RF, THERMAL AND STRUCTURAL ANALYSIS OF A HIGH POWER CW RF WINDOW[1]

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Abstract

The present Jefferson Lab Free Electron Laser window requirements were used to develop a RF window design. These requirements include 1.497 GHz as the design frequency, and require the window to pass higher modes that originate in the cavity. The VSWR should be less than 1.1:1 at the design frequency and no greater than 1.5:1 at frequencies up to 2.2 GHz. The finite element method was used with the same node and element connectivity for the RF, thermal, and structural models enabling loads to be passed directly. Dielectric losses from the RF analysis were passed directly to the thermal model as heat loads within the window. The temperature distribution is calculated and passed directly to the structural model. The broadband VSWR requirements of the window are achieved by varying appropriate geometry parameters. Maintaining these parameters at reasonable minimum dimensions provides for up to three atmospheres of pressure differential. The high thermal conductivity of BeO and a cooling channel located around the window edge enables efficient heat removal from the window and therefore high power throughput, greater than 100 kW.

1 INTRODUCTION

As radio frequency (RF) accelerator technology has advanced over the past several decades, the accelerating structures have improved to allow for higher accelerating field and beam current. These advances have occurred in both normal and superconducting structures. As these barriers have been broken, the fundamental limiting technology has become the RF transmission system. Specifically the RF vacuum window. Next generation accelerator systems will place high demand on the RF window. In the case of windows at frequencies near 500 MHz current technology limits the power to 200-300 kW CW, and at frequencies such as Jefferson Lab's FEL which operates at 1500 MHz the power is presently limited to around 50 kW CW. These limitations require additional power feeds which become more significant as the beam power per unit length requirements continue to rise. This paper addresses the RF, thermal and structural analysis methods and results to design a backup window for the JLAB FEL requirements.

2 REQUIREMENTS

JLAB FEL requires a wide RF bandwidth to pass higher modes that originate in the cavity and pass back through the window. The voltage standing wave ratio, 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 2.2 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.

3 MODELING

The finite element model is used to represent the waveguide space, the change in dielectric due to the window material and the metal boundaries of the waveguide/window. The voltage standing wave ratio is determined from the reflected and input power at the driven port. Figure 1 shows the finite element model surfaces and the BeO window which is defined by its dielectric constant and its loss tangent.

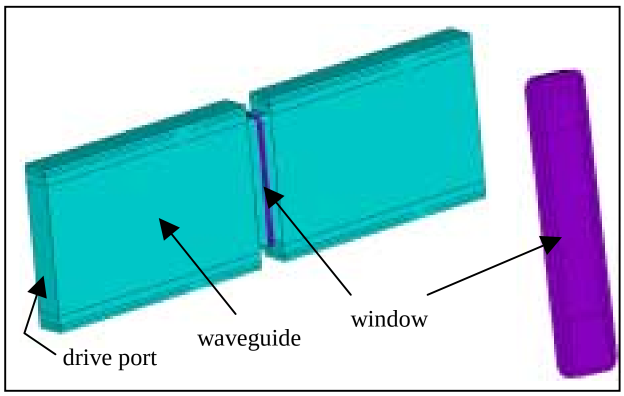

Figure 1, RF window/waveguide model

The window thickness is necessarily small to achieve broadband capability. We also require a relatively thick edge of ceramic to enable an edge attachment. This drives us to a window thickness that varies from its center

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to its edge. The window height is fixed at .986 inches, the other dimensions shown on Figure 2 are design parameters. Analysis was completed for many combinations of the design parameters, window center thickness, edge thickness, edge depth and window width.

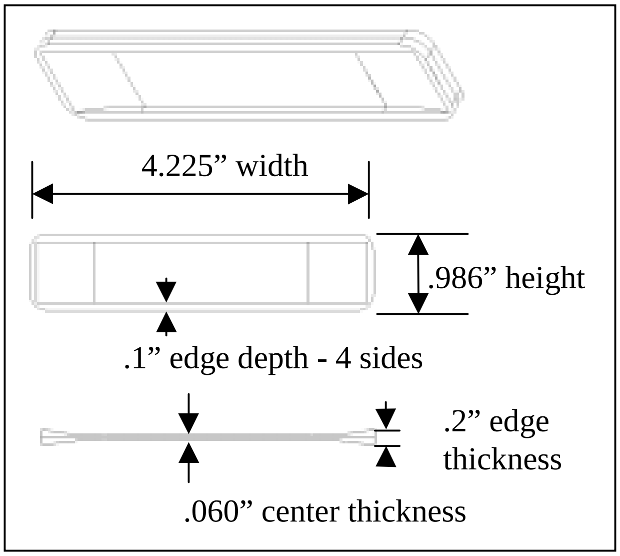

Figure 2, Window design parameters

Table 1 shows the results for a few of the combinations. The shaded geometry shows the dimensions that were determined to give the best overall RF and structural design.

