STUDY OF ARC-RELATED RF FAULTS IN THE CEBAF CRYOMODULES*

E. F. Daly#, D. Curry, J. Musson, G. Myneni, T. Powers, H. Wang, T. E. Whitlatch,
TJNAF, Newport News, VA 23606, USA
I. E. Campisi, ORNL, Oak Ridge TN 37831-6473

Abstract

A series of measurements has been conducted on two superconducting radio-frequency (RF) cavity pairs, installed in cryomodules and routinely operated in the Continuous Electron Beam Accelerator Facility, in order to study the RF-vacuum interaction during an RF fault. These arc-related fault rates increase with increasing machine energy, contribute to system downtime, and directly affect the accelerator's availability. For this study, the fundamental power coupler waveguides have been instrumented with vacuum gauges, additional arc detectors, additional infrared sensors, and temperature sensors in order to measure the system response during both steady-state operations and RF fault conditions. Residual gas analyzers have been installed on the waveguide vacuum manifolds to monitor the gas species present during cooldown, RF processing, and operation. Measurements of the signals are presented, a comparison with analysis is shown and results are discussed. The goal of this study is to characterize the RF-vacuum interaction during normal operations. With a better understanding of the installed system response, methods for reducing the fault rate may be devised, ultimately leading to improvements in availability.

INTRODUCTION

When an arc occurs in a cavity or its associated waveguide (WG), the RF source is momentarily inhibited to extinguish the arc. This RF fault, or RF trip, interrupts steady beam delivery to the experiments and reduces the availability of the machine. Operator intervention is required to turn the RF back on; operations typically resume within thirty to forty-five seconds. Users generally require less than 10 trips per hour to obtain acceptable data rates. Beam interruptions of less than one-quarter second, if achievable, would have negligible impact on experiments [1].

A significant amount of work has been conducted to investigate the arcing mechanism in the CEBAF cavities when installed in cryomodules [2] and in vertical dewar testing [3-5]. In the presence of field emission, sources of Compton-scattered electrons or photoelectrons ejected from the cavity have been shown to charge the cold window that separates the cavity vacuum space from the cold WG vacuum space. After some time, the window discharges and a light pulse is initiated near the window, either on the cavity-side or WG-side of the cold window. Nearly all of the arcs occur within the WG vacuum space. An ensuing release of gas, previously sorbed on the walls of cold window and WG, produces an increase in the pressure within the WG vacuum space. In addition, temperature increases on the warm window flanges are observed during all types of RF operations.

Three interlocks, developed and used for cavity and cryomodule hardware protection, monitor the arc signal, the cavity warm window temperature (CWWT), and the vacuum levels in the beamline and WG. The specific setpoints for these interlocks were originally developed for 4 GeV operations. Significant increases in trip rates are expected for higher machine energies. By gaining knowledge through characterization of the RF-vacuum interaction, modifications to the interlock setpoints or revisions to the control system may be devised to reduce or eliminate the RF trips.

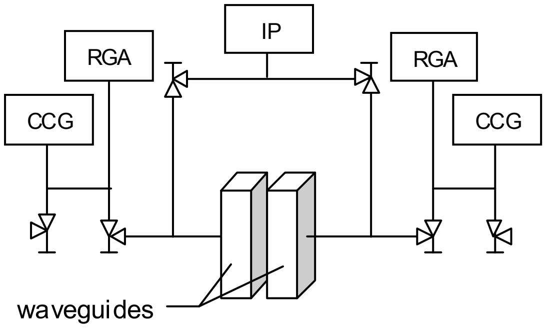

Figure 1: Schematic of the modified waveguide vacuum manifold.

TEST SET-UP

The original CEBAF WG vacuum manifold, consisting of a 20 liter/sec ion pump (IP) and a roughing valve, services a cavity pair. This is replaced with a manifold containing six valves that enable addition of instruments without venting the WG vacuum. The original IP is re-installed. Two residual gas analyzers (RGAs) and two cold cathode gauges (CCGs) are installed on the manifold (Figure 1).

Manifolds, prepared by vacuum baking, are installed at two locations – one in the south linac on cryomodule SL02, cavity pair 7/8, and one in the north linac on NL06 cavity pair 3/4. Cavity 8 in SL02 is by-passed due to a faulty cable for the arc detector. Original warm windows, made from polyethylene, are installed at SL02 while new

---

*Work supported U.S. DOE Contract No. DE-AC05-84ER40150
#eddaly@jlab.org

warm windows, made from alumina, are installed at NL06.

MEASUREMENTS

Cooldown

Both cryomodules were monitored during cooldown as part of the hurricane recovery effort [6]. The curves show a steady decrease in the partial pressures of each species. The onset of cryopumping is indicated by a sharp decrease in the pressures. Thermal equilibrium is achieved after approximately one week. The main species present in the SL02 cryomodule are water, hydrogen and nitrogen indicating the presence of water vapor in the vacuum system. Permeation through the polyethylene over time could explain the water peak. The main species present in the NL06 cryomodule are helium, nitrogen and oxygen. This module exhibited no water vapor, only dry air within the vacuum system.

