DEVELOPMENT OF HIGH POWER CW RF WINDOWS*

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Abstract

Over the past year Advanced Energy Systems Inc has undertaken a program to develop CW High Power RF windows utilising a unique fabrication approach. Our fabrication approach should result in a window that inherently places low stress on the ceramic. The design will provide for excellent cooling of the ceramic, which when combined with the use of a ceramic with a very high thermal conductivity, will result in a window having extremely high CW power capacity. We will present results of our design and analysis to date and results from fabrication tests. Finally we will review our plans to continue the development program. This program will include the fabrication of approximately twelve windows, six suitable for use at the JLAB linear accelerator and six suitable for use in the Cornell CESR accelerator. The program will also include the testing of these windows at JLAB and Cornell.

1 INTRODUCTION

As radio frequency (RF) accelerator technology has advanced over the past several decades, the accelerating structures have improved to allow ever higher accelerating field and beam current. The fundamental limiting technology has become the RF transmission system, specifically the RF vacuum window.

The first part of our effort was focused on developing a window design concept which could be used for a broad range of window requirements and then applying that concept to a detailed design for the JLAB 1.5 GHz window and a preliminary design for the CESR 500 MHz window. Evaluation of these design requirements led us to consider a novel process for joining the ceramic window element to the metallic waveguide iris components. Beryllium-oxide ceramic was selected for use in these windows due to it's excellent thermal conductivity, however the joining concept we have developed would work equally well with aluminium-oxide ceramics. In an effort to begin to characterize and qualify the process we designed and fabricated joint proof-of-process (POP) test articles. In parallel, we performed RF analysis, thermostructural analysis, and mechanical design to demonstrate the feasibility of designs using this process.

2 PROOF–OF-PROCESS TEST ASSEMBLY

AES designed and produced proof-of-process pieces to demonstrate the complete sequence of attachment necessary to fabricate a window. These pieces were then used to refine our design in preparation for the window prototype effort. Figure 1 is a photograph of the finished assembly. The process involves several discrete steps each of which requires optimisation and refinement.

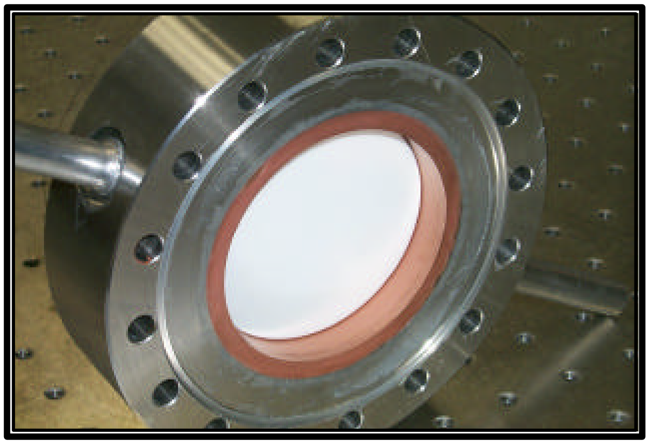

Figure 1: Finished Proof-of-Process Test Assembly

The joint region shown in figure 2 is composed of the ceramic, SST flange, and a copper sleeve. A cooling passage is located immediately adjacent to the ceramic between the sleeve and the SST flange.

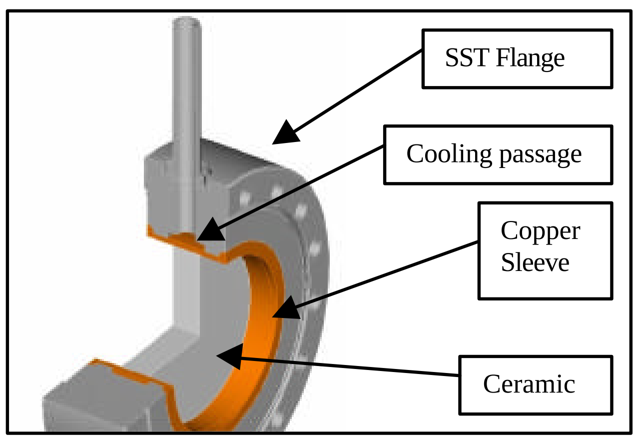

Figure 2: Section showing ceramic, copper, and SST

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3 JLAB WINDOW

3.1 RF Analysis

RF analysis was performed using finite-element code ANSYS on the 1.497 GHz, JLAB size, beryllium oxide window, to determine a design geometry. The JLAB FEL requires a wide RF bandwidth to pass higher modes that originate in the cavity and pass back through the window. The VSWR should be less than 1.1:1 at the design frequency of 1.497 GHz and should be no greater than 1.5:1 at frequencies up to 2.200 GHz. The height of the window was set at the height of the waveguide, .986 inches. The width of the window, its thickness, and other geometry variables were used to develop a design that meets the broadband VSWR requirements, enables a strong attachment, and withstands more than 3 atmospheres. Figure 3 shows the final VSWR curve from the finite element model.

