DEVELOPMENT OF A 50 KW CW L-BAND RECTANGULAR WINDOW FOR JEFFERSON LAB FEL CRYOMODULE*

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Abstract

A 50 kW CW L-Band Rectangular Ceramic Window has been developed for the Jefferson Lab FEL quarter cryomodule. RF properties of the windows were optimized using high-frequency simulation codes and S-parameter measurements confirmed the predicted broad band matching properties of the structure. Metallized AL 995 alumina ceramic was brazed to a thin copper eyelet and the eyelet to a copper plated stainless steel flange. Losses in the metallization were removed efficiently by a water cooling circuit. High power tests in a resonant ring showed that the ceramic temperature rise was very low at 50 kW CW level.

1 INTRODUCTION

The Jefferson Lab FEL injector uses a pair of superconducting cavities inside a quarter cryomodule. The RF waveguide assembly of each cavity consists of a warm RF window, a warm to cold vacuum waveguide and a cold RF window. Each of the two cavities needs 35 kW of RF CW power (including microphonic headroom) to accelerate a 5 mA beam to a total of 10 MeV. The polyethylene warm window used in CEBAF cannot handle that amount of power. Originally, a few warm windows were fabricated using the cold ceramic window's design [1] by replacing the niobium flange by a copper plated stainless steel flange. High power tests in a resonant ring showed that they failed at 20-25 kW CW power levels, due to thermally-induced stress cracking of the glass-free pure alumina ceramic. Infrared temperature measurements showed that the temperature rise at the center of the ceramic window was abnormally high, contrary to expectation. This material had exhibited the lowest loss at 2 K, but became very lossy at 300 K. It is a transparent polycrystalline alumina which is fired in hydrogen instead of air during manufacture. A partial reduction of the alumina produced an RF loss at 300 K but not at 2 K. Air firing restores the ceramic at 300 K to a state of low RF loss. When the lossy ceramics were replaced by a low loss alumina, the temperature rise at the center of the ceramic was much lower than that at the edge. Losses in the metallization therefore become dominant.

We took advantage of this opportunity to reduce thermal gradients and the ensuing stress by absorbing the heat where it is produced. This is accomplished by incorporating water cooling within the flexible braze transition between the ceramic window and the surrounding metal flange, such that the braze metallization is directly cooled by the water through a thin copper layer. In this configuration, the power level at which thermally-induced stress cracks can occur is limited by thermal gradients in the ceramic. These are produced by a non-zero thermal heat transfer coefficient between water and copper, and dielectric losses in the ceramic. The new design will provide higher transmitted power levels than the existing design, and consequently a better margin of safety for the Jefferson Lab FEL.

2 RF DESIGN

The voltage standing wave ratio (VSWR) should be a minimum, less than 1.10:1 at the nominal design frequency of 1.5 GHz and should be less than 1.50:1 at frequencies up to 2.2 GHz. Minimum VSWR at 1.5 GHz is achieved by providing a protruding iris in the frame from each side of the waveguide wall. This iris will produce a reflection which is opposite in phase to the unavoidable reflection from the ceramic. By choosing the proper iris size and thickness the reflections can be made to nearly cancel at the design frequency thereby producing a minimum in VSWR at that frequency.

The minimum will be either broad or narrow depending on the thickness of the window and size of the iris. If the window reflection is small and therefore the canceling reflection from the iris is also small, then the minimum will be broad.

The ceramic reflection is kept small by making that portion of the ceramic protruding into the waveguide as thin as possible. The edges of the ceramic, which are thicker for reasons of strength and providing a substantial boundary to braze to, are recessed into the waveguide walls. Fig. 1 shows the basic design of the window.

The ceramic is ground to a desired shape which varies in thickness, being 0.050" at the mid- section and 0.250" at the edges. The ceramic is thin enough to keep the VSWR low from 1.3 GHz to 2.2 GHz and thick enough to withstand a pressure differential of approximately three atmospheres. The ceramic is a polycrystalline high purity alumina (WESGO AL995) having a dielectric constant of about 9.3 at 1.5 GHz. The ceramic is placed at the center of a thin wall copper eyelet 0.9" in length. The length of the thin wall copper eyelet is chosen long enough to

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allow flexibility between the ceramic and the stainless steel flange.

The thickness at mid-section of the ceramic and the length of the eyelet have been optimized using HFSS [2]. The window is inserted between two 5.292" x 0.986" rectangular waveguides.

