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MULTIPACTING ANALYSIS OF WARM LINAC RF VACUUM WINDOWS*

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Abstract

Multipacting in accelerating structures is a complex phenomenon about which there is much to be understood. While multipacting research efforts have primarily been focused on superconducting radio frequency (SRF) systems, normal conducting accelerating structures which have a higher thermal capacity, and a greater vacuum pressure tolerance could benefit from additional investigation. This research details multipacting simulation methods and the results of 3-D electromagnetic simulations of RF vacuum windows used on normal conducting linac (NCL) cavities. Benchmarking of the peak electric fields in these structures, benefits of material processing and possible techniques for reducing or eliminating multipacting activities are discussed.

INTRODUCTION

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory routinely operates a proton-beam linear accelerator at a beam energy of 1.0 GeV and a beam power of 1.4 MW with better than 94 percent availability. The Linac consists of a normal conducting section for beam energies up to 186 MeV and a superconducting section for levels up to full energy. The NCL consists of six Drift Tube Linac (DTL) cavities and four Coupled Cavity Linac (CCL) cavities [1, 2]. The DTL cavities operate at a frequency of 402.5 MHz and are powered by 2.5MW-rated klystrons through Radio Frequency (RF) waveguide vacuum windows [2].

While these windows have not been the source of significant downtime to date, several operational issues arose due to failures with these structures. Most of the failed windows showed indications of RF heating on the ceramic disks that were caused by metallic coatings on their surfaces. The failure mode was attributed to electron activity in vacuum that was most likely caused by multipacting. Multipaction is a phenomenon where low energy electrons become resonant with an RF field resulting in an exponential multiplication of secondary electrons [3]. This condition occurs under vacuum and leads to a reduction in the efficiency of the system. At times, damage due to heating, repeated vacuum bursts and degradation of materials are likely to occur [3]. Although multipacting in the DTL sections at SNS has not been verified, indications of the phenomenon during high power conditioning of the vacuum windows drove the desire for additional investigation. This paper provides a brief overview of the RF vacuum window conditioning process and the status of the multipaction investigation

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CONDITIONING OVERVIEW

RF Test Facility

Each RF Vacuum window is processed and conditioned on the test stand at the SNS RF Test Facility (RFTF) before being installed for use on the accelerator. The test facility contains two RF transmitter systems that are capable of testing various high power components at 402.5 MHz and 805 MHz. The test stand incorporates a modified Low-Level RF (LLRF) subsystem that provides precision control for testing activities up to a pulse width of 1280 μS, repetition rate of 60 Hz and a peak power of 5 MW.

Window Conditioning Process

Before RF processing, the windows are usually baked at a temperature of 150 ˚C for approximately 72 hours while installed on a bridge waveguide under vacuum. DTL windows are installed in sets of two on the bridge waveguide and pumped down until the vacuum pressure achieves a range of $< 5 \times 10^{-8}$ Torr. A set of turbo pumps and a roughing pump are used to obtain this pressure requirement. Figure 1 shows a set of DTL windows installed on a bridge waveguide.

High power RF is then applied to the windows by a klystron connected to one port of the assembly while the other port is terminated to a matched waveguide load. The power through the windows is slowly increased while the vacuum activity of the system is monitored until a peak power of 2.5 MW at 8% duty cycle, the full rated power of the windows, is reached.

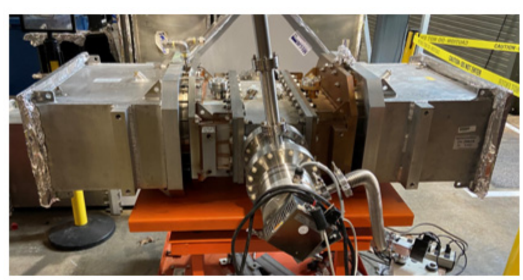

Figure 1: DTL Window Set Installed on Bridge Waveguide.

SIMULATION PROCESS

The DTL RF vacuum window was modelled and simulated using CST Microwave Studio. Each dimension was obtained using manufacturer drawing files or actual measurements from existing units. The model was simulated using waveguide ports for excitation and tuned to match the design performance of the windows. The waveguide sections were modelled as pure copper and the window as

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TiN-coated Alumina ceramic. Figures 2 and 3 show the model and the frequency response of the structure.

