

STUDIES OF ELECTRON ACTIVITIES IN SNS-TYPE SUPERCONDUCTING RF CAVITIES*

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Abstract

During vertical testing of SNS superconducting RF cavities, a lot of electron activity was observed. This could be evidence of in-cell multipacting, cell to cell electron migration or near-axis dark current. To study the potential for these electron activities in SRF cavities, a multi-purpose electron tracking code (FishPact) was developed based on the Poisson/Superfish Field solvers. Electron trajectories between the impacts in both medium- β and high- β [1] cavities are tracked under varying accelerating gradient (E_{acc}), RF phases, and emission locations. It is found that the high beta cavities show a greater propensity for potential sources of dark current than their medium beta counterparts. It is further proposed that field emission induced multipacting is a potential, though rare, source of further Q_0 degradation.

INTRODUCTION

During the production of the SNS cavities, two statistics became notable though not very well understood. One is the persistent “soft” multipacting barrier, which existed in 16 of the 18 high- β cavities but was not seen often in the medium- β cavities, even though earlier simulation suggested that two types of cavities were similar. Second is the statistically lower cavity gradient for onset of field emission. While high- β cavities are longer than the medium- β cavities, these two types of cavities underwent the same production processes, except that some cavities underwent several experimental processes between the production processes. Nevertheless, the lower onset of field emission and “soft” multipacting barrier associated with the high- β cavities were considered independent of pre-processing techniques, and also independent of active pumping or cavity isolation. While the two issues were eventually overcome or worked around for the SNS project, further understanding would be beneficial since future projects will continue to look into the same type of SRF cavities.

Since diagnosing tools for electron activity inside cavities are very limited, computer simulation offers valuable insight to understand the two phenomena. FishPact [2] was developed to simulate electron activities for the two types of SNS cavities. The simulation included multipacting electron trajectory, field emitted electron movement which partially contributes to the dark current and the coupling between the field-emitted electrons and the multipacting electrons or the multipacting enhanced by the field emitted electrons.

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FISHPACT AND NUMERICAL METHOD

FishPact uses the established, well-maintained and widely available SUPERFISH code [3] as the field solver to provide the electromagnetic fields in an RF cavity for electron trajectory tracking. The field interpolator provided by SUPERFISH was good enough for small scales often seen with multipacting electron trajectories.

The tracking code adopts the plain fourth order Runge-Kutta algorithm. Accuracy of impact location was achieved by iterations of halving the time-step instead of assessing each individual Runge-Kutta step.

For the multipacting part of the code, traditional counter functions and enhanced counter functions were calculated through the user-defined secondary electron yield coefficient for niobium, which depends on the electron impact momentum [4]. FishPact also can simulate each electron’s elastic collision with the cavity wall. The present code implementation is suited for a single electron in an axial-symmetrical RF cavity.

Multi-cell cavity geometries of SNS medium- β and high- β shapes were used in the simulation. The SUPERFISH code was run first, then FishPact code read the SUPERFISH solution file for the electron tracking process. Using shapes of medium and high β cavities, electron emission along the upper cavity wall was simulated including the left and right beam pipe. Because of axial symmetry, testing was only carried out on the upper cavity wall. Emission sites located every 5 mm along the cavity wall were examined and the electrons were considered to be emitted with average axial accelerating gradient varying from 8 – 24 MV/m, in 2 MV/m steps. Each of these fields was also varied on phase from 0° – 360° in steps of 20° . In all, 69,394 electron trajectories were tracked at the location of their first impact and the final energy upon impact were recorded.

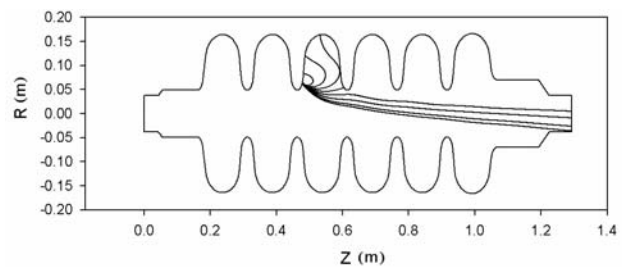


Figure 1: Typical electron trajectories in a medium- β cavity.

Since the probability of the electron emission along the wall was assumed to be uniform, the statistics mostly

reflected the geometry effect of the cavities. Multipacting electrons were counted if they survived up to 20 impacts. Field emitted electrons were tracked through a single impact only. Possible multipacting electrons originating by field emission were tracked both by secondary electron emission and elastic collision against the wall. Figure 1 shows such an example of the electron tracking.

RESULTS

Potential Sources of Dark Current

Under the varying source positions, E_{acc} , and phases tested by the FishPact code in both the medium and high beta cavities, it was found that more electrons exit the cavity through the left and right beam pipe prior to a first impact in the high beta cavity (1502 electrons exit out of 34498 emitted electrons) than exited in the medium beta cavity (878 out of 34896), suggesting that the high beta cavity shows a greater potential to exhibit problems arising from dark current. It is important to note that although more electrons exit the beam pipe in high beta cavities than in medium beta cavities, less than 5% of emitted electrons will exit the beam pipe in either scenario (Figure 2).

