RF Cavity Vacuum Interlock System*

K. Jordan, K. Crawford, R. Bundy, H. F. Dylla, J. Heckman, J. Marshall, R. Nichols, S. O'Sullivan, J. Preble, J. Robb, W. Schneider, R. Sundelin, J. VanDyke

Continuous Electron Beam Accelerator Facility
12000 Jefferson Avenue
Newport News, VA 23606

Abstract

The Continuous Electron Beam Accelerator Facility [1] (CEBAF), a continuous wave (CW) 4 GeV Electron Accelerator is undergoing construction in Newport News, Virginia, USA. When completed in 1994, the accelerator will be the largest installation of radio-frequency superconductivity.

Production of cryomodules, the fundamental building block of the machine, has started. A cryomodule consists of four sets of pairs of 1497 MHz, 5 cell niobium cavities contained in separate helium vessels and mounted in a cryostat with appropriate end caps for helium supply and return. Beam vacuum of the cavities, the connecting beam piping, the waveguides, and the cryostat insulating vacuum are crucial to the performance of the machine. The design and initial experience of the vacuum systems for the first 2 1/4 cryomodules that makeup the 45 MEV injector will be discussed.

1. INTRODUCTION

CEBAF's accelerating system consists of 338 superconducting radio frequency (SRF) cavities. A cavity contains five highly coupled 1.5 GHz TM_{010} π mode resonators, an input coupler, and two higher order mode output couplers. Four pair of cavities are arranged into a common vacuum vessel called a cryomodule. CEBAF's injector contains 2 1/4 cryomodules, and each of the north and the south linacs contain 20 cryomodules. An acceptable cryomodule provides an energy gain of $\geq$ 20 MV while dissipating $\leq$ 43 watts to the superfluid helium bath. The cryostat must also have $\leq$ 13 watts static heat leak [2]. The vacuum system and the associated interlocks play an important part in achieving these goals. The beam vacuum minimizes the impurities within the cavities and insures the gradient with minimal losses. The waveguide vacuum provides a guard vacuum to the cavities, inhibits electrical breakdown in the waveguide, and lessens the static heat load. The insulating vacuum minimizes the gaseous conduction in the cryostat and, like the the window vacuum, reduces the static heat load. Each of these vacuum subsystems (the beam, waveguide, and insulating with their associated interlocks) are essential to cryomodule performance.

2. BEAM VACUUM AND INTERLOCKS

The cavity or beam vacuum is the most critical to prevent cavity performance degradation through contamination and to provide a clear path for the electron beam. The typical layout for the machine is shown in Figure 1. At the upstream end of each module there is a 30 l/s DI ion pump, and between each module there is a standard 30 l/s ion pump. Each of these ion pumps is separated by gate valves. There are fast closing valves between every four cryomodules and at either end of both linacs. There exists one relay rack with the control electronics and 24 ion pump power supplies for each set of four cryomodules.