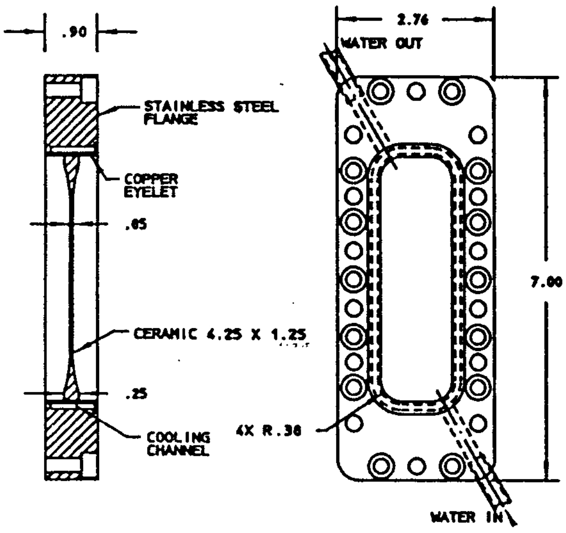

Figure 1 Basic design of the window

The calculated VSWR of the window between 1.3 GHz and 2.2 GHz is given in Fig. 4 (dotted line). When using a dielectric constant of 9.3, the minimum is at 1.48 GHz and the VSWR at the operating frequency of 1.497 GHz is less than 1.02:1. Choosing a dielectric constant lower than 9.3 would shift the minimum to higher frequencies.

3 WINDOW FABRICATION

Fig. 2 shows the main elements of the window: the ceramic, the thin wall copper eyelet and the copper plated stainless steel flange. The ceramic was ground from AL-995 material and metallized with a conventional tungsten-manganese process.The ceramic was first brazed to the copper eyelet using 50-50 copper-gold alloy. This assembly is then brazed to the copper plated stainless steel flange using copper-silver eutectic alloy. After brazing and leak checking, the ceramic window is coated with 35 Å of chrome oxide on the vacuum side to prevent multipactoring.

Fig. 3 shows the completed window with cooling tube as seen from the klystron side.

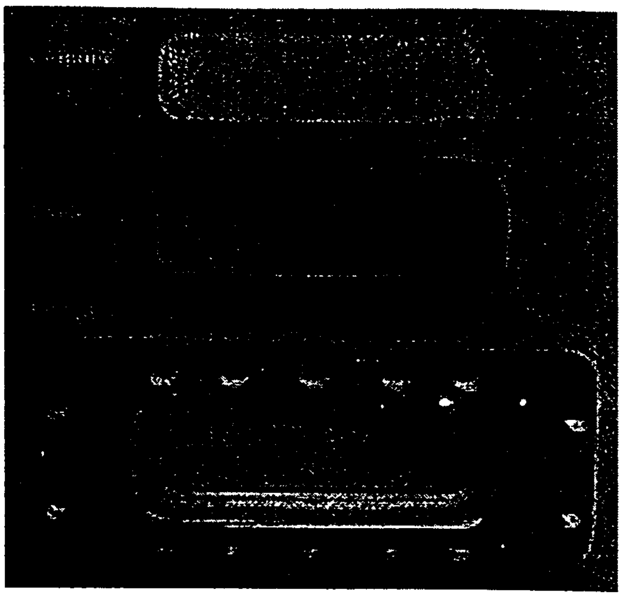

Figure 2. Main elements of the window

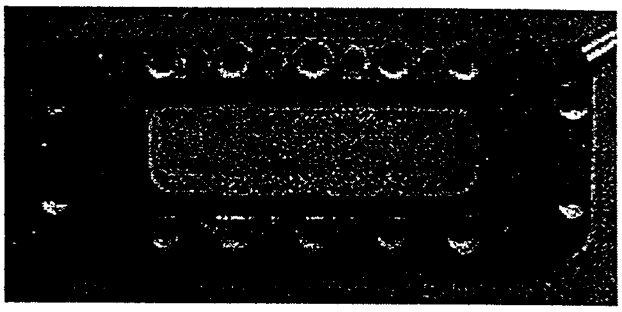

Figure 3. Completed window

4 LOW POWER TESTS

The window was measured using a vector network analyzer. The analyzer was calibrated in 5.292" x 0.986" waveguide using the Thru-Reflect-Line (TRL) method. The measured and calculated VSWRs as a function of frequency are shown in Fig. 4.

