EXPERIMENTAL EVALUATION OF 350 MHz RF ACCELERATOR WINDOWS FOR THE LOW ENERGY DEMONSTRATION ACCELERATOR*

K. Cummings, D. Rees, W. Roybal, Los Alamos National Laboratory, Los Alamos, NM 87545 and
S. Lenci, Communications and Power Industries, Inc, Palo Alto, CA 94303 and
S. Risbud, University of California, Davis, CA 95616 and
C. Shang, Lawrence Livermore National Laboratory, Livermore, CA 94551 and
D. Wilcox, EEV, Ltd. Chelmsford, England

Abstract

Radio frequency (RF) windows are historically a point where failure occurs in input power couplers for accelerators. To obtain a reliable, high-power, 350 MHz RF window for the Low Energy Demonstration Accelerator (LEDA) project of the Accelerator Production of Tritium program, RF window prototypes from different vendors were tested. Experiments were performed to evaluate the RF windows by the vendors to select a window for the LEDA project. The Communications and Power Industies, Inc. (CPI) windows were conditioned to 445 kW in roughly 15 hours. At 445 kW a window failed, and the cause of the failure will be presented. The EEV windows were conditioned to 944 kW in 26 hours and then tested at 944 kW for 4 hours with no indication of problems.

1 INRODUCTION

For the LEDA project, the radio frequency quadrupole (RFQ) requires 2.1 MW of RF power. This power is supplied by three 1.2 MW continuous wave (CW) klystrons in a redundant configuration. The power from each klystron is divided into four equal parts to minimize the window stress. Under typical operating conditions, each window is designed to transmit up to 300 kW of CW RF power. The goals of these experiments are to select a reliable window, to determine what diagnostic equipment is needed to ensure window reliability, to develop a conditioning routine, and to increase the durability of RF windows by better understanding the failure mechanism of windows.

2 EXPERIMENTAL APPARATUS AND PROCEDURE

2.1 Window Geometry

The RF window prototypes from CPI and EEV are both coaxial windows and are illustrated in Fig. 1 and Fig. 2, respectively. The cross section of the EEV window is shown in Fig. 3. Both windows used half-height WR 2300 waveguide and AL995 alumina ceramic. For both prototypes the waveguide transition on the vacuum side was copper plated stainless steel waveguide, and on the air side it was aluminum.

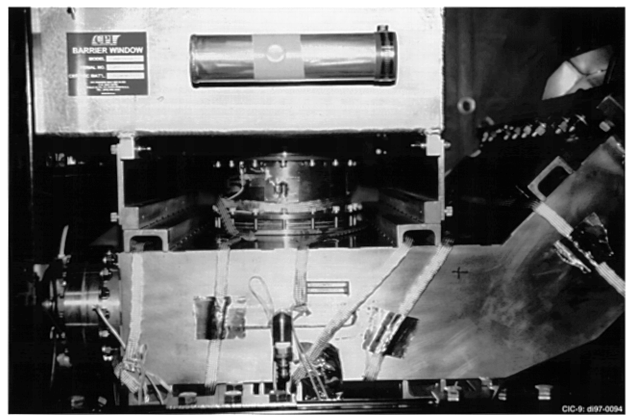

Figure: 1 CPI RF Window

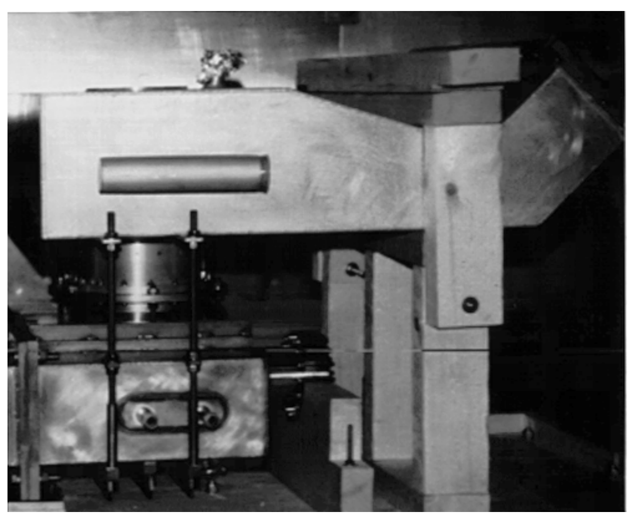

Figure: 2 EEV RF Window

2.2 Test Stand Description

An experimental test stand was designed and built to test the windows to 1.0 MW of CW RF power. The test stand includes diagnostic equipment to test, condition, and

