# STUDYING OF MULTIPACTING IN MICRO-PULSE ELECTRON GUN*

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*Abstract*

Depending on the complexity of multipacting phenomenon, more works are focused on the occurrence of multipacting in the micro-pulse electron gun. In this paper, the multipacting resonance condition is determined in a reentrant cavity model of the gun. The resonance parameters work as the input for VORPAL simulations in order to achieve a steady state saturation in the cavity. The simulation results showed that the gun can give rise to electron beams with high currents and short pulses.

## INTRODUCTION

To meet the FEL as well as the high energy accelerators specification, the electron beams of injectors with high currents and short pulses are required. The advent of R-F guns together with photocathodes is expected to have a promised achievement in the injector field. In 1993, Mako firstly developed a novel concept by making use of multipacting effects [1], and the concept is about a kind of electron gun known as micro-pulse electron gun (MPG) that can be initiated with a single electron and resonantly amplified to saturation inside a vacuum RF cavity. Comparing to the RF guns and photocathodes, MPG not only give rise to electron beams with high currents and short pulses [2], but it has a simpler structure.

The primary focus of MPG studying is the multipacting effect due to its great impact on the performance of MPG. The multipacting resonance parameters are calculated by a novel method proposed in our recent work [4]. These resonance parameters work well in the codes, such as MultiPac and VORPAL. Under the condition of resonance, steady state saturation has been achieved in 3-D simulations, and the simulation results showed that the gun can give rise to electrons beam with high linear current density and short pulses, which is 40A and 20ps, respectively. More details of simulations are presented below in this paper.

## RESONANCE CONDITION FOR THE MICRO-PULSE ELECTRON GUN

The micro-pulse electron gun is one kind of microwave gun that employs secondary electrons which resonantly amplify in a RF cavity to produce micro-pulses [3]. A number of initial electrons, which emit off one side (as shown in Fig. 1), transit the cavity under the work of RF field, and finally they strike the other side in odd multiple of half period and generate secondary electrons at the same time. For designing of MPG, it is important to calculate the multipacting resonance parameters which ensure the occurrence of steady state saturation.

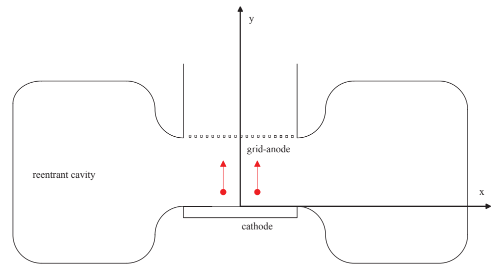


Figure 1: The reentrant cavity of micro-pulse electron gun.

### *Design parameters for the gun*

In our recent article [4], a novel method used to figure out the multipacting resonance parameters is proposed, and this method is available in our gun design. Based on the demand of high energy accelerators, a target impact energy is firstly chose, then by using the basis electron motion equations, the resonance parameters are calculated as shown in Table 1.

Table 1: Basic Design Parameters

| **Parameters** | **Values** |
|---|---|
| Cathode/Anode Material | MgO |
| Frequency | 2.856 GHz |
| Impact Energy | 45 KeV |
| Gap Distance D | 12 mm |
| $V_{rf0}$/D | 6.5 MV/m |
| Transmission Factor | 50% |

The structure of cavity is carefully picked as shown in Fig. 1, though it is not necessary in our multipacting researches. This kind of geometry of outer walls can be adjusted to maximize Q value. More importantly, it is clear that the reentrant cavity can give rise to higher beam quality than the parallel plates cavity, which had been observed in our simulations. One reason for the phenomenon is that the out-of-phase electrons will be omitted automatically in the processing of multipacting, because of the radical defocusing of RF field in the cavity. The disadvantage of escaping of electrons from axis to outer walls is the multipacting effect in the copper outer walls, which would be in the form of thermal damage and RF power consumption in the surface. In the future, more work should focus on it.

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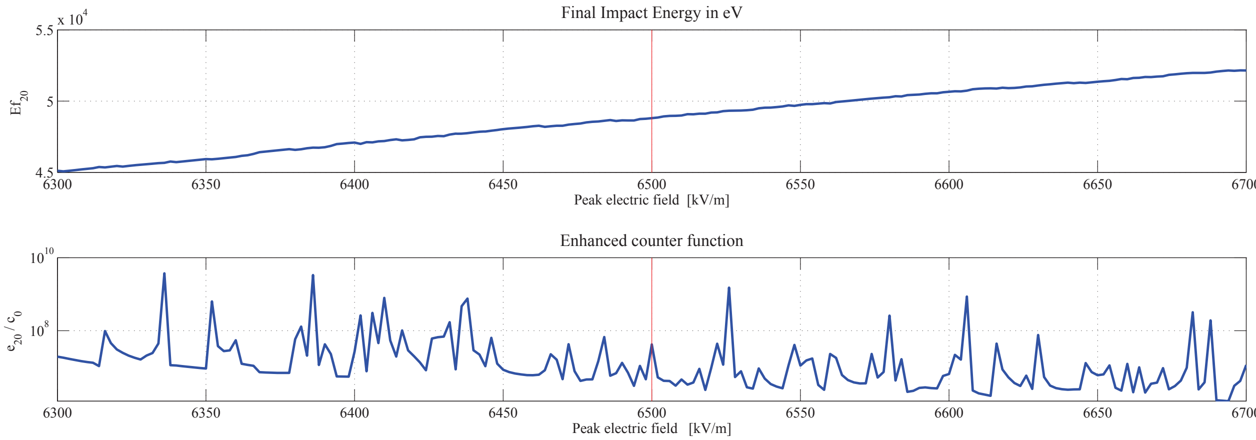


Figure 2: MultiPac simulation results. (above)Average impact energy in eV after 20 impacts; (below)Enhance function after 20 impacts, note that multipacting occurs only when the enhanced function is greater than one. MultiPac neglects the space charge effect.

