Arcing Phenomena on CEBAF RF-Windows at Cryogenic Temperatures*

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Abstract

During the CEBAF commissioning tests some of the superconducting cavities had light emitting discharges (arcing) which were observed in the guard vacuum space between a warm polymeric rf window and the cold ceramic rf window. A dedicated off-line test system was implemented to investigate the conditions under which arcing may occur and to gain some understanding of the mechanisms leading to this phenomenon through optical spectral analysis. This paper reports on the photoemission spectra observed during the dedicated tests on a single cell 1500MHz niobium cavity with a ceramic window operated at 10MV/m and 2 K. The light emission was detected using a spectrometer with an intensified photodiode array. The effect of moving the window away from the beam line using a waveguide elbow is reported.

I. INTRODUCTION

The CEBAF accelerator system uses 338 superconducting niobium cavity assemblies at 2 K to provide a continuous electron beam of 200 µA and 4 GeV after 5 recirculations through 2 anti-parallel linear accelerators. Each cavity is equipped with a ceramic rf window located in the input coupler waveguide 7.6 cm away from the beam axis. This window hermetically seals the sensitive superconducting surfaces against the waveguide guard vacuum in line with the 5 kW klystrons. The CEBAF rf windows are presently made from a high-purity (99.9%) polycrystal-line aluminum oxide (Al_2O_3) sheet of dimensions 13.3 cm x 2.5 cm x 0.4 cm thick, which is brazed to a thin niobium foil frame that is in turn electron beam welded to a solid niobium frame for connection to the waveguide system in a bolted flange joint. This window separates the cavity vacuum space from the guard vacuum space which is separated from the pressurized waveguide by a room temperature polyethylene window. During the commissioning of the accelerator many of the cavities were limited by frequent (more than once per day) waveguide vacuum discharge trips which were detected by a photomulitplier tube and caused operation of the machine to be interrupted. In most instances the operating field levels at which this occurred was in excess of the specified operating level of 5 MV/m. To reliably obtain the design value of 400 MeV linacs, the maximum field obtained in 46 of the cavities were limited by arcing. Furthermore, 17 cavities were reduced below 5MV/m because of arcing. Increasing the machine energy above the design value of 4GeV will require that more cavities be operated at levels at which arcing may become a problem. Because of the desire for a 6 GeV to 10 GeV upgrade in the future, a better understanding of the phenomena is required.

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II. BACKGROUND

These arcing phenomena have been investigated during the past three years and several reports have been published describing the results [1–7]. Two basic phenomena have been observed which are interpreted to be vacuum discharge phenomena [1–4]. In one type of event, the stored energy, as measured by the transmitted power signal, is fully dissipated in less than 5µs. This is accompanied by a large, short duration X-ray pulse of approximately 500kRad/hr for less than 5µs and a short intense light pulse which is detected at the beam pipe and on both the cavity and waveguide side of the ceramic window. This class of phenomena, which we call "electronic quenches," are interpreted as the effects produced by the sudden injection or liberation of a large number of electrons into the cavity. The electrons and their secondaries quickly absorb the rf energy stored in the cavity and produce an intense bremsstrahlung pulse as they strike the cavity wall, beam pipe, or endplate.

In the second type of event, the cavity stored energy is dissipated in several hundred microseconds (typically 500µs) and there is a substantial rise in the pressure of the guard vacuum. During this time light is observed in the waveguide vacuum space. When the cavity energy reaches a minimal level the discharge is extinguished. This type of event is interpreted as a discharge occurring in the window/rf-coupler region which is sustained by the stored energy in the cavity. It has been observed that the discharge may be sustained indefinitely by rf energy supplied by a 2 kW klystron [2]. The light emission during this type of discharge has three different temporal phases. During the first 5 µs a relatively large light pulse, which has the same temporal and spectral characteristics as that of an electronic quench, is observed. For the next 500 µs an emission, which has distinctly different spectral characteristics from an electronic quench, is observed. This is followed by a long tail, which has similarities to the long decay tail of the electronic quench. [3]

III. EXPERIMENTAL STUDIES

In an effort to better understand the arcing phenomena, off-line spectroscopic studies of the light emitted by the discharge have been performed. The basic experimental setup which used a single cell cavity is shown in Figure1. The light produced in the waveguide vacuum space was monitored through a sapphire viewport mounted on the coax-to-waveguide adapter. This light was transmitted from the viewport to a PMT and, through a 300ns optical delay line, to 0.275m spectrometer. Commercial grade acrylic fibers which provide reasonable transmission from 350nm to 720nm [1] were used as an optical media. The spectrometer configured with a 990 element intensified photodiode array which allowed the available spectrum to be recorded with 0.6 nm resolution. Absolute precision was verified using a mercury vapor source. Through the use of gating and delays different temporal regions of the discharge were examined.

