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# MULTIPACTING ANALYSIS OF THE SNS DRIFT TUBE LINAC (DTL) RF VACUUM WINDOW USING SPARK3D*

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## *Abstract*

An ongoing study at the Spallation Neutron Source (SNS) seeks to better understand and address potential multipacting issues associated with the Drift Tube Linac (DTL) RF vacuum windows. An analysis of several failed operational windows showed indications of excessive RF heating on the TiN-coated alumina ceramics. Coupled with vacuum bursts and arcing during conditioning and/or operational periods, these problems have been attributed to electron activity likely caused by multipacting. The status of the study, 3-D electromagnetic simulation results, mitigating techniques and a future experimental plan for studying multipacting in the SNS DTL vacuum windows are presented.

## INTRODUCTION

The normal conducting section of the SNS linac consists of a Radio-frequency Quadrupole (RFQ), six 402.5-MHz Drift Tube Linac (DTL) and four 805-MHz Coupled Cavity Linac (CCL) cavities. Each DTL cavity is powered by a 402.5-MHz klystron rated at 2.5 MW peak power up to an 8% duty-cycle. Pulsed RF power from each klystron is transmitted to the DTL cavities via waveguide RF vacuum windows [1,2].

The goal of the SNS to consistently achieve greater than 90% availability during scheduled beam operation, coupled with the elevated power demands of the ongoing Proton Power Upgrade (PPU) project, requires increased reliability of components with potential catastrophic failures. While not a source of significant downtime, it is vital for failures associated with the DTL vacuum windows to be minimized. Initial results from the multipacting study [3] highlighted the importance of preparing and processing the vacuum windows for multipacting suppression. The study showed that the area around the TiN-coated alumina ceramic was most prone to multipacting. However, details on breakdown/discharge power levels and the region(s) of localized multipacting activity were not provided. Using Spark3D, additional details and results from the study are presented.

## SIMULATION OVERVIEW

The DTL RF vacuum window was modelled using CST Microwave Studio (MWS) [4] and simulated using Spark3D [5] for multipactor analysis. Spark3D is a simulation tool for RF breakdown power analysis in passive devices. It allows for the direct input of field results and the corresponding mesh profile from CST MWS simulations. Spark3D computes breakdown thresholds by employing the Vaughan model for Secondary Emission Yield (SEY) characterization and uses an algorithm for path integration in a full 3-D tracking environment [5].

The high-power conditioning setup detailed in [3] was maintained for this phase of the project. Field results from CST MWS were imported into Spark3D and two cases representing "As Received" (Unprocessed) and "Baked" (Processed) conditions for SEY were analyzed using data shown in Fig. 1 [5,6]. As with the initial phase of the project, the SEY properties of the TiN-coated alumina ceramic were modified to reflect that of Titanium Nitride (TiN). For each case, 10,000 initial electrons were used for the detection of multipacting in a search range from 1 W to 3 MW. The upper power limit was adjusted to 3 MW to ensure that the study adequately covered the fully beam-loaded operating conditions of the PPU project.

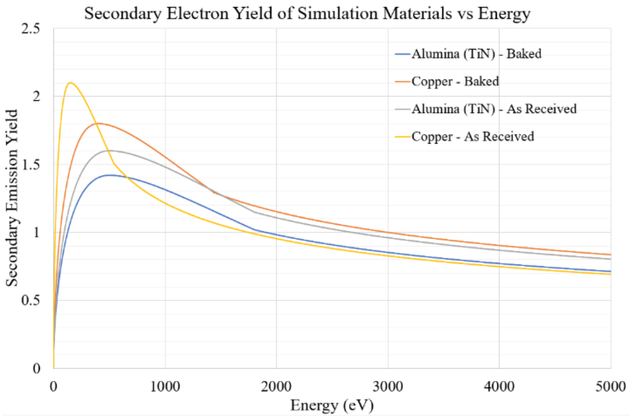

Figure 1: Simulation SEY Curves.

