APPLYING THE NONE-STATIONARY THEORY TO THE MULTIPACTING ANALYSIS OF A CYCLOTRON RF CAVITY*

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Abstract

The most of the available multipacting theories are based on assumptions on the emission velocities of secondary electrons and restrict the electron-surface impact pattern to double surface impacts. And these theories can only predict the multipacting conditions in the form of Hatch diagram, which is a formularization of RF voltage vs. frequency multiplied by gap distance, and have very little information on the dynamics of multipacting processes. However, the None-stationary multipacting theory introduced by S. Anza *, uses more physical statistic way to dealing with the emission velocities of secondary electrons and have no restrict on the electron-surface impact pattern. In this paper we first extend the None-stationary multipacting theory. And then, we have made a careful analysis on the dynamics of a multipacting process observed during RF conditioning of a cyclotron, by using the none-stationary theory. This analysis gives us an inspiration to both figure out the problem and develop a cure to it.

INTRODUCTIONS

During RF conditioning process of a compact cyclotron, an asymmetrical signals between the positive and negative half of the RF cycles from a RF pickup has been observed. A preliminary guess for the cause of this asymmetry is the multipacting between the ceramic RF window and DEE plate. We modified the none-stationary multipacting theory [1], and made it valid for multiple surface materials. Then we used the modified the none-stationary multipacting theory to verify the guess and the results are self-consistent.

PROBLEM DESCRIPTIONS

The asymmetrical signals between the positive and negative half of the RF cycles from a RF pickup, are sketched in channel 1(yellow line) of the Fig. 1.

Our initial guess is that the origin of this asymmetry comes from the difference between the secondary emission yields (SEY) of DEE plate (copper) and ceramic RF window (Aluminium oxide compound), which need to be verified. According to measurements by LHC group in CERN [2], the SEY of copper is shown in Fig. 2. In the following study, a maximum SEY of 2.2 is chosen, which is between the maximum SEY of as received sample and sample baked out at 100 ℃.

According to measurements done by Suharyanto, et al.,[3] the maximum SEY of Aluminium oxide compounds based ceramic is roughly 4 times of the copper SEY, as shown in Fig. 3.

Figure 1: Signals of the RF conditioning process of a Compact cyclotron.

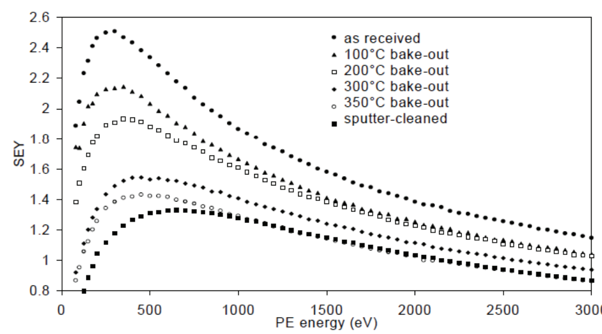

Figure 2: Measured SEY of copper. [2]

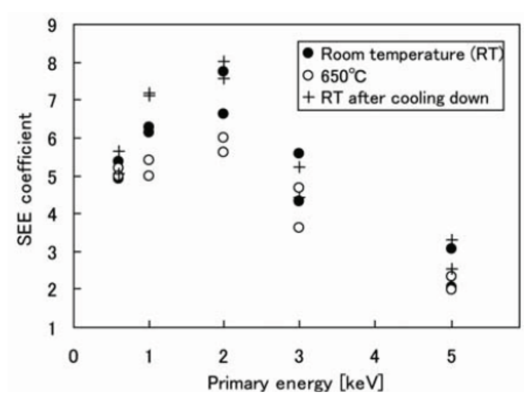

Figure 3: Measured SEY of Aluminum oxide compounds based ceramic. [3]

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As the DEE plate and the RF window are in parallel, and the electric field between them is approximately unique and perpendicular to the DEE plate and the RF window, the none-stationary multipacting theory can be used to analysis the mulitpacting between the DEE plate and RF window in the absence of the magneto-static field. And hopefully explain the cause of the asymmetric signals in channel 1 of Fig. 1. The original none-stationary only deals with the parallel plates' geometry with the same surface SEY property. But it is easy to extend the theory to deal with different surface SEY properties by distinguish the upper and lower plate with different SEY curves. The parameters for none-stationary multipacting theory based analysis are listed in Table 1.