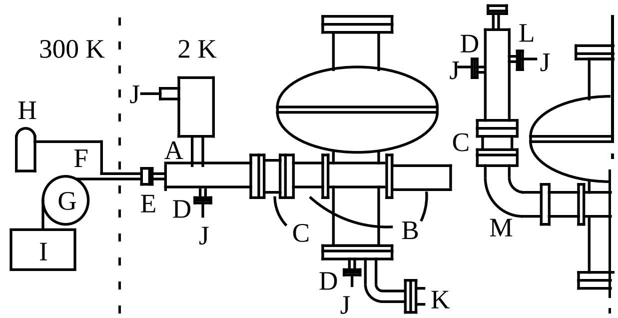

Figure 1. Single-cell cavity configurations showing (A) variable coax-to-waveguide adapter, (B) fundamental power coupler, (C) cold window assembly, (D) field probe adapters, (E) sapphire view port, (F) optical fibers, (G)optical delay line, (H) PMT, (I) spectrometer with intensified detector array, (J) rf cables, (K) vacuum pumpout port, (L) fixed coax-to-waveguide adapter, (M)waveguide elbow.

A series of three experiments were performed. In the first experiment, a standard ceramic window configuration was used. In the second, a right angle elbow of about one-half of a wavelength was placed between the fundamental power coupler (FPC) and the same window top hat configuration, see Figure 1. In the third experiment, the window frame assembly was removed and a 127 µm sheet of kapton was placed between the FPC and the tophat using indium seals. The spectroscopic data taken for each of the experiments is presented as Figure 2. Each spectral plot represents the average of several (11 to 27) individual spectra. For the purpose of identifying observed spectral lines, electroluminescence measurements were made on the ceramic material. For this experiment, a sample of the ceramic material was placed in an electron microscope and irradiated with a 100 pA 30 keV beam. The emitted light was collected and transmitted using UV grade fused silica optics and fibers. The results of this data is presented as Figure 3.. Arc rate measurements, presented as Figure 4, were taken for the two ceramic window configurations. The standard position test was performed both before and after the elbow experiment to insure that the cavity arcing characteristics were not effected by the experiment.

Discussion

The irradiated alumina samples, Figure 3, show the commonly present electroluminescence spectra of alumina [9, 10, 11]: a Cr+ impurity line located at 694.1nm and a broad spectra centered at 340nm caused by F-centers. The Cr+ line was again observed in the spectra of Figure 2a, but, in addition a line at 396.1nm appeared. All of the other lines observed in the ceramic widow discharges were also present in the kapton window discharge. The hydrogen lines and the line located at 589.9nm seem to be present independent of the window material. These lines are probably due to desorbed gasses which contribute to sustaining the discharge. The group of unidentified spectral lines between 375nm and 500nm on the kapton window are assumed to be generated by the kapton. Further, occurrence of the aluminum line in the data taken

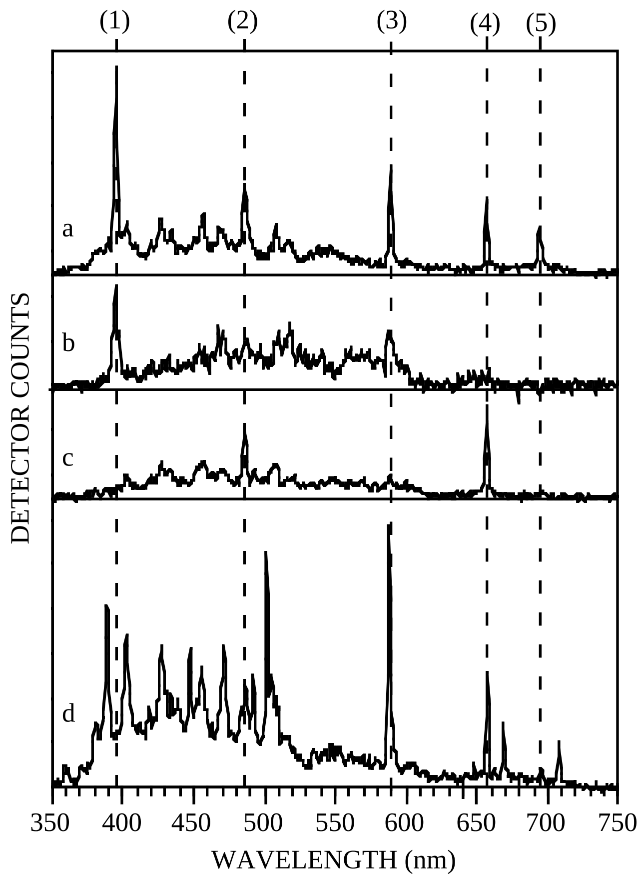

Figure 2. Optical spectra of waveguide vacuum discharges for a) Alumina window, 800us gate b) Alumina window, 1 us gate, c) Alumina window with elbow, 300us gate, d) kapton window, 800 us gate. Marked spectral lines indicate (1) 396.1nm (Aluminum [8]), (2) 486.4nm (Hydrogen [8]), (3) 589.9nm (unknown), (4) 656.3nm (Hydrogen [8]), (5) 694.1(chromium [9]).

