LA-UR- 98-3591

RESULTS AND LESSONS LEARNED FROM CONDITIONING 1 MW CW 350 MHZ COAXIAL VACUUM WINDOWS[*]

CONF-980827--

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ABSTRACT

The reliability of the radio frequency (RF) windows on the Low Energy Demonstration Accelerator (LEDA) is critical to the success of the Accelerator Production of Tritium Program (APT). On the APT accelerator there will be over 1000 windows, each passing on the order of 250 kW of CW RF power. This power level is well above power levels historically used in RF windows. Based on the high-power RF test results of the RF window prototypes from vendors, the coaxial windows made by EEV Ltd. of Chelmsford, England, were selected for LEDA. This paper describes the high-power RF testing of the 16 EEV coaxial windows. The RF window diagnostic equipment, data acquisition system and test stand are described. The results of the high power RF testing of the windows are presented. The successes and failures in the conditioning, manufacturing and testing techniques of the windows are presented. The conditioning timeline, power profile and the conditioning waveform are also discussed.

1 INTRODUCTION

To select a reliable RF window for the radio frequency quadrapole (RFQ), prototype windows were tested from three different vendors. Based on the prototype test results EEV, Ltd. of Chelmsford, England was selected as the vendor for the 350 MHz RF windows. This paper describes the high power acceptance testing of the windows ordered for the RFQ. Under normal operating conditions these windows are required to transmit up to 250 kW of continuous wave (CW) RF power. Prior to acceptance from the vendor each window was conditioned to 1 MW of CW RF power and run at 1 MW for four hours to obtain steady state results. The power was generated by a EEV klystron capable of producing 1.2 MW CW RF power at 350 MHz.

2 EXPERIMENTAL SETUP

2.1 Window Geometry

The cross section of the EEV window is shown in Fig. 1. The window is a coaxial AL300 alumina ceramic. The air and vacuum side flanges are half height WR2300 and T-bars are used on the air and vacuum sides of the window to transition to the coaxial line. The waveguide transition on the vacuum side is copper plated stainless steel waveguide, and on the air side it is aluminum.

2.2 Test Stand

The experimental test stand is capable of testing four windows at a time. The four windows are in two pairs in a back to back configuration. The test stand is capable of passing 1 MW CW RF power through the windows. The windows are both air and water cooled. The water cooling is circulated through the vacuum side

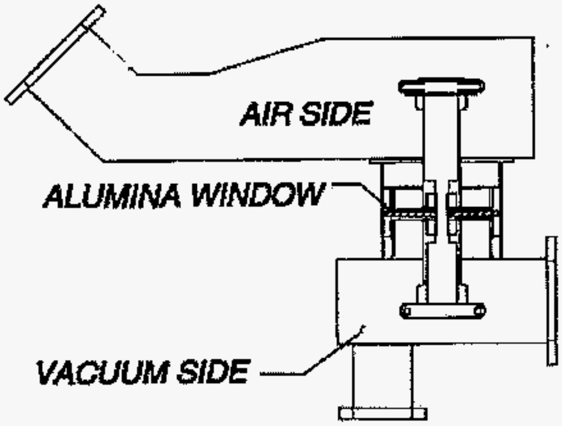

Figure 1. Sketch of the EEV Window

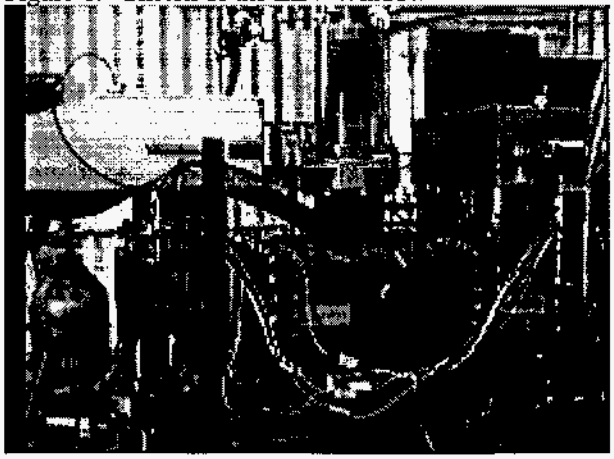

Figure 2. RF Window Pair on the Test Stand

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[*] Work supported by U.S. Department of Energy.