RF Processing

During initial introduction of RF into cavity 7, transient partial pressures of hydrogen, nitrogen and oxygen were observed. It is possible that with a faster data acquisition rate, more species may have been observed. Prior to processing, the ion pump signal indicated a stable pressure of 8 x 10^{-9} torr. With RF on, pressure transients up to 10^{-7} torr for these three species were observed. After seven hours of conditioning, the vacuum levels within the WG were stable.

Arc-Vacuum Faults

There are three interlocks that protect the cavity and waveguide. The arc detector interlock indicates a fault if the arc signal is greater than an arbitrary voltage level for longer than 500 microseconds. Once RF is switched off, the arc generally extinguishes in three to five milliseconds. The CWWT interlock indicates a fault if the signal exceeds an arbitrary voltage determined empirically to correlate with warm window temperature for each cavity. The vacuum interlock indicates a fault when one of two conditions is met – if the WG pressure exceeds 5 x 10^{-7} torr instantaneously or if the pressure exceeds 1 x 10^{-7} torr for more than five seconds. The lower, slower trip level allows for occasional vacuum spikes that recover quickly [7].

Over a period of eight months, 54 faults have been recorded in the SL02 cavity 7 by triggering on the arc signal only. Once triggered, the arc and vacuum signals were recorded – the arc on a fast time scale and the vacuum on a slower time scale. These events can be sorted into two classes – arcs that extinguish in less than five milliseconds and arcs that continue for up to ten milliseconds. The decay times for the arcs of shorter duration are consistent with previous measurements [2]. The extended duration arcs were traced to a drive laser

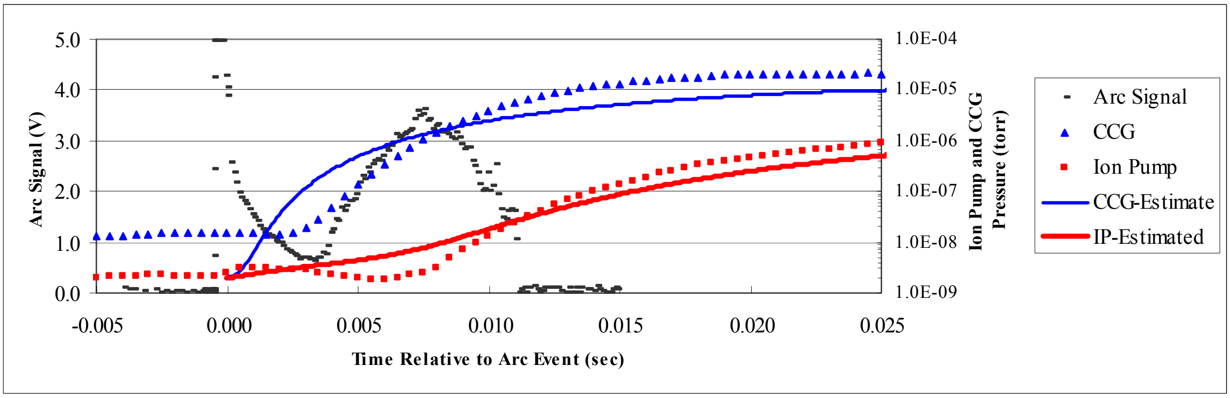

Figure 2: Arc interlock trip followed by increase in pressure within vacuum manifold.

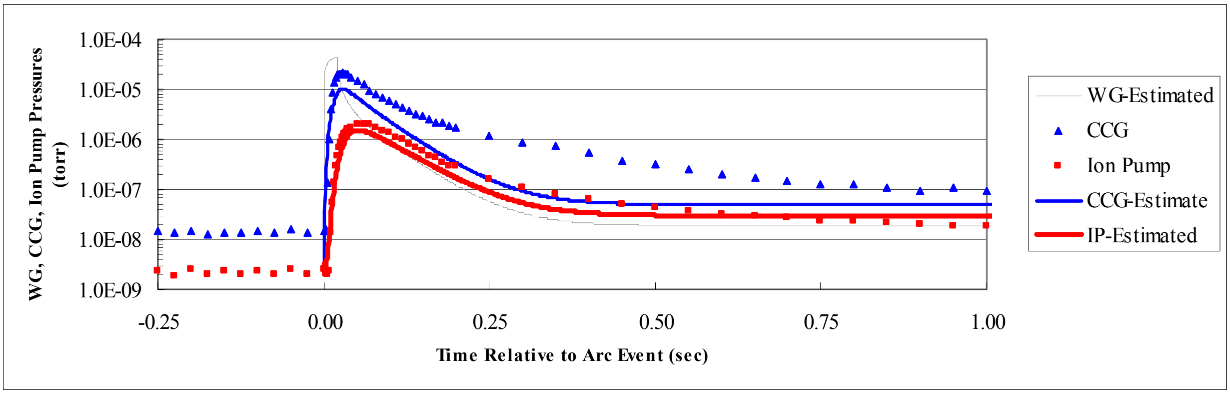

Figure 3: WG vacuum predicted to recover below 10^{-7} torr sooner than CCG or IP.

turn-off time set in the injector. The arcs were being sustained until the drive laser was shut off (Figure 2). The vacuum level then increases, due to the release of sorbed gases within the WG, to a peak value at ~25 milliseconds followed by a recovery in several tenths of a second.