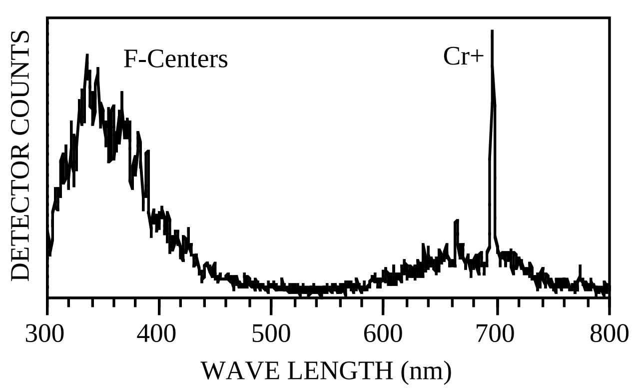

Figure 3. Optical emission spectra from an alumina sample irradiated with a 100pA, 30 keV electron source. The Cr+ line is located at 694.1 nm.

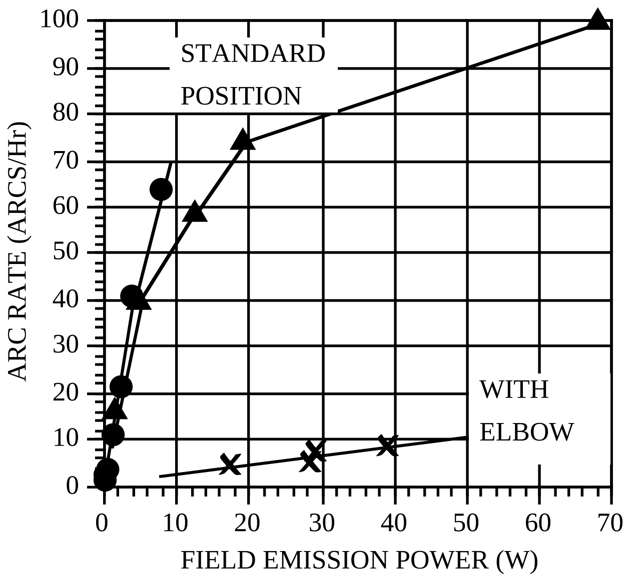

Figure 4. Arc rate as a function of additional power dissipated due to field emission for the same ceramic window with and without a waveguide elbow .

during the first 1μs of the discharge indicates that the process which generates it may have a significant roll in the initiation of the discharge. As can be clearly seen in Figure4, the displacement of the window further away from the beam axis significantly reduces the arcing rate. The absence of the aluminum line in the spectra of these discharges seems to indicate that the arcing phenomenon might be different in nature than in the standard configuration where direct electron impact might be involved in the process. The spectral data taken during this experiment show only the hydrogen lines. This further indicates that the discharge process in this configuration is different than the configuration in which the window has a direct line of sight to the cavity vacuum.

While the exact mechanisms which initiate these discharges are not well understood, two mechanisms which contribute are x-radiation and electron bombardment of the ceramic material. Theoretical studies indicate that secondary electrons, created when field emitted electrons from within the cavities strike the irises adjacent to the fundamental power coupler, have trajectories which would allow them to strike the ceramic window [12]. An additional source of electrons is x-radiation induced photoemission. Electron currents on the order of 10 nA on have been measured on an isolated window frame assembly with a correlation to field emission in the cavity. Some current flow does occur when there is direct radiation through the walls of the cavity. The introduction of a waveguide elbow between the cavity and the window reduces the measured currents [7].

IV CONCLUSIONS

The spectra measured during a waveguide vacuum arc for three different window configurations has been presented. Several spectral lines have been identified. Lines for aluminum (396.1 nm) and Cr+ (694.1 nm) have been identified as indicators of a possible arc initiation mechanism when the ceramic window is located in the standard position. Other observed spectral lines were also present in the discharges involving kapton window material and a ceramic window in an alternate location. Electroluminescence measurements were performed which confirm the presence of a Cr+ line at 694.1 nm and a broad F-center emission located at 340 nm consistent with previously seen emission from warm resonant ring studies [11]. The location of the window was shown to have a major impact on arcing rate. A reduction of arcing rate by an order of magnitude was seen when a window was separated from the cavity by a half-wave right angle waveguide elbow. More detailed work is required to understand the complex interdependencies involved in the arcing process.

V REFERENCES

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VI ACKNOWLEDGMENTS

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