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T-Bar. The air cooling goes through the air side T-bar,down the inner conductor, exits the inner conductor through a series of holes and is directed over the ceramic. Then the air exits the outer conductor through a series of holes. A RF window pair in a back to back configuration is shown in Figure 2.

2.3 Diagonsitc Equipment

The RF window test stand includes many diagnostics. The vacuum pressure is measured at three places in each window pair. It is interlocked to the RF power. The pressure setting for the RF interlock is adjusted during the conditioning routine. Each RF window has two fiber optic arc detectors, one on the air side and one on the vacuum side. The arc detectors are also interlocked with the RF power and will shut down the RF drive for 1.6 seconds upon detection of an arc. The water and air inlet and exit temperatures are monitored and interlocked with the RF power. In addition, the temperature of the outer coaxial surface in the region of the alumina ceramic is also monitored and recorded. An infrared camera was used to obtain the temperature distribution across the ceramic.

2.4 Data Acquisition System

The data acquisition system is used to record data from the RF window test stand and the klystron. The coaxial RTD and vacuum and arc detector data is read by a LabView program and archived. The air and water temperatures are recorded by the klystron transmitter PLC. The RGA data are read from a second LabView program. A master processor has access to all the data and allows for a common display.

3 EXPERIMENTAL RESULTS

3.1 Processing Results

The ceramic on the prototype windows was coated with copper black to prevent multipacting. During the high temperature bakeout, the coating was discolored and redistributed over the ceramic and metal surfaces. These surfaces were grit blasted to remove the coating. The prototype windows conditioned to 1 MW in 26 hours and no excessive heating or arcing were observed. The first two windows after the prototypes were not grit blasted. Excessive heating and arcing were seen as shown in Figure 3, and one of these windows failed at 500 kW. From then on, all the windows were grit blasted.

All the grit blasted windows achieved the expected power level of 1 MW and conditioned in a timely manner. Windows that were originally grit blasted at EEV had to be grit blasted again at LANL. The difference in the grit blasting is assumed to be due to differences in nozzle size and geometry. At LANL a small nozzle with a 90° bend was used allowing easy access to the corners and back sides. EEV has now adapted the same nozzle as at LANL. The windows were grit blasted with 220 alumina grit at 55 psi.

3.2 RF Conditioning Results

A low vacuum pressure is essential during RF conditioning. At higher pressures, more arcing and heating occurred. The vacuum interlocks were set at 1 x 10^{-5} Torr for power levels less than 100 kW, 5 x 10^{-6} Torr for power levels between 100 kW and 500 kW, and 2 x 10^{-6} Torr for power levels above 500 kW.

During conditioning it is important to monitor the rate of temperature increase as a function of RF power. By conditioning 4 windows at a time, nonlinear temperature increases are easier to detect. An example of the nonlinear temperature increase is illustrated by the windows that were not grit blasted as shown in Figure 3. If a large temperature increase is detected, the power level is immediately reduced until the temperatures are more typical.

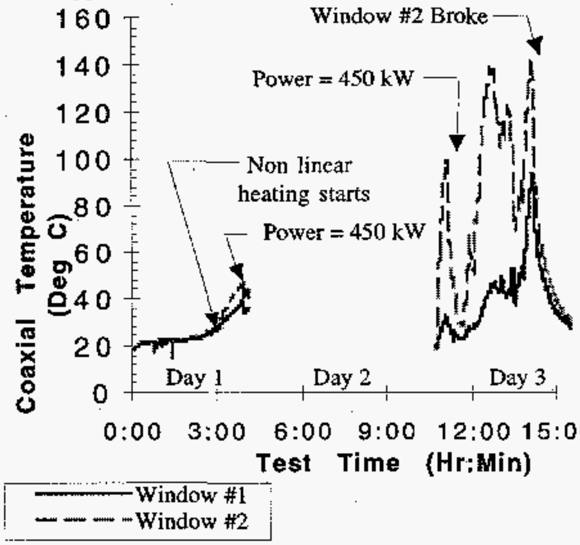

Figure 3. Window Temperature vs. Test Time of Two Windows that were not Grit Blasted.

3.2 High Power Test Results

The time to condition the windows to 1 MW is shown in Figure 4. The average conditioning time is approximately 19 hours and the average outer coaxial temperature near the ceramic at 1 MW is approximately 75 degrees C.