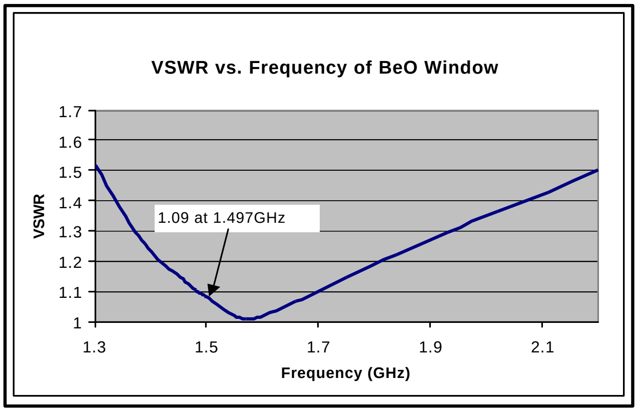

Figure 3: VSWR vs Frequency for the JLAB BeO Window

3.2 Thermal Analysis

ANSYS was used for its multi-discipline capability, along with the calculation of VSWR, the heat loss in dielectric is determined. This loss is a function of the dielectric constant, the loss tangent, the frequency and the electric field in the BeO. The heat loads were determined at 1.497 GHz assuming a dielectric constant of 6.7, a loss tangent of 3×10^{-4}, and 100 kW of through power. The total power lost in the ceramic was determined to be 19.3 watts. The finite element code determines a volumetric heat load for every dielectric element in the RF model. A direct transfer of the heating rates is accomplished by using the same element and node numbers in the thermal model as was used in the RF model. A 0.1 inch thick copper band was included with convective boundaries on its outer surface to represent water cooling. Figure 4 shows the resulting thermal contours. The maximum temperature occurs in the center of the ceramic, which is the location of the maximum electric field. The high thermal conductivity of BeO, nearly that of copper, keeps the temperature rise through the window to only 3.3 C.

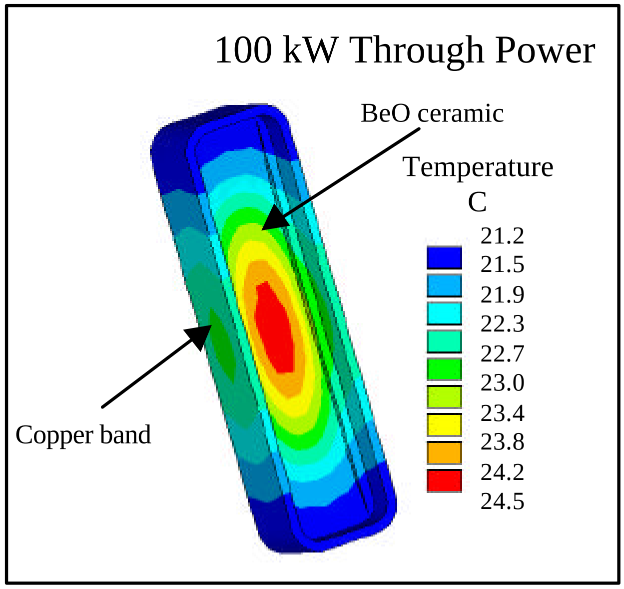

Figure 4: Temperature profile through the JLAB window for 100 kW of thru power

3.3 Mechanical Design

A complete detail mechanical design has been performed for the JLAB window based upon the POP process steps and incorporating results from the thermo-structural analysis. Because of the small size of the assembly, the tooling for the JLAB window will be a near copy of the tooling used for the POP Figure 5 shows the complete JLAB window assembly.

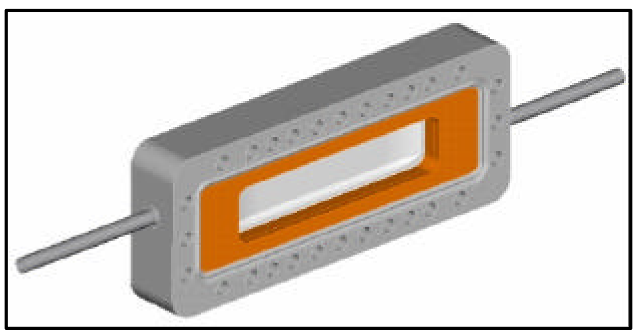

Figure 5: Complete JLAB Window assembly

4 CESR WINDOW

4.1 RF Analysis

As a result of RF analysis work done prior to the start this project[1] we had a good understanding of the RF characteristics of the CESR window. A substantial body of work had been done to generate an RF design for the 500 MHz window utilizing an BeO elliptical ceramic. The RF analysis for this window was done using MAFIA. The window was self-matched using the elliptical iris, which forms the flange for the 0.5” thick BeO ceramic, as a matching element. Matching was achieved by varying the thickness of the flange. Shown below in figure 6 are the electric fields as calculated by MAFIA. We were able to achieve a very good match using this configuration and found that the window was fairly broadband and not overly sensitive to small deviations in the frame dimensions.