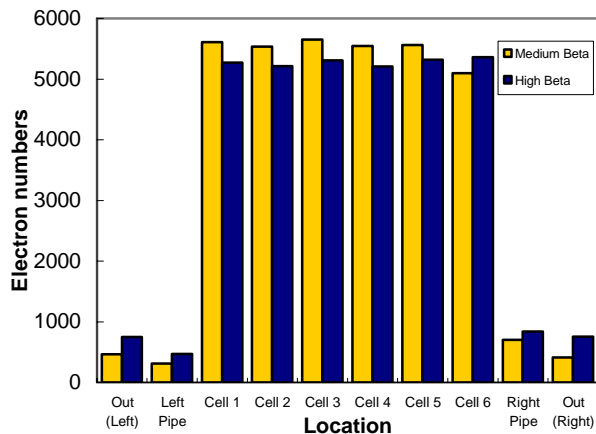


Figure 2: Location of first impact of emitted electrons.

Our simulations suggest that the disparity between the number of exiting electrons in the high and medium beta cavity at a given initial E_{acc} increases rapidly with increasing E_{acc} . While at 6-8 MV/m, only a slight difference in exiting electrons is exhibited, the difference grows to nearly a factor of 2 at 24 MV/m (Figure 3). This points to the potential for far greater dark current at high E_{acc} in a high beta cavity than in a medium beta cavity.

When these exiting electrons, potentially representing sources of dark current, are examined for their energy upon leaving the accelerating cavity, it is found that the average energy is much higher for high beta cavities than for medium beta cavities (Figure 4). The average energy of an electron exiting the medium beta cavity is 2.8 MeV with no electron above 7.9 MeV. In the high beta cavity, this average is shifted significantly upward to 6.2 MeV

with final energies up to 16.2 MeV, more than double that found in the medium beta cavity. This indicates that not only are more electrons exiting the high beta cavity, but they are also leaving with a higher average energy, representing a potentially serious Q_0 drop from the load of dark current. Finally, an examination of the emission source of electrons indicates that all the electrons originate in areas extending from the tips of the iris up to 38 mm upwards along the iris contour.

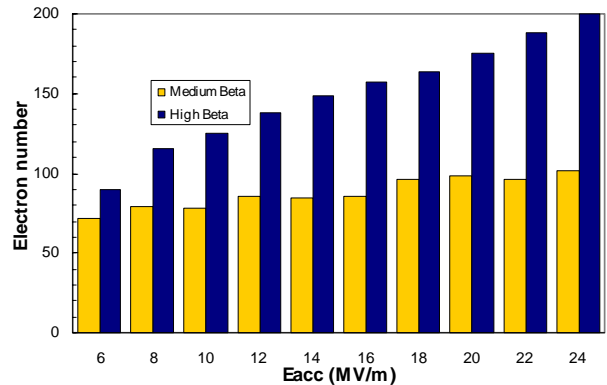


Figure 3: The number of Exit Electrons for Varying E_{acc}

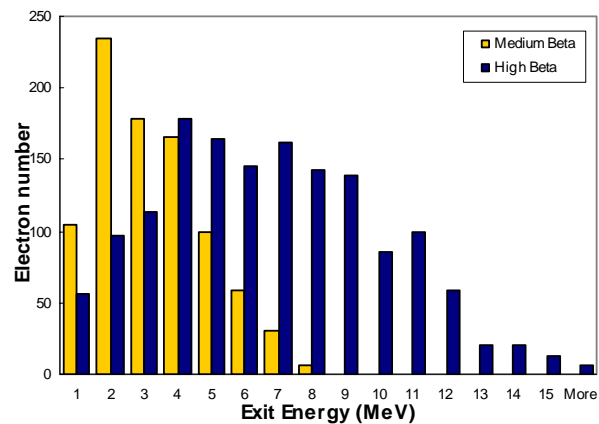


Figure 4 Energies of emitted electrons as they exit the cavity. Electron number is the total number for E_{acc} from 8 MV/m to 24 MV/m.

Field Emission enhanced Multipacting

The multipacting analysis of the two types of cavities suggested similar behavior, as is shown in Figure 5. But in fact, the majority of the high- β cavities experienced a “soft” multipacting barrier as shown in Figure 6, which did not occur in medium- β cavities. The accompanying radiation level measurements done during vertical tests suggested that the field emitted electrons may be the cause.

Examinations of field emitted electrons in high beta cavities originating on the tips of the irises close to the center of the cavity revealed a unique multipacting possibility. The field emitted electrons were accelerated by the electric field to the equator portion of the cavity where multipacting was induced as shown in Figure 7.

