ELECTROMAGNETIC DESIGN OF 402 MHz NORMAL CONDUCTING COAXIAL WINDOW FOR SNS FACILITY*

A. I. Pronikov, R. Agustsson, S. V. Kutsaev†, A. Yu. Smirnov, S. Thielk
RadiaBeam LLC, Santa Monica, CA, USA
Y. Kang, S. W. Lee, J. Moss, Oak Ridge National Laboratory, Oak Ridge, TN, USA

Abstract

RadiaBeam has developed a novel design of MW-class high-power RF windows to be used in high-power proton accelerators, such as SNS. This design is based on the utilization of a coaxial window between two waveguides to coax transitions, instead of a ceramic window in a uniform cylindrical waveguide, which provides several significant benefits. In this paper, we will present the RF and engineering design of this window.

INTRODUCTION

Modern accelerator facilities such as the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) [1], operate in a high-power pulsed regime and require reliable high-power RF components. One such component is the RF power coupler [2], which provides power delivery from the RF power source to the load. The critical part of the waveguide couplers is the RF window. It is the point where the RF feed crosses the vacuum boundary and thus forms part of the confinement barrier.

Although RF windows must be designed to have good impedance matching for RF transmission, there is still power dissipation inside the dielectric, which inflicts mechanical stresses and can result in fatigue degradation under the cyclic load of a pulsed regime. Conventional RF vacuum windows are made of ceramics, and brazed to a pillbox cavity. The use of ceramics presents several major challenges and issues that limit the performance of the existing RF windows. First, the fabrication and machining of large ceramic disks can be challenging. Size also complicates the ceramic-to-metal brazing process complexity due to temperature differentials and residual stress. Finally, coatings such as TiN are needed to suppress multipactor discharge, which is technologically challenging to apply over a large area.

Another set of problems is related to the dielectric losses, subsequent heating, and thermal expansion, defined by the loss factor and thermal conductivity of the dielectric. In our approach, we used Kyocera AO479U high-purity alumina as the most promising ceramic option among the others, since it has the lowest tanδ value, reasonable thermal conductivity, and excellent surface properties [3, 4].

RF DESIGN

We have developed a novel design of a high-power RF window (HPW) that will be used to feed 402.5 MHz DTL cavities with 3 MW power @10% duty factor in SNS linac. This design is based on the utilization of coaxial windows, instead of pillbox, which provides several significant benefits.

First, the diameter of the ceramic disk in the coaxial line is reduced for the same RF power compared to in TE-mode waveguide design, since it operates in low impedance TEM mode. For 600 kW average power at 400 MHz, the window size can be reduced from 13” to 8” [5], which significantly reduces the fabrication complexity and improves structural stability, while keeping the TE11 mode cut-off frequency in the coax ~50% higher than the operating frequency. Second, the cooling of coaxial windows can be performed from both the inner and outer conductor sides. Then, the field distribution in the coaxial line is more uniform, which reduces dielectric losses and thermal gradients. Importantly, the multipactor discharge in coaxial windows can be suppressed by applying DC voltage bias between inner and outer conductors. Last but not least, coaxial windows provide wider RF bandwidth without requiring cavity resonances, which is important for accelerating cavity operation.

Figure 1: The design of a 402 MHz RF window for SNS drift tube linacs.

A conceptual design is shown in Figure 1. The HPW consists of three main parts: air side with WR2100 waveguide, coaxial part with a transition section and RF window, and vacuum side with WR2100R waveguide, connected to the DTL cavity [6]. The window has different waveguide cross-sections at the ends because of the narrow coupling port to the SNS DTL cavity and no physical space to install an adapter to a standard WR2100 waveguide.

The RF design of HPW included several steps. First, we achieved the lowest possible level of reflections by choosing a proper ratio of inner and outer conductor diameters, and the dimensions of special chokes for the 50 Ω coaxial part as presented in Figure 2. The level of reflections at the operating frequency of 402.5 MHz was below - 51 dB.
Then, using an airside loop and a vacuum side loop, we obtained the lowest possible level of reflections, regardless of the length of the waveguides. In the regions near the loop of the air side and the loop of the vacuum side, the TE$_{10}$ mode is transformed into the TEM mode and vice versa. To compensate for the mismatching that occurs when two waveguides of unknown lengths are connected to the end flanges, we adjusted the dimensions of both loops at a distance of at least 5/8 wavelength from both sides. This way we were able to achieve the lowest possible level of reflections at the operating frequency.