### *MultiPac code is used for confirming the resonance phenomenon*

It is convenient to calculate the resonance parameters by using electron motion equations, then more works should focus on simulations in order to find a better resonance condition because of the error caused during the process of numerical calculation. MultiPac [5], a 2D multipacting code with known secondary emission properties, is proposed to confirm the resonance phenomenon. As gap distance D and RF electric field $V_{rf0}$ have been calculated, scanning an extensive electric field zone in MultiPac is suggested here in order to find a proper resonance condition, and Fig. 2 shows the simulation results.

It is clear that multipacting occurs around 6.5 MV/m electric field, and at that point the average impact energy equals to 48.5KeV, which found to be a litter higher than the expected impact energy. The phase map as shown in Fig. 3 indicates the resonance phase at 6.5 MV/m. Combing with the MultiPac results, the proper running parameters for the gun is determined, and these parameters work as the input in our further simulations.

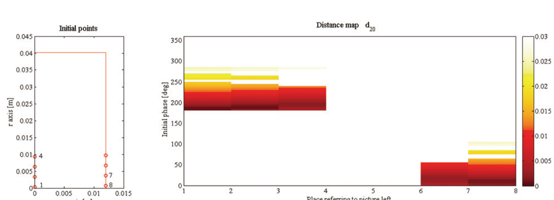


Figure 3: (right)The vertical axis is the resonance phase in degrees and the horizontal axis is the initial points referring to picture in the left, the dark band in figure indicates the possible multipacting electrons.

## SIMULATIONS OF MICRO-PULSE ELECTRON GUN

Modeling multipacting to steady state saturation is of interest in determining the performance of MPG. In the case of the complexity of multipacting effects, more work should focus on it. A VORPAL code which allowing the study of effects of multipacting in vacuum devices [6-7] is used. Table 1 shows the basic parameters for VORPAL simulations. At the beginning, a sinusoidal RF voltage has been motivated in the cavity, a group of electrons have been loaded ten periods later in order to synchronize with the electric field.

The electrons emit from the cathode and hit the grid-anode a half of period later, and the process of grid-hitting can't be directly observed before saturation, but it exactly showed as a sub-peak of curve after saturation in Fig. 4. The steady state saturation, which is demanded for the running of MPG, has occurred in the gun.

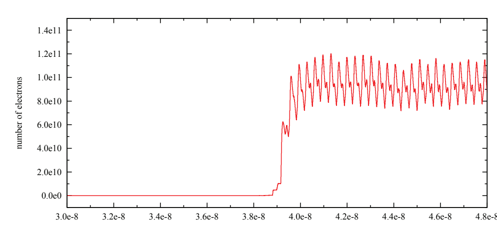


Figure 4: Number of physical electrons as a function of time in 2-D simulation, steady state saturation has occurred in the gun.

The Fig. 5 shows the current plotted as a function of time, and the current that monitored outside of the cavity saturates at about 40 A. Along with the increase of currents, bunching structures and choppers become less efficient and more difficult to design [8]. One advantage of MPG is that it can produce a prebunched electron beam before injected

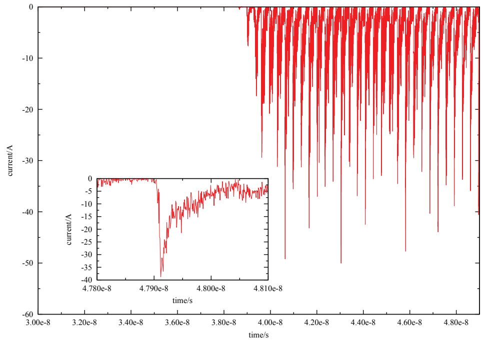


Figure 5: The time history of currents monitored by a sheet behind the grid-anode. The subgraph shows the beam pulse width in details. The time interval between any two peaks is one period.

into accelerating tube. The simulation results showed that the beam pulse width equals to 20ps as shown in the subgraph of Fig. 5, which is 5.7% of the period of running frequency. In addition, because the transit time from one electrode to another is one-half period, the time interval between any two peaks in Fig. 5 is one period.

## SUMMARY

In this paper, a comprehensive analytical study has been taken about the effect of multipacting in micro-pulse electron gun with the combination of MultiPac and VORPAL simulations. The basic parameters for cavity of gun has been calculated, it worked as the input parameters for Multipac and VORPAL. In 3-D simulations, steady state saturation has been reached due to the balance of electrons loss caused by space charge effect and secondary emission, and high currents and short pulses have also been achieved in the gun. By setting resonance parameters properly, it is easy to have the steady state output in MPG.

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