

## Some Operational Characteristics of CEBAF RF Windows at 2K\*

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### Abstract

A CEBAF superconducting rf cavity was instrumented to examine RF window behavior at 2K. Of special interest was window performance at levels of cavity power dissipation considerably above normal operating conditions. A variety of transient electronic activity was observed to occur at or near the rf window, including the emission of light, a precipitous increase in reflected power, and interesting cooperative effects between the window and cavity. Typically, the initiation of this activity at the window is correlated with the presence of a high x-ray and energetic electron flux at the window produced by the cavity. Electronic activity at the window can occasionally trigger the sudden disappearance of all stored energy in the cavity, herein referred to as an "electronic quench". Variable delays of up to 40  $\mu$ sec have been observed between the onset of window activity and the decay of the cavity field, which can occur in less than 200 nsec and is always accompanied by an intense pulse of x-rays. When the cavity is off resonance with negligible stored energy, rf fields at the window can be increased even further without the appearance of these effects.

### I. INTRODUCTION

It is common experience at most laboratories that superconducting cavities, even after very careful cleaning, can show substantial degradation in performance after installation in horizontal cryostats [1]. It is believed that this is due in part to particulates introduced into the cavity from the mounting of couplers and other components during assembly. To avoid this degradation in the CEBAF design, an rf window is attached along with other components directly to the cavity in the clean room immediately after processing. This procedure serves to seal pairs of cavities as hermetic units which are then evacuated in the clean room and remain under vacuum during assembly into the horizontal cryostat [2].

The success of this procedure can be seen in production test results in which the performance of cavities installed in the tunnel shows little degradation when compared to performance measured immediately after processing [3]. This direct attachment to the cavity in the cleanroom, however, places additional requirements on the window design, namely, that it operate at 2K, 8 cm from the beam line. These unique conditions have produced unusual operating behaviour which is the subject of this paper.

The CEBAF cold rf window consists of a thin, high-purity aluminum oxide ceramic mounted in a niobium waveguide flange. It is sealed to the cavity fundamental

power coupler port, separating the cavity vacuum from a guard vacuum maintained by a 300K polyethylene window outside of the cryostat. In this location, the 2K window is exposed to the outgassing load from the guard vacuum and an intense x-ray flux from the cavity when field emission is present.

In the presence of very high levels of field emission in the cavity, the window produces occasional flashes of light. Operationally an arc detector (photomultiplier) watching the window and waveguide space shuts off the rf source when a sustained flash of light occurs. Because an excessively high rate of such trips could disrupt operations, a series of investigations have begun to examine the phenomena in detail.

### II. EXPERIMENTAL ARRANGEMENT

To study this behavior, a standard CEBAF cavity was tested in a vertical cryostat configuration shown in Figure 1.

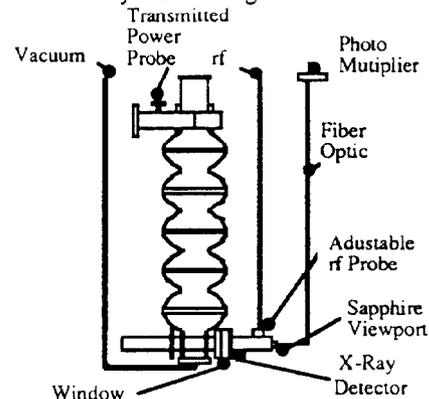


Figure 1.

In this arrangement, the waveguide normally used to carry rf power to the window was replaced by a coax-to-waveguide transition consisting of an adjustable coaxial rf probe coupled to a shorted niobium waveguide, which was in turn bolted to the window.

A fiber optics cable carried light from the window as viewed through a sapphire viewport to a photomultiplier tube outside of the cryostat. A radiation-sensitive diode was placed next to the window to monitor x-rays produced by field-emitted electrons striking the cavity surface.

Reflected and transmitted power, photomultiplier output, and radiation detector output signals were monitored and recorded simultaneously in a 100  $\mu$ sec time interval triggered either by a change in reflected power or photomultiplier signal or both. For all measurements the input rf coupling probe was critically coupled before an event.

### III. RESULTS

A variety of events were seen involving the four parameters recorded. The simplest and least frequently

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observed event involved light and reflected power transients and is shown as Figure 2.

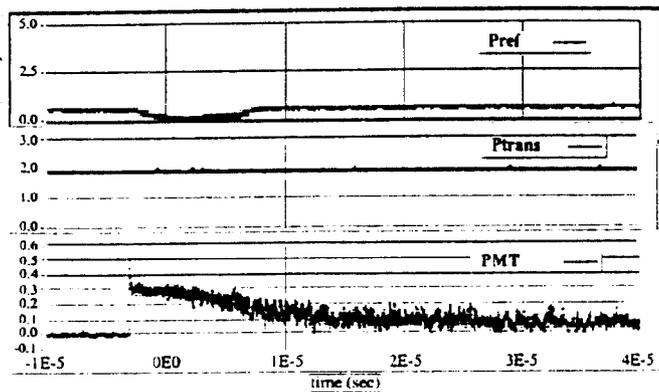


Figure 2.