Warm Window Temperatures

Four integrated circuit temperature sensors (LM35) are installed on the outside midpoint of each of the warm window flanges. This enabled a direct comparison between the CWWT signal and an actual temperature indication on the flange exterior. As expected, the ceramic windows, which dissipate more power, operated at higher equilibrium temperatures. One study [8] indicated that CWWTs and LM35s responded initially to changing RF conditions equally well. The CWWTs reached equilibrium ten times faster than the temperature sensors. The LM35s, although slower, provide a more precise indication of the flange temperature.

VACUUM ANALYSIS & DISCUSSION

There is no practical way to directly measure the pressure within the cold WG. In lieu of this, a finite-difference transient vacuum model was created to first match the observed pressure response of the vacuum within the manifold and at the ion pump, and then predict the transient response within the cold WG.

Assumptions & Model Description

The model assumes molecular flow of only one gas species present within the system. Based on RGA data, nitrogen gas was chosen as the dominant species. The outgassing rate of the stainless steel manifold is assumed to be 6×10^{-10} torr*liter/sec*cm^2 [9]. The ion pump speed is constant at 20 liter/sec. The cryo-pumping speed of the cold WG surface is conductance-limited by the opening to the manifold, and is estimated as 20 liter/sec.

The implicit finite difference model is small, containing only nineteen nodes. The total run-time was chosen as five seconds, based on measurements, with discrete time steps of 0.1 milliseconds. Using a square-wave gas pulse and iterating, the calculated response was matched to the measurements, and then the total gas load was estimated.

Results

Calculated and measured peak pressures at the CCG and ion pump were similar in the range of 10^{-5} to 10^{-6} torr, and the rise and decay times agreed well (Figures 2 & 3). The estimated gas released in the manifold is ~2.5×10^{-5} torr*liter during an arc fault. The model shows that the gas is rapidly released into the manifold from the WG. Then the ion pump and cold WG remove the gas from the manifold. The peak pressure within the WG is estimated as ~10^{-4} torr, but recovers more quickly than the ion pump pressure since the gas source and pump are coincident (Figure 3). The model shows that the WG vacuum recovers below the setpoint more quickly than the ion pump – in ~ ¼ second.

CONCLUSIONS

The RF-vacuum interaction in the cold WG has been characterized. Measurements of arc signals are consistent with previous data that have been recorded. Vacuum recovery times on the order of ¼ second have been observed, indicating that it may be possible to automatically turn RF on after an arc event is detected.

RGA scans of the WG vacuums show distinct differences between polyethylene and ceramic warm window vacuums during cooldown. Comparisons of the thermal response of the two window types indicate that the ceramic windows have higher equilibrium temperatures during operation.

FUTURE WORK

More data will be acquired at both locations to characterize the cavity pairs in operation. The NL06 cavity pair, which has replacement ceramic warm windows installed, requires further studies as well to understand potential differences in operation caused by the different window materials.

ACKNOWLEDGEMENTS

Thanks to the Vacuum Group for preparing and installing the hardware. Thanks especially to R. Michaud from Operations who assisted with the data reduction.

REFERENCES

[1] A. Hutton, private communication.

[2] T. Powers et al., “RF Window Arcing Studies Update – A Comparison of Results from Cryomodule 17 and Vertical Cavity Testing,” JLab Tech. Note TN-94-059.

[3] T. Powers et al., “Arcing Phenomena on CEBAF RF Windows at Cryogenic Temperatures,” IEEE Trans. on Nucl. Sci., Proc. of the 1995 Particle Accelerator Conf., Vol. 3, p. 1645-1647.

[4] L. Phillips et al., “Some Operational Characteristics of CEBAF RF Windows at 2 K,” IEEE Trans. on Nucl. Sci., Proc. of the 1993 Particle Accelerator Conf., Vol. 2, p. 1092.

[5] V. Nguyen-Tuong et. al., “Electronic Activity at CEBAF Cold RF Window Induced by Cavity Operation,” JLab Tech. Note TN-94-063.

[6] A. Hutton et al., “JLab Hurricane Recovery,” these proceedings.

[7] G. Myneni, “South Linac RF Thunder Storm Sensitivity and the Modification of Wave Guide Vacuum Interlocks,” JLab Tech. Note TN-00-023.

[8] H. Wang, Internal Report on Warm Window Heating

[9] O’Hanlon, J. F., *A User’s Guide to Vacuum Technology*, 2nd Edition, Wiley & Sons, 1989.