## SIMULATION PROCESS

After the import of field results from CST MWS, the EM field properties were verified and an analysis region covering the vacuum sections described in [3] was defined. An imported continuous wave signal at 402.5 MHz was used for the simulation. Given the relatively short time scale over which multipacting occurs, it was deemed unnecessary to define a 60 Hz, 1.3 ms wide pulse for the simulation to reflect what is used at SNS. Figure 2 shows a cross section of the critical region of analysis with the particle space being the vacuum region enclosed by the red and green material boundaries.

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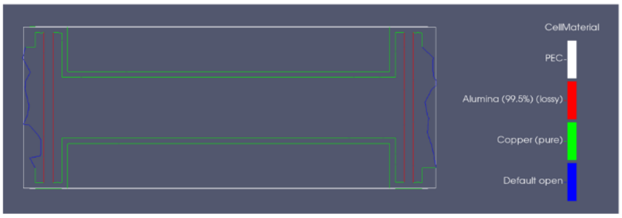

Figure 2: Multipactor Analysis Region (Cross Section).

The model was simulated using the Default, Charge (Fixed Factor) and Charge Trend multipactor criteria provided within Spark3D. Each criterion provides a semi-unique method for the determination of discharge at certain input power levels. The Default criterion uses a software-defined factor that varies based on the ratio of the current number of electrons to the initial electrons at each RF half-cycle. Multipactor is then indicated if this factor is exceeded. The Charge (Fixed Factor) criterion is comparable to the default criterion, but the detection factor is fixed by the user. Lastly, the charge trend criterion signals the detection of multipactor based on the fit of the evolution of electrons to an exponential curve [5].

## SIMULATION RESULTS

The threshold breakdown power for each criterion is summarized in Table 1.

Table 1: Breakdown Power Simulation Results

| **Multipactor Criterion** | **Peak Breakdown Power (“As Received”) [kW]** | **Peak Breakdown Power (“Baked”) [MW]** |
|---|---|---|
| Default | 31.49 | 2.25 |
| Charge (Fixed Factor = 5) | 30.97 | 2.31 |
| Charge Trend | 30.97 | 2.39 |

As with results from the initial phase of the study, the benefits of material processing before conditioning and/or operational periods cannot be understated. Results showed a good agreement between the three criteria used for the study and a major increase in the breakdown power threshold for the processed case when compared to the unprocessed case.

Figure 3 shows the initial electron distribution for the simulation. Figure 4 shows the electron evolution for the Default criterion of the “As Received” case after a 2 µs run time. Figure 5 and Fig. 6 show the electron evolution and the area of localized multipacting activity for the Default criterion of the “Baked” case after a 1 and 2 µs run time. Electron distributions for the other multipactor criteria of each case produced similar results.

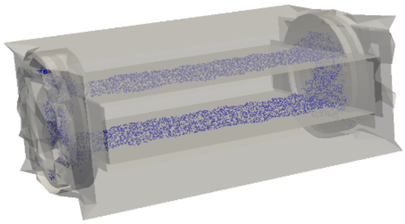

Figure 3: Initial Electrons on High Field Locations.

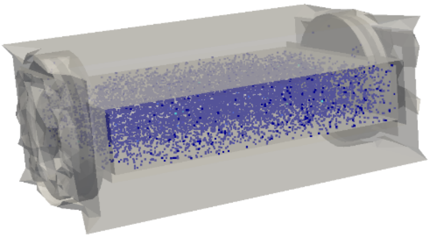

Figure 4: Electron Distribution after 2 µs (Default Criterion - “As Received” Case).

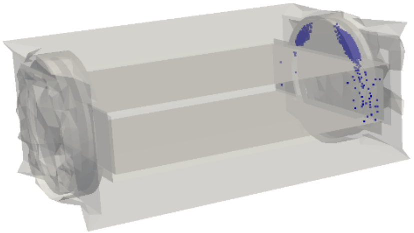

Figure 5: Electron Distribution after 1 µs (Default Criterion - “Baked” Case).

