For CDS INR it is 1.9 kV. To provide this voltage the frequency of nearby accelerating cells are shifted opposite to each other. The drift tube in first cell is lingered and shortened in the next. The necessary frequency shift was obtained using the equivalent circuits method:

$$\Delta\omega = \frac{k * k_c * \omega_0}{4} \qquad (4)$$

Where k is voltage multiplication factor, ω_0 is operating frequency. For CDS INR structure the frequency shift is 800 kHz. The numerical simulation with the frequency shift applied shows no multipacting on operating acceleration rate. By the application of the drift tube shift the loss in Z_e is 0.5% and <1% in Q factor.

SUMMARY

In this paper the estimation of multipacting in CDS structure is considered. For CDS PITZ structure an analytical estimation and numerical simulations were provided. The results of simulation with high SEY coefficient are matching with experimental results.

For CDS INR structure the results obtained shows the multipaction possibility on the operating field levels. In this case a method of multipactor damping was considered. The efficiency of the method was shown for CDS INR structure.

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