The transients are coincident. An event of this type is consistent with a plasma being created in the waveguide on the outside of the cold window. The discharge, once initiated, can effectively reflect rf power, produce light, and be fed by an abundant supply of frozen gas on the cold waveguide walls. This process can, but need not, involve the window and has no immediate effect on the cavity. This is evident from the lack of change in the transmitted power signal in the 100  $\mu$ sec time window. Since the external  $Q$  of the fundamental power coupler port is  $6.6 \times 10^6$ , the minimum time constant for any change of stored energy in the cavity produced only by events in the fundamental power coupler waveguide or window is nearly a millisecond.

For most events, however, a new and extremely interesting phenomenon was observed in which the stored energy decayed from  $10^3$  to  $10^4$  times faster than expected. Figure 3 is typical.

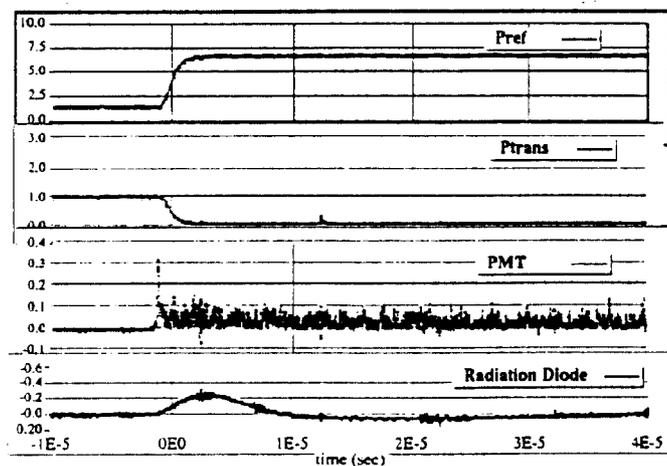


Figure 3.

Here, the transmitted power decays in a few microseconds, indicating a quenching process inside the cavity triggered by activity initiated at the window, but with the window not participating in the energy dissipation. An intense radiation pulse, centered exactly on this fast energy decay indicates a sudden proliferation of electrons appearing in the cavity field as the energy-absorbing mechanism, or "electronic quench". Here all signal transients occur at the same time.

This simultaneity, however, is often absent. In some fraction of the events another new phenomenon was observed, yet even stranger. A variable time delay, sometimes as much as 200 times longer than the cavity "electronic quench" time, appears between the light pulse and the transmitted power decay. The reflected power transient remains coincident with the light pulse, and the x-ray pulse remains centered on the transmitted power decay or the collapse of the cavity field. An example is shown in Figure 4, in which the delay is about 35  $\mu$ sec.

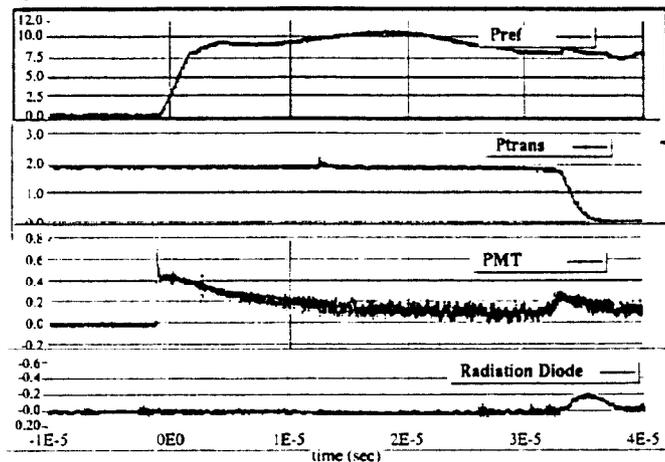


Figure 4.

A variety of delay times have been observed between 0 and 40  $\mu$ sec. It has been observed that the delay time tended to process toward zero with continued arcing.

The mechanism for this time delay is not understood. One possible explanation is that a discharge at the window would trigger the arc detector and at the same time liberate a cloud of frozen gas from the window. This gas propagates into the cavity field. After some level of ionization and the production of enough secondary electrons, an electron avalanche precipitously absorbs the cavity energy. It is known that in some events a plasma or conducting medium exists briefly in the fundamental power coupler at the beam pipe just after the trigger. This can be discerned from the shape of the reflected power signal in Figure 5.