Table 1, Comparison of Geometry results

Geometry				VSWR	
Edge thickness	Edge depth	Window width	Center thickness	1497. MHz	2200. MHz
.25	.15	3.5	.10	2.86	2.00
.25	.15	4.0	.10	1.24	2.40
.09	.25	4.2	.05	1.06	1.53
.10	.25	4.0	.04	1.27	1.51
.10	.20	4.225	.06	1.09	1.50

4 RF RESULTS

The voltage standing wave ratio, VSWR, was determined for the shaded geometry at a frequency range from 1.3 GHz to 2.2 GHz, figure 3. At 1.497 GHz , the nominal frequency, the VSWR was determined to be 1.087. The width of the window helps provide for a minimum VSWR near the design frequency. The center thickness of the window is made small but still can withstand more than 3 atm.. The edge depth is minimized but kept large enough for the cutting process, and the edge thickness is then decreased until the VSWR at 2.2 GHz is at 1.5:1.

The finite element code 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 6.7, a loss tangent of .3 e-3, and 100 kW of through power. The total power lost in the ceramic was determined to be 19.3 watts.

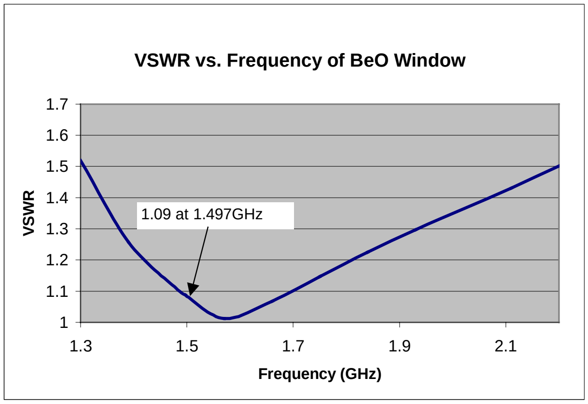

Figure 3, VSWR for required frequency range

5 THERMAL ANALYSIS

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 thermal model as was used in the RF model. A .1 inch thick copper band was modeled with convective boundaries on its outer surface to include water cooling. Figure 4 shows the resulting thermal contours. The maximum temperature occurs in the center of the ceramic, which is

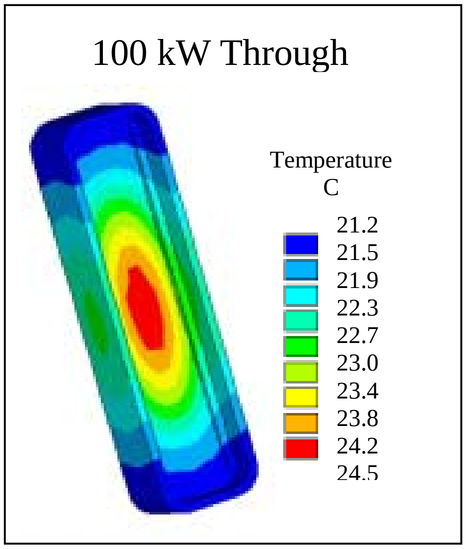

Figure 4, Window temperature contours

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.

6 STRUCTURAL ANALYSIS

The same node and element set were used to determine stresses in the window and copper band for the resulting temperature distribution with 3 a atmosphere pressure differential assumed across the window. Stress contours are given in figure 5 for the maximum and minimum principal stresses. The maximum principal stress is local and occurs, in the model, on the top and bottom edges on the applied pressure side, as shown in the figure. The stress in the window center peaks about 2650. Psi. The allowables given by Brush Wellman for Thermalox 995 are 30. ksi flexural, 18. ksi tensile and 225. ksi compression. These stresses are well within the published allowables.

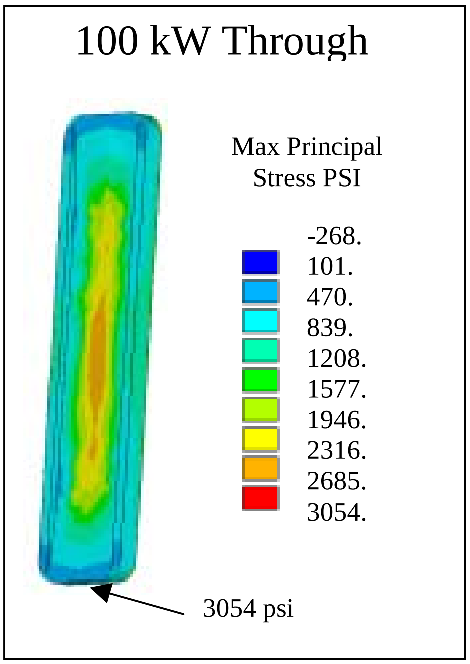

Figure 5, Principal stress in window

7 CONCLUSIONS

By varying appropriate geometry parameters the broadband VSWR requirements of the window are achieved. Maintaining these parameters at reasonable minimum dimensions provides for up to 3 atmospheres of pressure differential. The high thermal conductivity of BeO enables efficient heat removal from the window and therefore high power throughput, > 100 kW.

REFERENCES

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