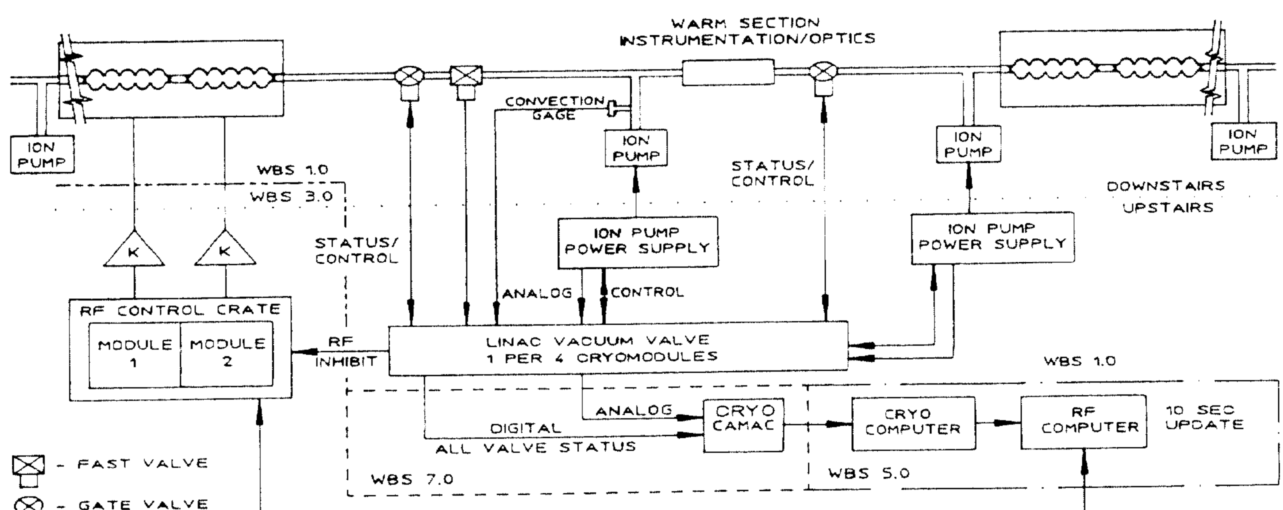

Figure 1. Functional Interlock Schematic.

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This pressure is typically $< 10^{-9}$ torr during beam operation. The region inside the four cavity pairs of a cryomodule has a cold (2K) surface area of 6.4 m^2. Air products or helium that come into contact with this surface will condense and freeze out. Surface contamination of more than a few monolayers will degrade the Q_0, increasing the RF losses and cryogenic heat load. This type of performance degradation is reversible through warming up and pumping on these air products. To minimize this, the cavities are leak checked to $1 \cdot 10^{-10}$ torr liters / sec during assembly and have the beam line gate valves interlocked to $\leq 1 \cdot 10^{-9}$ torr. During operation the cavity vacuum typically runs at 10^{-10} torr, while the warm beam pipe runs at 10^{-9} torr.

There are two classes of pressure faults: "Slow" and "Fast." Each of the beam line gate valves are interlocked to the nearest upstream and downstream ion pump. In the event of a "slow" pressure fault, *i.e.*, $> 10^{-9}$ torr for 100 sec and $< 10^{-7}$ torr, the beam line valves on each side of the ion pump would close. These valves close in 400msec. In the event of a "fast" pressure fault *i.e.*, $> 10^{-7}$ torr for a pair of adjacent pumps, the beam line valves for the group of four cryomodules would close as well as the fast isolation valves. The fast valves close in 10 msec. When any valve moves off the open status microswitch, the fast shutdown signal is interrupted and the electron beam inhibited. Either of these faults will interrupt the high power RF for the adjacent cryomodule.

3. WAVEGUIDE VACUUM AND INTERLOCKS

The waveguide vacuum is required to be $< 10^{-7}$ torr for operation. This provides protection from RF discharges in the fundamental power coupler waveguide as well as providing thermal insulation between the 300 K teflon/ polyethelyne RF window and the 2 K ceramic window.

The waveguides for each cavity pair are connected with a 38 mm manifold to a single 20 l/sec ion pump. When the cavities are assembled as a cryounit, this region is pumped out and leak checked. The region between the ceramic and teflon/polyethelyne window is continually pumped as the four cryounits are assembled as a cryomodule and installed in the accelerator. When this pressure rises above $1 \cdot 10^{-7}$ torr a fault is generated inhibiting the high power RF to that cavity as well as interrupting the electron beam. When the cryomodule is cold this vacuum is 10^{-9} torr.

4. INSULATING VACUUM AND INTERLOCKS

The insulating vacuum is a moderate vacuum between 10^{-7} and 10^{-4} torr which minimizes gaseous conduction between the 2 K helium vessel and the 300 K vacuum vessels. The cryomodule's insulating vacuum space is also evacuated in the test lab prior to its installation in the accelerator. This sealed vessel will not be actively pumped in the accelerator enclosure. It will only be monitored with a cold cathode (CC) gauge. The CC gauge, and a spare, are mounted to the supply End Can which is the upstream end of the cryomodule. This type of gauge is accurate in the 10^{-4} to 10^{-8} torr range. One should note that as the cryomodule is cooled down, the residual gasses freeze out on the 40 K heat shield, which is cooled down first, and the 2 K helium vessel. This generally results in a vacuum improvement of two orders of magnitude. The pressure must be $\leq 10^{-4}$ torr before the cooldown begins. This interlock consists of an alarm to alert the Main Control Center (MCC) of a vacuum failure. In the event that this vacuum spoils, the insulating space would be continually pumped with a turbo molecular pump.