Table 1 summarizes the RF parameters of the designed window and compares them to the existing window design. The resulting reflection level and bandwidth are shown in Figure 3. The $S_{11}$-parameter is $-67.9$ dB at 402.5 MHz and the bandwidth is 15.1 MHz at $S_{11} = -32.7$ dB level. These results are comparable or better than those of the existing pillbox window [7], because the current SNS window has a simulated $S_{11}$-parameter is $-56$ dB, a bandwidth is 7 MHz, and a much larger ceramic diameter. The peak electric field is located at the chokes for impedance matching on the inner conductor of the coax as seen in Figure 4. At nominal power of 3 MW, the peak fields don’t exceed 1.4 MV/m, and will not lead to RF breakdown events.

Table 2: Characteristics of Ceramics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>A0497U</th>
<th>AL300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel. permittivity</td>
<td>9.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Loss tangent</td>
<td>2.0e-5</td>
<td>3.0e-4</td>
</tr>
<tr>
<td>Thermal cond., W/K/m</td>
<td>30.0</td>
<td>26.8</td>
</tr>
<tr>
<td>Max. heating, °C</td>
<td>0.3</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Initial thermal simulations were conducted assuming a single circuit flow path that travels through a channel in the air-side inner conductor, circulates inside the inner diameter of the ceramic window, and exits through a separate channel in the air-side inner conductor. This design eliminates braze joints that separate water from vacuum.
volumes, a highly desirable design goal for accelerator systems. However, the initial simulations highlighted the need to incorporate cooling on the outside surfaces of the waveguides as well as the ceramic because thermal losses in copper on the inner surface of the outer conductor were at least 120 W, leading to additional heating of the ceramics by 30 °C.

In response to this problem, the engineering model was updated to include additional cooling lines that are bonded to exterior surfaces during the sub-assembly braze runs. Thanks to the additional five cooling pipes, it was possible to significantly reduce the maximum heating as shown in Figure 5. We have got that the heating of A0497U made of Kyocera ceramics is no more than 0.3°C at an average power of 360 kW and no more than 7°C for AL300 ceramics.

![Figure 5: Thermal simulation results for A0497U at an average power of 360 kW.](image)

**MULTIPACTING SIMULATIONS**

Multipactor discharge can cause a breakdown in high-power RF components, especially in ceramic windows. This phenomenon starts if certain resonant conditions for electron trajectories are fulfilled and if the impacted surface has a secondary yield larger than one. At best, the multipactor can cause additional heating of the ceramic, which will become an additional problem in removing heat from the ceramic, so understanding at what power and in what area of the ceramic a multipactor discharge can form is very important.

The most important parameter when modeling multipactor is the choice of SEY for ceramics. The SEY parameter of TiN depends on the coating quality. A reasonable peak SEY for TiN is between 1.2 – 1.5 [3,5,8]. Since we assume that our A0497U ceramics will have a TiN coating, we took the value for SEY in this range for the multipactor simulations, performed in CST Particle Studio (PIC).

The growth of the total number of electrons formed because of the multipactor is described by the relation: \( N = N_0 e^{\alpha \Delta t} \), where coefficient \( \alpha \) shows the level of electron multiplication. The simulation results for different input power levels are shown in Figure 6. According to this plot, multipactor discharge is possible at a peak power of more than 1.5 MW and is more dangerous at a peak power of more than 2.0 MW. The possible area of the multipactor is near the chokes of the inner conductor as shown in Figure 7. These results are similar to those observed in the existing SNS HPW, where they are mitigated through RF conditioning.

![Figure 6: Dependence of the \( \alpha \) coefficient on the level of input power.](image)

**SUMMARY**

RadiaBeam has developed a novel design of high-power RF windows to be used in high-power proton accelerators. This design was based on the utilization of a coaxial window between two waveguides to coax transitions, instead of a ceramic window in a uniform cylindrical waveguide, which provided several significant benefits like smaller diameter of ceramics, lower reflection level, wider bandwidth, and the possibility to cool the ceramic disk from the inside. Thermal simulations demonstrated the need for cooling the outer contour of ceramics and waveguides. Multipactor simulations demonstrated the possibility of a discharge at power levels higher than 1.5 MW, similar to the existing window, and will be conditioned out. The probable area of the multipactor discharge occurrence is located near the inner conductor at a radius of about 50 mm.
REFERENCES