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evaluate the RF window prototypes. The power was transmitted from the klystron through a circulator to the experimental test section, and finally into a water load where it was absorbed. The experimental test section includes an RF window, vacuum waveguide, and a second RF window in a back-to-back configuration. Thus, the vacuum section was bounded by the two windows. Each window has a four-inch pump port and the vacuum waveguide between the windows included an eleven-inch pump port. The vacuum was obtained by using three CT-8 Cryo-pumps. STABIL-ION gages, calibrated to a 2% accuracy, were used to monitor the vacuum pressure. Saito, et. al. have found that for the dominant method of coaxial window failure is thermal fracture[1], therefore, infrared imaging of the ceramics windows was used as a diagnostic tool. PRISM DS infrared imaging cameras by Flir Systems (320 x 244 pixels) were used to monitor the temperature of the ceramic during conditioning and testing. The infrared cameras were connected to a VCR to record video footage. Images could also be stored on a PC card which could be downloaded for further data analysis. On the CPI windows, a special port was dedicated for infrared imaging. NaCl windows, which have a high transmission in the IR range, were used for thermal imaging. These windows could be interchanged with a Lexan lens. On the EEV windows, a port with a sapphire lens was used which could mount either an arc detector or be used for infrared imaging. Both window prototypes had arc detectors which were interlocked to the RF drive power. Dual directional couplers were used to measure the forward and reflected power both before and after the test section. Resistive Thermal Devices (RTD) were attached

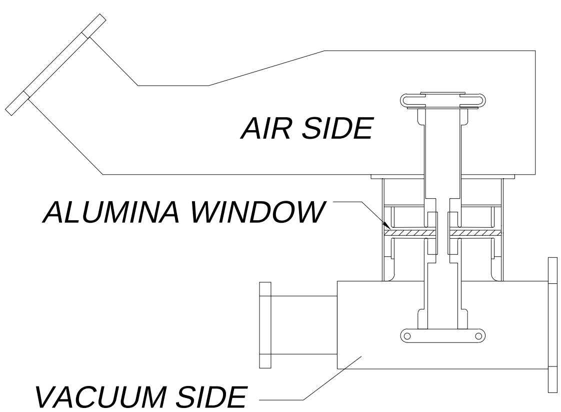

Figure: 3 Sketch of the EEV window

to the outside surface of the coaxial window near the alumina ceramic to measure the surface temperature. Both windows were air and water cooled. The air and water supply and return temperatures and flow rates were also monitored. An X-ray detector was used to detect X-rays near the vacuum section as a multipactor diagnostic. A LabVIEW program recorded the forward and reflected power on the three directional couplers, the coaxial surface temperatures near the ceramic, the air and water supply and return temperatures, and the vacuum pressure. The arc detector and vacuum pressure were interlocked to the RF power, and the interlock set points could be varied.

2.3 Test Parameters

Half-height WR 2300 waveguide was used to join the RF window prototypes to the test stand and to the vacuum section between them. For the rest of the test stand, full-height WR 2300 waveguide was used. The power was generated by a Thomson klystron capable of producing 1.3 MW CW RF power at 351.93 MHz; however, the power was limited to the 1.0 MW because of the power limitation of the water load.

3 EXPERIMENTAL RESULTS

3.1 CPI RF Window Test Results

A low temperature bakeout was performed for 8 hours at roughly 130 °C on the CPI windows. Before conditioning began, the air flow was measured as 85 cfm through one window and 95 cfm through the second window. The water flow rate was set to 3 gpm. The CPI window was conditioned with pulsed RF power. The RF “Tickle” method of processing (a short pulse on top of a pulse), was used[2]. However, the benefit was not quantifiable. The approach was to start with a short pulse width and then increase the pulse width with time. During conditioning the vacuum pressure was allowed to rise to a maximum of 5E-8 Torr while maintaining the RF power level. Once the vacuum pressure decreased to approximately 2E-8 Torr, the RF power was increased. The windows were conditioned for approximately 15 hours to 445 kW CW power before failure. On one CPI window, excessive heating was observed using the IR camera in the center conductor region. It was first attributed to multipactor; however, we later learned this to be incorrect and now believe that the failure mechanism described below led to a source of molten copper being available which was deposited onto the window ceramic by a subsequent arc. After the arc occurred, no significant CW power could be transmitted through the window because of excess heating in the window; nevertheless, the window did maintain the vacuum seal. The testing was discontinued and the window was shipped to CPI for analysis. The analysis showed that a bolted connection close to the ceramic window was made from a inappropriately soft material. Due to thermal cycling a gap opened in the connection, resulting in a plasma and an arc. This led to localized ceramic melting and the deposition of evaporated materials on the ceramic surface. CPI decided to do some minor modifications to the design of the window, and both windows were rebuilt. The redesigned windows have not yet undergone high-power testing.