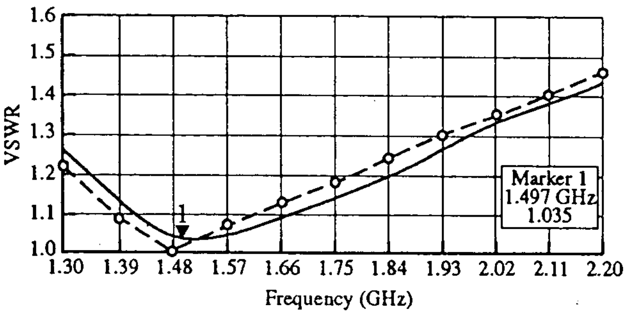

Figure 4. VSWR vs Frequency. Comparing measured data (solid line) to HFSS calculation (dotted line)

The actual measured VSWR confirmed quite well the calculated values.

5 HIGH POWER TESTS

The window was first tested in a resonant ring [3] with air on the two sides to evaluate its thermal performance. RF power up to 53 kW was applied to the window while the ceramic temperature was monitored by an infrared-thermometer. For a window cooled with 34°C Low Conductivity Water (LCW), the temperature rise of the window ceramic is shown on Fig. 5. At 53 kW, the temperature rise was only 7.2 °C. On the other hand, when the window was not cooled with LCW, the temperature rise above room temperature increased to 36°C.

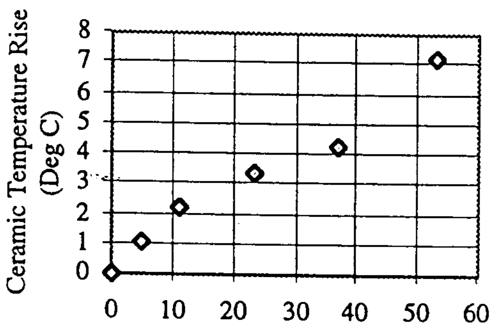

Figure 5. Ceramic temperature rise vs power

The window was examined after testing. No visible damage was observed, and it remained leak tight.

High power testing of the windows under vacuum is carried out using a test setup which uses two windows back-to-back with a vacuum region in between. This test setup is evacuated with a 160 l/s ion pump and is equipped with a pressure gauge, an electron probe and an arc detector. An infrared-thermometer is used to record the temperature of the window ceramic from the air side. The window test setup is also equipped with an interlock system which shuts off automatically the RF power if there are any sustained light longer than 100 µs and/or any increase in the pressure between the two windows beyond $3x10^{-7}$ Torr.

Fig. 6 shows the layout of the high power test setup. RF power was fed by a 35 kW klystron. The output side was terminated with a matched load. Prior to applying high CW power, the windows were conditioned up to a peak power of 35 kW with a pulse width of 5 µs and a repetition rate of 100 Hz. During the conditioning, sudden gas bursts and electron currents were observed. After conditioning, CW power up to 35 kW could be applied quickly to the windows without any sign of electron activity. The temperature rise above LCW temperature (33°C) of the window 2 was 5.7°C at 31 kW.

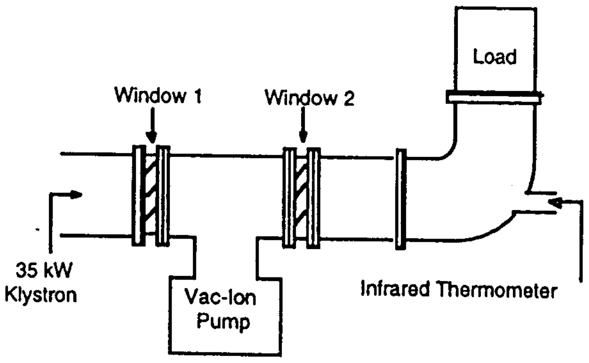

Figure 6. High power test setup

6 CONCLUSIONS

A window has been designed and fabricated which meets fully the design goals. Both low and high power tests of the window have been performed. As temperature rise of the window was very low at 50 kW, it should be possible to use the window at power higher than 100 kW, which is required to increase the beam current of the FEL injector beyond 5 mA.

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8 REFERENCES

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[2] Ansoft HFSS, by Ansoft Corporation, http://www.ansoft.com, commercially licensed software
[3] V. Nguyen-Tuong and L. Phillips, "Resonant Ring and RF Window Testing", Jefferson Lab TN #95-022