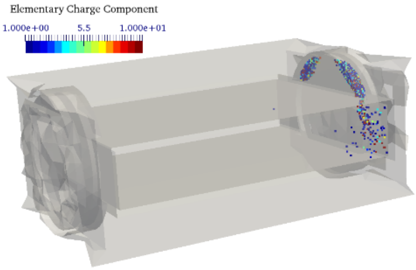

Figure 6: Electron Distribution after 2 µs (Default Criterion - “Baked” Case).

Similar to phase 1 results, the area around the TiN-coated alumina ceramic appears to be most prone to multipacting activity. Note the electron activity in the cavity section where the alumina ceramic window resides. This result most likely reflects why some of the operational windows failed and why indications of excessive heating, arcing and metallic particle deposition on the alumina ceramic were observed.

## MITIGATING TECHNIQUES AND A FUTURE EXPERIMENTAL PLAN

Two of the most popular methods for suppressing multipacting involve geometrical changes and/or surface treatments. While geometrical modifications are sometimes ideal, a total redesign that eliminates the phenomenon is usually extremely challenging or unrealistic. Surface treatments that typically cover baking, cleaning, and the coating of impact surfaces are performed with the goal to improve (reduce) the secondary emission coefficient and thus minimize or prevent the emission of secondary electrons [7][8].

The results of the simulation laid the foundation for two potential solutions listed below:

- TiN Coating on Critical Copper Surfaces in Vacuum
- Addition of Grooves in the Cavity Sections

### *TiN Coating on Critical Copper Surfaces in Vacuum*

The use of TiN coating on ceramic windows of RF power coupling structures is widely used and highly established. It is rare, however, to have such coatings applied to metallic surfaces. For superconducting applications where a significant amount of multipacting research resides, the application of these coatings on metallic surfaces would likely lead to undesirable loss, heating, and transmission effects [7-9].

The DTL windows under investigation are normal conducting structures that do not share those concerns to the same degree. These structures have a higher thermal capacity and a greater vacuum pressure tolerance. Given recent advancements in coating technologies, the coating of the area around the alumina ceramic is being studied as a potential solution. TiN coatings which are typically a few nanometres thick are not expected to affect RF transmission through the device. This is because most surface currents are expected to flow through the copper because of the skin depth.

Initial results from simulation show an improvement in the threshold breakdown power for this scenario. The SEY property of the copper materials that form the cavity sections around the ceramic windows were modified to reflect the TiN coating. Results from the “Baked” materials simulation case are shown in Table 2.

Table 2: Breakdown Power Simulation Results

| Multipactor Criterion | Peak Breakdown Power (TiN on Copper) [MW] |
|---|---|
| Default | > 3.0 |
| Charge (Fixed Factor = 5) | > 3.0 |
| Charge Trend | > 3.0 |

For each case, the threshold breakdown power exceeded 3 MW. Given these results, a plan to modify a coating chamber at the SNS for coating DTL windows has been established. The goal is to further investigate the coating of critical metallic surfaces as a potential multipacting mitigation solution.

### *Addition of Grooves in the Cavity Section*

The addition of grooves in waveguide structures as a multipacting suppression technique has been presented [8][10]. Preliminary simulation results using a single DTL window show that the inclusion of grooves in the cavity section could potentially be another multipacting suppression solution. It is worth noting that the width of the groove appeared to have a stronger suppression correlation when compared to the depth.

Additionally, the area of localized multipacting activity has given thought to the potential benefits of localized vacuum pressure improvement. A future experimental plan could involve the addition of a vacuum port on the cavity section of the structure for further investigation. The port could be added to the structure with minimum transmissions effects with the aid of an RF screen. The goal would be an assessment of the impact of localized vacuum pressure improvement on multipacting activity.

## SUMMARY

An ongoing study at the SNS seeks to better understand and address potential multipacting issues in the SNS DTL RF vacuum windows. Phase 2 results from the study using Spark3D provided additional information on the threshold breakdown power limit and the area of localized multipacting activity. Two potential solutions have been identified and are under investigation. It is likely that the best potential multipacting suppression technique will be a combination of potential solutions.

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