Different RF waveforms used in conditioning included CW, pulsed, and amplitude modulation. In CW conditioning the power could only be increased in discrete steps. The power is increased in decibels, thus, the steps are quite large at high RF power levels. At times, large gas loads were seen due to the large power increase. Pulsed conditioning helps decrease the average power and the heating in the window; however, it does not eliminate or reverse the nonlinear heating which leads to the failure of the window. Amplitude modulation was used as a conditioning method to pass a power region of high outgassing. CW conditioning is easily compared to amplitude modulation in Figure 5.

In this particular case, CW conditioning was used during the first four hours and amplitude modulation was used the remainder of the test time. The increased speed of conditioning the windows with amplitude modulation is easily observed.

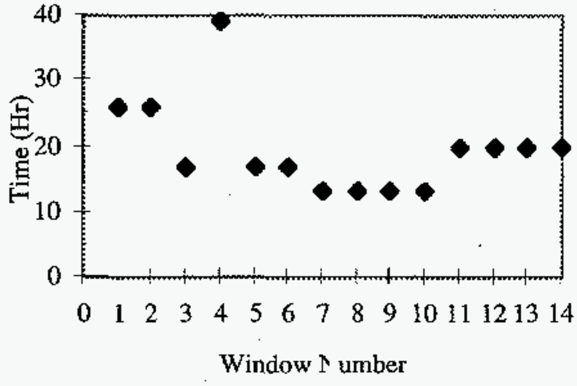

Figure 4. Comparision of Conditioning Times to 1 MW

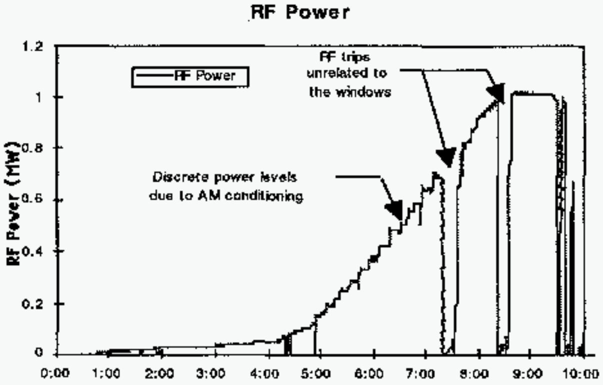

Figure 5. RF Power vs. Test Time with CW Conditioning until 4 hrs. and Amplitude Modulation after 4 hrs.

4 DISCUSSION

Grit blasting is believed to reduce cause of the nonlinear temperature increase by cleaning the surface and changing the surface topography[1]. Changes in the surface topography dull the potential field enhancement sites which reduces multipacting. Surface characterization work showed the grit blasted samples to have a higher carbon content on the surface than non-grit blasted samples[2].

In amplitude modulation a continuous range of power levels are conditioned. As previously discussed, in CW conditioning discrete power levels are conditioned, and when returning to a previously conditioned power level, multipacting may still be seen. With amplitude modulation there are no discrete power levels and multipacting does not reoccur at specific power levels.

During conditioning, two separate phenomena, multipacting and ion bombardment, are thought to be occurring[1]. The signs of multipacting are rapid fluctuations in the vacuum pressure and nonlinear temperature increases with power[3,4]. Multipacting tends to occur at specific power levels for a given window geometry. The second phenomenon is believed to be due to ion bombardment. As electrons are freed from the surface, they are colliding with molecules in the vacuum chamber which produces ions. The ions collide with the surfaces on the vacuum chamber, which causes heating and additional electrons to be freed due to the high kinetic energy of the ions at the time of the collision. As more electrons are freed, more ions are made. Ions may also form when molecules are exposed to small electric fields at less than very good vacuum conditions and the electric fields pull the molecule apart. These ions are then accelerated by the Lorenz forces into a surface where they cause heating and liberate more gas that further drives the process. The ion bombardment can be observed by a slow steady increase in the vacuum pressure. Following the slow steady pressure increase, nonlinear heating can be observed.

5 CONCLUSIONS

Sixteen windows passed 1 MW of power and stabilized to steady state conditions. Grit blasting was found to be a critical processing step to avoid excessive heating and arcing at higher power levels. Amplitude modulation is the recommended method of RF conditioning because it conditions a continuous range of power levels while minimizing the gas load.

6 ACKNOWLEDGEMENTS

The authors would like to thank the people from LANL that helped with the experimental set up, especially Michael Borrego, Jeff Espinoza, Don Clark, J.D. Smith, Stephen Ruggles, Phil Torrez, Manuelita Rodriguez and Michael Collins.

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