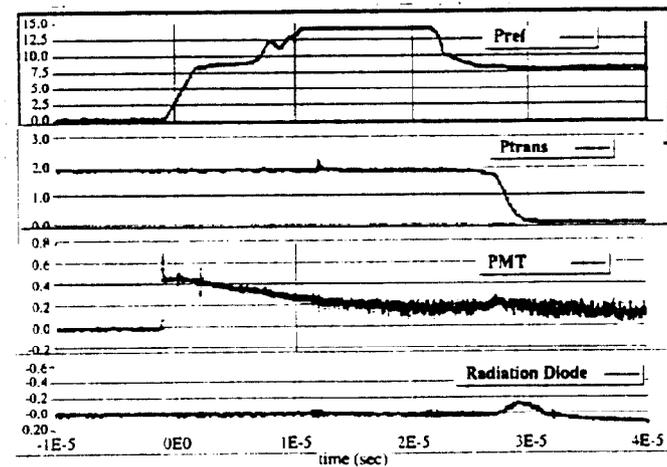


Figure 5.

By the end of the trace the signal has saturated at a value indicating complete reflection of the incident rf power from the discharge in the waveguide. At 20  $\mu$ sec, however, the reflected power signal is even greater, indicating some portion of the reflected power signal is momentarily augmented by rf power emitted from the cavity. This may be attributed to a sufficient quantity of charge in the coupler region at the beam pipe to lower the external  $Q$ , briefly allowing an increased power flow from the cavity to the waveguide.

Some of these measurement have been repeated with similar phenomena observed on production test cavities and, more extensively, on a special single-cell cavity which has been instrumented to examine the spectral content of light emitted [4].

Another interesting event is shown in Figure 6.

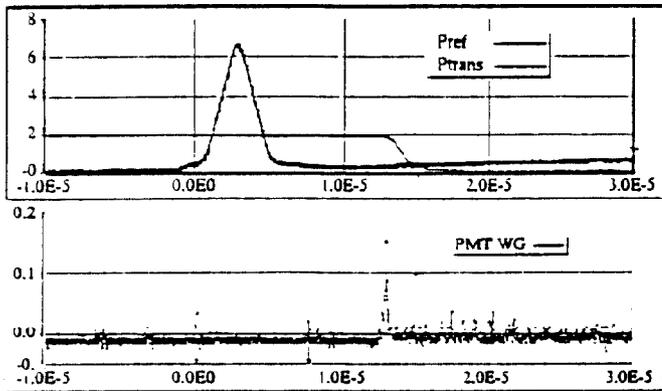


Figure 6.

Here there is no light pulse at all. A small phantom pulse in the light signal (PMTWG) coincident with an electronic quench at 13  $\mu$ sec arises from the fact that the fiber optic and photomultiplier assembly are not immune to x-rays. The event was triggered on a reflected power transient shown here on a very reduced vertical scale to illustrate the size of the rf pulse emitted from the cavity. Without light at the photomultiplier, it would seem that this event occurs completely on the cavity side of the window.

One of the most important observations established by this series of tests is the fact that all of the phenomena mentioned above do not occur unless field emission is present. Furthermore, when field emission is present, the arc event rate, which can be as high as 10 per hour, increases with increasing rf power dissipation in field emission.

In fact, window field alone cannot induce this activity. To demonstrate this, the rf system was tuned to the coupler waveguide mode (the waveguide resonator formed by the shorted end of the waveguide coupler and the detuned short of the cavity which includes the window) at 1427 MHz. Under these conditions, the cavity is empty and no field emission is produced. This was done in the middle of a testing period in which arcing events were regularly observed. About 75 W was coupled into this resonance, producing electric fields at the window more than seven times higher than before. No arcing was observed until the rf system was returned to the accelerating mode (1497 MHz).

In one testing period in which arcing occurred with field and rf power held constant, the arc event rate was seen to condition, suggesting the removal of gas from the waveguide walls or window by repeated discharges.

The addition of gas, however, does not necessarily increase the arc rate. In one experiment with arcing present, the test was interrupted to add 7.8 Torr-liters of air into the guard vacuum on the coupler side of the cold window. The test was resumed and except for some initial low field multipacting, which was conditioned away in 10 minutes, there was no significant change from the preceding test.

#### IV. DISCUSSION

We assume that the window is charging in the presence of field emission. Flashes of light which trigger the arc detector are produced when a discharge occurs.

There are several thoughts on the process by which field emission might induce a surface charge on the ceramic window. It has been suggested that secondary electrons produced near the coupler by field emission current could follow trajectories terminating on the window surface [5]. Another means of surface charging arises from photoelectron emission induced by x-rays arising from field emission in the cavity passing through the window.

Window charging has been demonstrated by electrically insulating the entire window from the cavity and waveguide coupler by inserting thin sheets of VESPEL between flanges. Current flow from the window was monitored during operation. In the absence of field emission, the window current was less than one pA and independent of field. In the presence of field emission, the current rose to as much as 20 nA.

Both charging mechanisms described are consistent with the observed increase in arc rate with increased power dissipation in field emission. Tests are in progress which will isolate these mechanisms.

#### V. ACKNOWLEDGEMENT

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