Even though the secondary electron yield is not high enough to support self amplified strong multipacting, the constant “capturing” of the field emitted electrons was persistent enough to generate enough secondary emission and to absorb the RF power which contributed to a “Q-dip” shown in a typical vertical test (Figure 6).

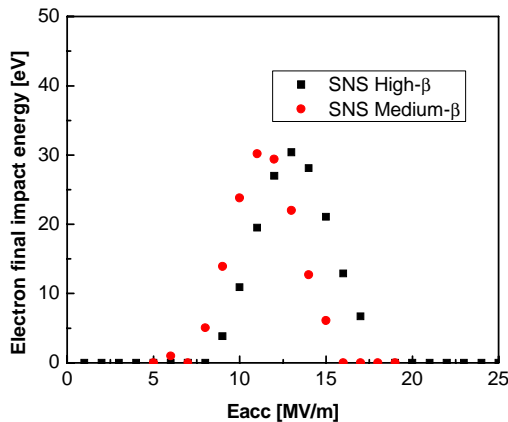


Figure 5: Electron final impact energy of stable trajectories in SNS cavities.

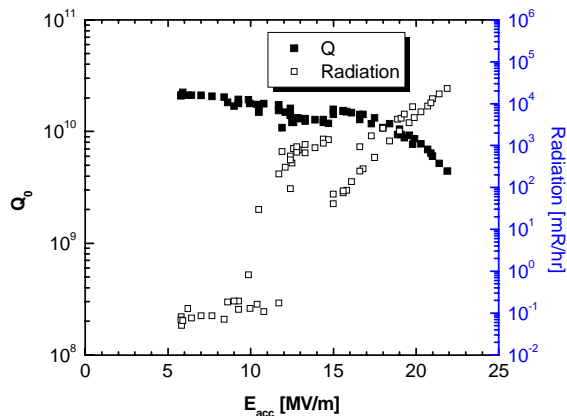


Figure 6: Q vs. E_{acc} curve and radiation measured for SNS high- β cavity HB13.

There are several aspects worth noting concerning these field emission induced multipacting simulations. Though numerous instances could be found in the high beta cavities, no examples of field-emission-induced multipacting could be found in medium beta cavities. The relative ease with which field emission induced multipacting was found in the high beta cavity compared to the lack of a definitive result in the medium beta cavity is a clear indication of significant differences in the cavity geometries. Further studies may perhaps lend insight into the potential problems and sources of Q drop in the high beta cavity.

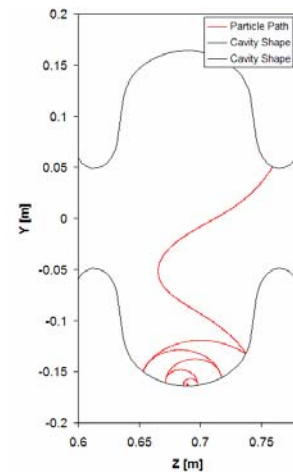


Figure 7: An example of field emission induced multipacting in a high beta cavity.

Within the high beta cavity, the limits at which field emitted electron “capturing” could occur for a given site often formed a “hysteresis” loop similar to field emission induced multipacting (Figure 8). The area within this loop increases or diminishes with the probability of the multipacting occurring at any phase or beam energy. In the high- β cavity the lower area of the “hysteresis” loop coincides with the peak of the electron impact energy shown in Figure 5.

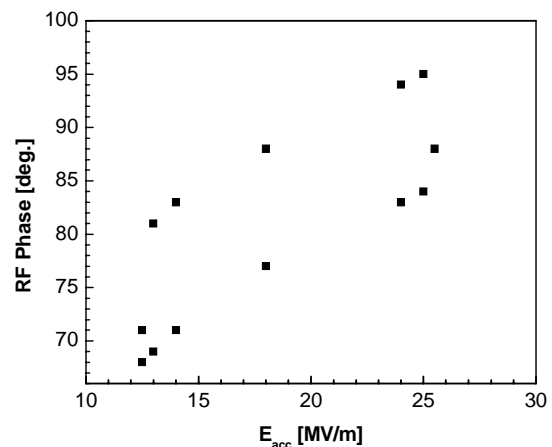


Figure 8: “Hysteresis” loop exhibiting the boundaries of the presence of field-induced-multipacting for a given site.

It is important to understand that even if the probability of field emission induced multipacting remains extremely low, it is the belief of the authors that at certain operating fields, any cavity surface imperfections could lead to the increased possibility of field emission induced multipacting. This reemphasizes the necessity of clean room procedures to remove potential contamination that could lead to multipacting and Q drop.

CONCLUSIONS

Studies of electron activities with FishPact code of SNS medium- β and high- β cavities showed that the high- β cavities have more field emitted electron activity, which may contribute to more potential dark current than in medium beta cavities. We also proposed a possible new mechanism of multipacting activity being induced and enhanced by field emitted electrons which may explain the high occurrence of a multipacting “soft” barrier not predicted by traditional multipacting analysis. More work is clearly needed to understand these effects and studies shall spread to other similar cavity geometries as well.

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