Table 1: Summary of Parameters used in Analysis

Item	**Value**
Geometry type	Parallel plates
Distance between Dee Plate and RF Window	500 mm
Voltage Amplitude	20 kV
Frequency	106 MHz
Maximum of SEY	Al_2O_3: 9.0; Cu: 2.2
Total Simulation Period	150 ns (>15 RF Cycles)

THE MODIFIED NONE-STATIONARY THEORY ANALYSIS

Results are shown in Fig. 4, Fig. 5, Fig. 6 and Fig. 7. The initial seed electrons are near the surfaces of both DEE plate and RF window and part of them will impact the surface of either DEE plate or RF window (according to the direction and initial phase of the electric field) in a very short time. Here according to the peaks of electron emission/impact rates of RF window in Fig. 5, Fig. 6, and the peaks of time evolution of SEY of RF window in Fig. 7 in the first 10 ns, electrons are first impact the RFwindow. As the initial electrons are too close to the surface of RF window, they cannot be accelerated to the energy that the SEY is larger than 1. So within the first 10 ns, the SEY are less than 1 except 2 small peaks as shown in Fig. 7 and the electron population between the DEE plate and RF window are decreased as shown in Fig. 4.

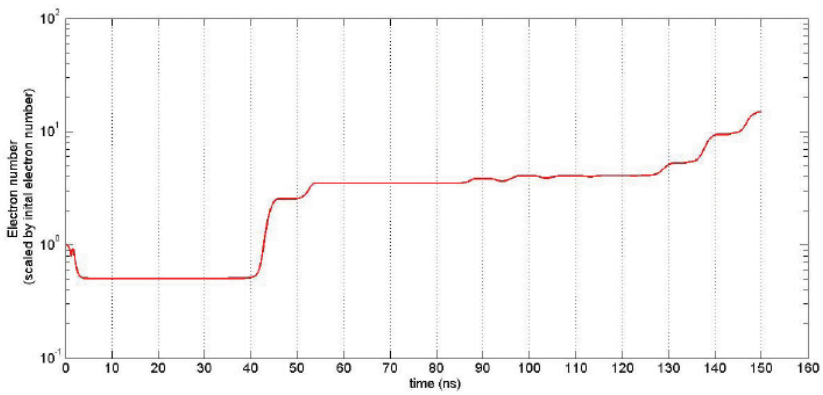

Figure 4: Time evolution of the electron population between the DEE plate and RF window.

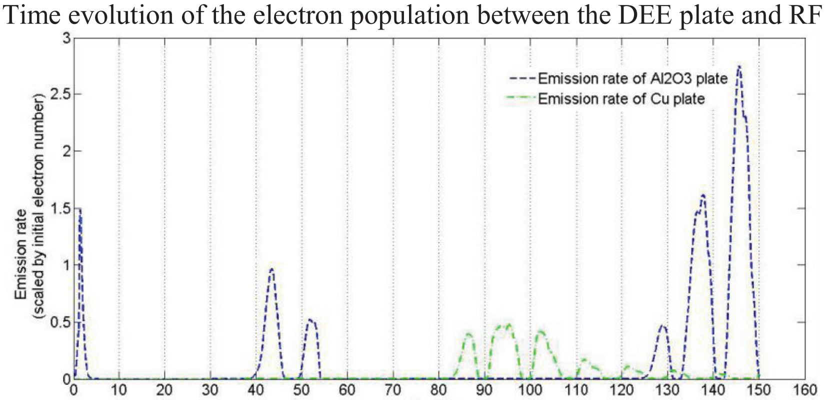

Figure 5: Electron emission rates of RF window (Al_2O_3) and DEE plate (Cu).