3.2 EEV RF Window Test Results

The air flow rates were measured as 80 cfm and 100 cfm through the two windows. The water flow rate was set to 4.5 gpm on each window. No bakeout was conducted on the EEV window, and it was conditioned using only CW power. The EEV window was conditioned to 950 kW in approximately 26 hours, as illustrated in Fig. 4. At low power levels, the arc detectors would occasionally trip and a corresponding increase in gas pressure was observed. These trips were suspected as being caused by a fluorescence due to multipactor, which was not seen at higher power levels. Saito, et. al. have observed a fluorescence with a monochrometer on a test window and correlated it with multipacting associated with the impurities in alumina ceramic [3]. The vacuum pressure interlock was set to 5E-7 Torr. Slight increases in the gas pressure over 5E-7 Torr lead to a "run away" in the pressure, thus the gas pressure was carefully controlled by reducing the RF power when necessary. The high-power acceptance test for the EEV windows consisted of running the EEV windows at approximately 950 kW for 4 hours. During this time, there were no indications of any problems. The EEV window had both air and vacuum region arc detector viewports. After the high-power acceptance tests, the air

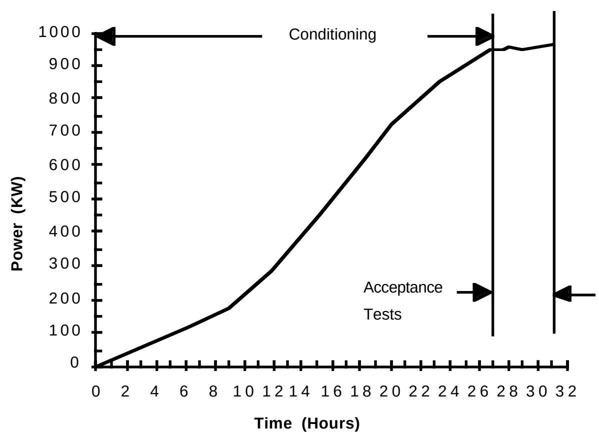

Figure: 4 EEV Forward Power vs Time

side arc detector was replaced by an IR camera. The IR imaging on the EEV window showed no indications of any problems or hot spots during operation. Another test conducted on the EEV windows was to use the windows in a degraded vacuum environment. Two of the three Cryo pumps were shut off, and the vacuum pressure was increased to 3.9E-6 Torr. There were no indications of any problems after running one hour at full power. The EEV windows were also tested using a reduced air flow rate of 25 cfm as opposed to the 80 cfm to 100 cfm used during the conditioning and acceptance tests. At full power, there was no noticeable increase in the water cooling temperature, but the vacuum pressure did increase by half an order of magnitude. The temperature of the ceramic increased by approximately 10 °C; nevertheless, the temperature gradient across the window remained small.

4 DISCUSSION

Monitoring the power during the pulsed conditioning method was more difficult than the CW conditioning method. Since there was no quantifiable benefit observed for pulsed conditioning, future windows will be conditioned CW. The IR camera is an invaluable diagnostic tool to observe the temperature profile on the ceramic window, especially during conditioning, to detect any indications of failure. For example, the IR camera showed an elevated temperature on the CPI window before the failure. The benefit of the X-ray detector as a diagnostic was not evident, as during the entire conditioning and test procedure, no X-rays were detected.

5 CONCLUSIONS

Los Alamos National Laboratory has ordered an additional 15 windows from EEV for the RFQ on LEDA. There seems to be no indication of any problems with the EEV windows. We realize that testing the windows into a matched load is not the same environment as passing RF power through the windows into an accelerator cavity with beam. Our future tests include testing the EEV windows passing power into RF cavities, as well as retesting the modified CPI windows, and finally testing the EEV windows to destruction by increasing the voltage standing wave ratio (VSWR).

6 ACKNOWLEDGEMENTS

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