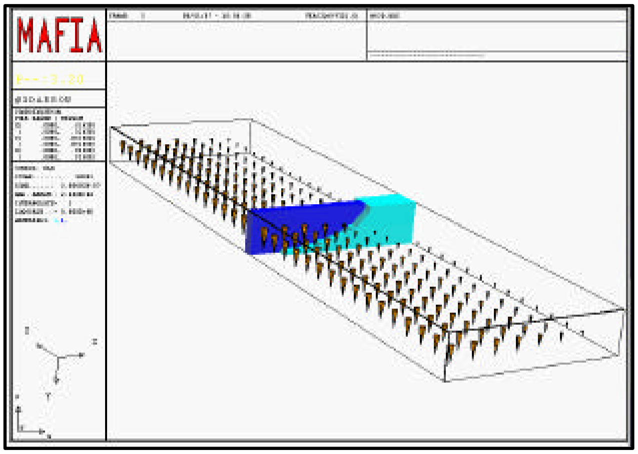

Figure 6: CESR window electric fields as calculated by MAFIA

4.2 Thermal Analysis

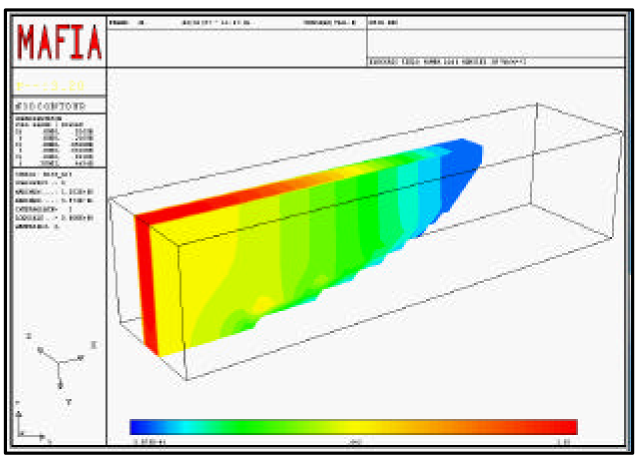

Figure 7: Heat load in CESR Ceramic

The heat load in the ceramic as calculated by MAFIA is shown in figure 7 and was used as the input for an ANSYS thermal analysis of the window. ANSYS analysis generated the temperatures and stress in the ceramic. Thermal results corresponding 1 MW forward power indicated a ΔT in the center of the ceramic of only 4.2 C. Thermal stresses combined with the one atmosphere pressure stresses are only 2.8% of the ceramic tensile strength. The reason for the good thermal performance of this window design is the excellent thermal conductivity of the BeO ceramic, and the good thermal path to the edge cooling channel.

The thickness of the ceramic in this window is constant. We evaluated the effect of a shaped ceramic, thinned out in the middle in a fashion similar to the JLAB window. Unlike the JLAB window the CESR window does not have a broad band operating requirement, the thinning was done in a effort to reduce heating in the ceramic. The heat load and resulting thermal stress in the ceramic was indeed reduced, however the reduced thickness also resulted in an increase in the pressure stresses. The result was that there is no net gain in shaping the thickness of a BeO ceramic for this application. The principle difference between the JLAB window and the CESR window, aside from the size, is that the CESR window has a goal of a 250C bakeout. The primary focus of our thermal analysis has been to determine the impact of this bakeout on the window assembly and ensure a suitable joint configuration.

4.3 Mechanical Design

A preliminary mechanical design has been completed for the CESR window based upon the POP process steps that incorporates the results of the thermo-structural analysis. The complete CESR assembly is shown in figure 8. Tests and further analyses will determine the flange material and the details of the final attachment process.

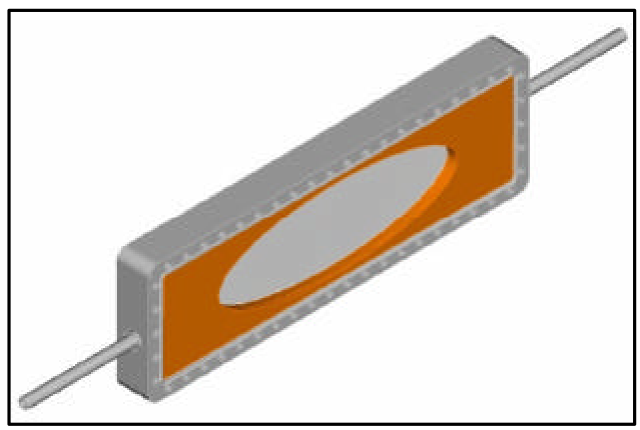

Figure 8: Complete CESR Window Assembly

5 CONCLUSION

We will soon begin the procurement of BeO ceramics for the JLAB and CESR window. We plan to fabricate six windows of each type. Five of each which will be made available to JLAB and Cornell for test and other use as they see fit.

REFERENCES

[1] E. Chojnacki, et al., “Design of a High Average Power Waveguide Window.”, Proceedings of the 1997 Particle Accelerator Conference, Vancouver BC.