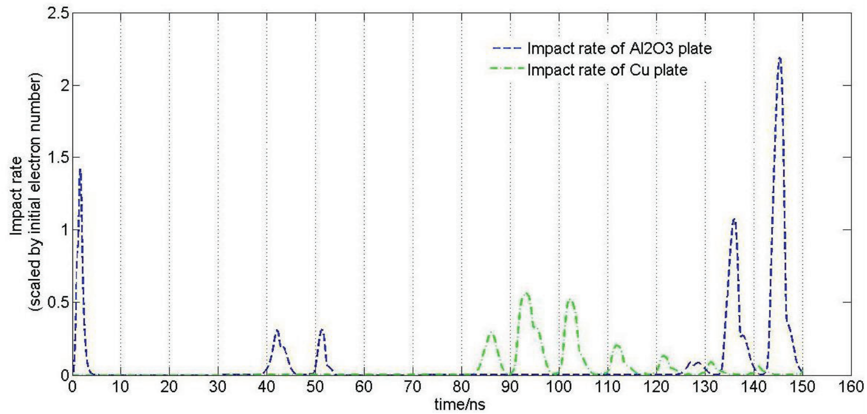

Figure 6: Electron impact rates of RF window (Al_2O_3) and DEE plate (Cu).

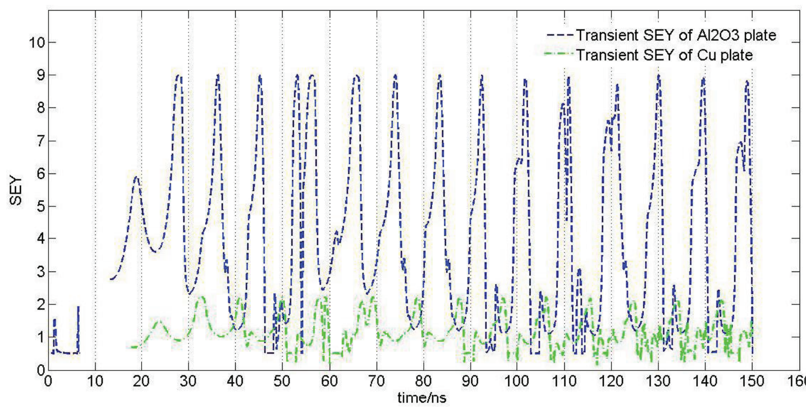

Figure 7: Time evolution of SEY of RF window (Al_2O_3) and DEE plate (Cu).

After 4~5 RF cycles, initial electrons near DEE plate will be accelerated to RF window, and electron population increased exponentially as shown in Fig. 4 at the time between 40 ns and 60 ns. From Fig. 5 and Fig. 6, we can see that between 40 and 60 ns, electrons are impact to RF window and emission rate is roughly 2~4 times of impact rate which lead to a fast increase of electron population. After 4~5 more RF cycles, when electrons impact the DEE plate, we can see from Fig. 5 and Fig. 6 that at the time between 80 ns ~ 120 ns, the electron emission rate is slightly larger than electron impact rate which causes the electron population increased very slightly between 80 ns ~ 120 ns, as shown in Fig. 7. The range of the phase when the electrons impact and emit from the DEE plate is also extended from ~20 ns to ~40 ns, which indicate that the multipacting afterwards will mainly determined by the geometry and electric field rather than by the initial distribution of seed electrons. After 120 ns, the phases of electrons between DEE plate and RF window continually extended, and in each RF cycle electrons will impact to both DEE plate and the RF window, as shown in Fig. 5, Fig. 6, and Fig. 7.

The electron population net gain can be roughly evaluated by electron emission rate over electron impact rate at the same time. For the DEE plate case, the electron population net gain is close to 1 according to Fig. 5 and Fig. 6. And for RF window, the electron population net gain is much larger than 1. So the increase of the electron population is mainly caused by electron impact on RF window. And according to Fig.5 and Fig. 6, the phases that electron impacts (or emits) to (or from) the DEE plate have 1/2 RF cycle's difference with the electron impacts (or emits) to (or from) the RF window. The origin of the asymmetrical signal as shown in Fig. 1 comes from the difference between the secondary emission yields (SEY) of DEE plate and ceramic RF window, as shown in Fig. 7. According to [4], multipacting current will lead to a drop of voltage between parallel plates. From (1) and (2) we can conclude that in the half RF cycles when electron impact the RF window, the electron populations will increase significantly and the voltage between the DEE plate and RF window will drop more than the other half RF cycles.

CONCLUSIONS

An asymmetrical signal between the positive and negative half of the RF cycles from a RF pickup has been self-consistently explained by a modified none-stationary multipacting theory. And the significant difference between the SEY value of ceramic RF window and the SEY value of copper turns out to be the major cause of the asymmetrical signal.

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