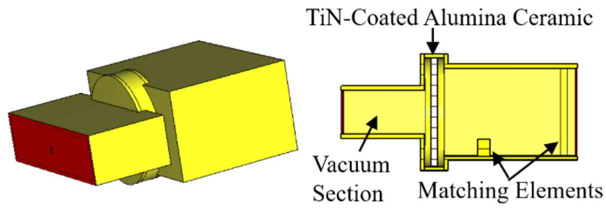

Figure 2: Model of the DTL Window.

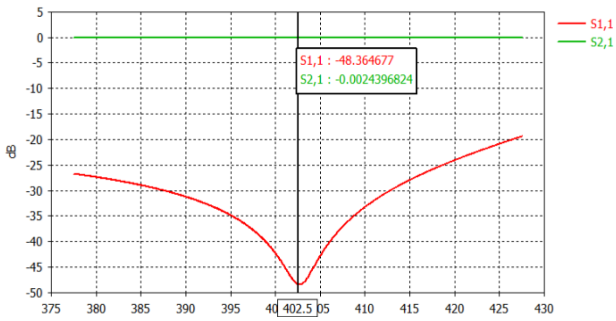

Figure 3: Frequency Domain Response of the DTL Window after Tuning.

Peak Electric Field Benchmarking

The first step of the Multipaction simulation effort was the benchmarking of the peak electric field in the structure. Simulation results were compared to analytical calculations of the peak electric field in a rectangular waveguide. The value of the peak electric field in a rectangular waveguide can be calculated using Eq. (1) [4].

$$E_o = \sqrt{\frac{P}{\frac{1}{4}\frac{\sqrt{1-(\frac{\lambda_f}{\lambda_c})^2}}{Z_o}ab}} \quad (1)$$

In Eq. (1), P is the input power to the structure, λ_f is the wavelength at the frequency of interest, λ_c is the cutoff wavelength, Z_o is the impedance of free space and a and b represent the broad and narrow wall dimensions, respectively [4]. Table 1 shows a comparison of the analytical and simulation results for a standard, half-height WR2100 waveguide.

Table 1: Comparison of Analytical and Simulation Results

Input Power	Calculated Peak E-Field	Simulated Peak E-Field
0.5 W	121.632 V/m	120.925 V/m
100 W	1,720.14 V/m	1,716.92 V/m
100 KW	54,396 V/m	54,342 V/m
1 MW	172,014 V/m	171,843 V/m

Multipaction Simulation Setup

The next step of the simulation process was focused on the high-power conditioning setup and analysis. A 9-inch-long section of waveguide under vacuum was modelled to simulate the bridge waveguide. Figures 4 and 5 show a model of the conditioning setup and the frequency response of the structure.

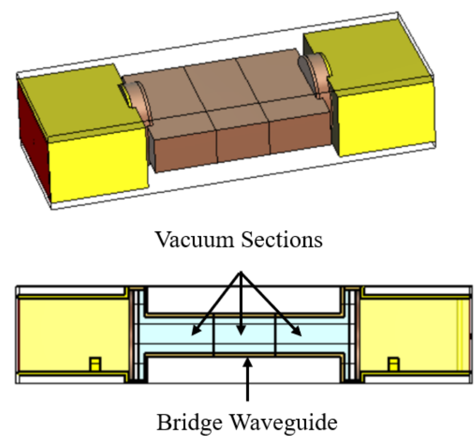

Figure 4: Model of the High Power Conditioning Setup.

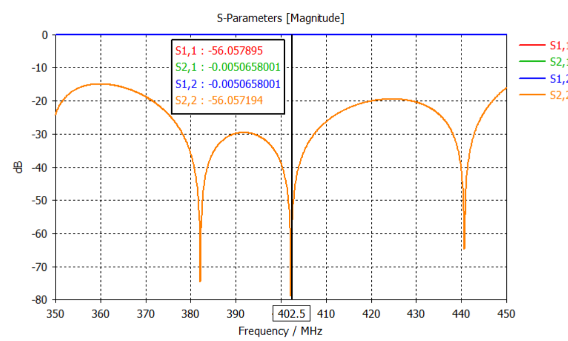

Figure 5: Frequency Response of the Setup.

Two simulations utilizing the particle-in-cell solver from CST Microwave Studio were configured for the multipaction simulation. One simulation included materials that had Secondary Electron Yield (SEY) Curves reflecting an unprocessed, “as received” condition and the other had SEY properties that reflected processed (baked) material conditions. The SEY is material dependent and is a critical determinant for the occurrence of multipaction. It characterizes the probability of electron multiplication when a primary electron strikes a surface [5].

Each simulation was initialized with 3000 Maxwellian source particles that were distributed throughout the vacuum section of the high-power conditioning setup model. The as-received model simulation utilized a default Furman (ECSS) copper material provided with CST Microwave Studio. To reduce the complexity of the model and simulation time, the electrical properties of the ceramic window (Alumina) on both simulations were maintained, but the Vaughn particle properties were modified to reflect Titanium Nitride (TiN). Using data from Hilleret’s material study [6], the SEY and energy maximums for the ceramic

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window in the as-received simulation were set to 1.6 and 500 eV, respectively. Data from the same study were used to configure material properties for the "baked" simulation. The SEY and energy maximums for Alumina and Copper were set to 1.42 and 500 eV and 1.8 and 400 eV, respectively. Those values are consistent with results for copper baked at 300 ˚C and Titanium Nitride (TiN) at 150 ˚C [6].

SIMULATION RESULTS

External fields at 402.5 MHz from the frequency domain simulation of the conditioning setup were used to run the multipacting simulation. Both models were simulated for 50 nS (~ 20 RF periods) and the RF power was parametrically swept from 0 to 1 MW in steps of 25 kW. The program was configured to stop each iteration of the sweep if the average number of secondary electrons exponentially increased over 3 RF periods. The results were then analyzed for indications of multipaction. Figures 6 and 7 show results of both simulations. Figure 8 shows areas of the structure are prone to multipaction.

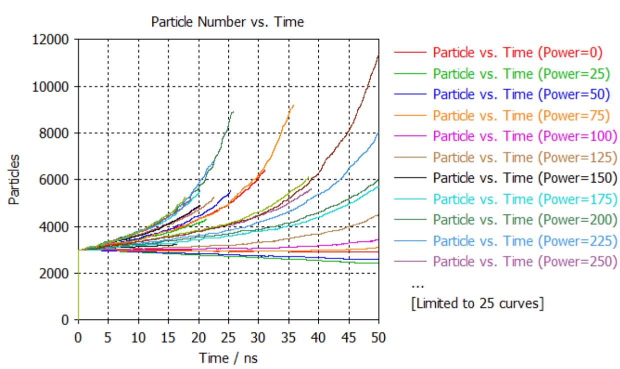

Figure 6: "As-Received" Model Results.

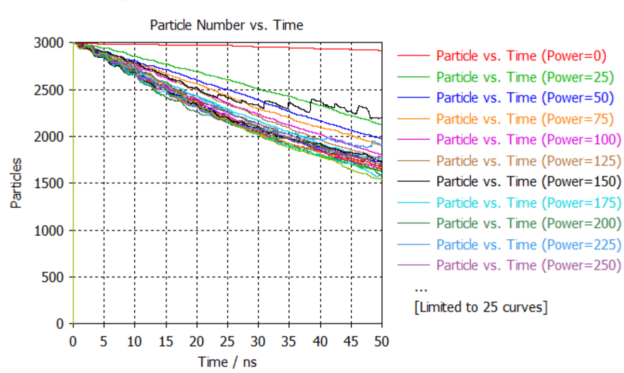

Figure 7: "Baked" Model Results.

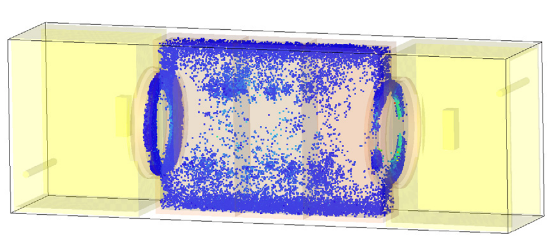

Figure 8: Parts of the Structure Prone to Multipaction.

Unlike the results of the "baked" simulation, the as-received simulation showed possible multipacting bands around 150, 250, and 275 kW as well as a continuous band from 325 kW up to 1 MW. The highest concentration of particles was located within the gap sections around the ceramic. These sections appear to be critical areas that are prone to multipaction. Baking was shown to have a significant effect on the reduction of multipacting in the simulation due to lower SEY curve maximums. This effect reinforces the significance of material preparation in reduction or elimination of multipacting.

SUMMARY

Multipaction, which has been the suspect of operational issues in the DTL sections at SNS, is being studied. Benchmarking of the peak electric field and a comparison to analytical results were the first steps of the ongoing study. Preliminary simulation results of the high-power conditioning setup of DTL RF vacuum windows reiterated the importance of preparing and processing these structures to reduce the likelihood of multipaction.

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