5. INSTRUMENTATION AND CONTROL ELECTRONICS

5.1 Ion Pump Power Supply

The overview of the controls architecture is shown in Figure 2. Both the 20 l/s waveguide ion pumps and the beamline 30 l/s ion pumps are powered from the same type of power supplies. This power supply is similar in design to one used at Fermilab [3]. The supply has a short circuit current of 70 milliamps. During normal operation, $< 10^{-8}$ torr, the output voltage is reduced to +3kV to extend pump life and reduce leakage currents. The power supply has an internal log amp which converts six decades of current to a 1.5 volts per decade output; 0 to +10 volts, +10 volts being 10^{-11} torr (actual limit is 2.5 $+10^{-10}$ torr). This amplifier is protected by a self-biasing FET in the event of a discharge. The power supply has overcurrent protection which shuts the high voltage off if the vacuum does not improve to the low 10^{-6} range after 15 minutes of being turned on or in the event of a vacuum failure. The supply can be controlled locally or remotely from the MCC via TTL pulses (100 msec) generated on the ion pump power supply interface card.

5.2 Beam Line and Waveguide Ion Pump Control Cards

The purpose of the Beam Line and Waveguide Ion Pump Control Cards (BLIPC & WGIPC) are to monitor the pump pressure, generate pressure faults and to provide status and control to the main control center (MCC). Each of these printed circuit (PC) boards are DIN 3U x 220 mm and control two ion pump power supplies. These buffer the pressure signal and generate permits for control of RF power, gate valves, fast valves, and power supplies.

The BLIPC has set a point at $< 10^{-9}$ torr for the gate valve and RF permit, which is set to retrigger a 100 second timer. This function prevents an interruption in operations from a short duration pressure variation but does not compromise the system in the event of a small leak. When the ion pump power supply is turned on, it is started in the 5kV mode but at $< 10^{-8}$ torr the card switches to the low voltage mode (LVM), 3kV. At $> 10^{-7}$ torr the adjacent gate valves are closed and the fast valve is triggered. This card also receives a permit from the convectron controller which prevents the ion pump from being turned on at atmospheric pressure. The $< 10^{-9}$ torr fault does not latch *i.e.*, require a reset to clear; however, the $> 10^{-7}$ torr fault does latch. The WGIPC has set a point at $< 10^{-7}$ torr for the RF permit which is latched in the RF control module. This card also has the $< 10^{-8}$ torr set point for the low voltage mode (LVM).

5.3 Gate and Fast Valve Control Cards

The beamline gate valve control card receives both a pressure permit (at $< 10^{-9}$ torr) and an ON status from the two adjacent ion pump power supplies. The valves, which have hard-wired permits, may be operated either locally or remotely. The vacuum controls are equipped with a key operated local control lock out. The valve status would indicate OPEN, CLOSED, or REQUEST if they were attempted to be opened when the vacuum was bad on either side of the valve. The fast valve control card accepts the 10^{-7} torr trigger from all of the ion pumps for four cryomodules, the circuit has a programmable logic device (PLD) to close only this valve if there is a coincidence fault on two adjacent ion pumps. This prevents unnecessary valve cycling. The fast valve is a VAT monoseal valve.

6. OBSERVATIONS FROM INJECTOR

Experience so far has been excellent. The beam vacuums typically run $\leq 10^{-9}$ torr in the warm region and, when cold the cavity vacuum comes down, in the 10^{-10} torr range. The window vacuums typically run 10^{-7} torr warm and 10^{-9} torr cold. We have been experimenting with alternate warm window materials, high density polyethelyne in lieu of teflon, to reduce permeation. The insulating vacuum has typically been 10^{-6} to 10^{-7} torr when cold.

The following changes in the control philosophy have precipitated from one year of operations:

a. The only means of monitoring vacuum in our beam line system is using the ion pumps and their associated electronics. Since ion pumps do not always draw current at atmospheric pressure, hence indicating a good vacuum, we have installed a Pirani gauge with the ion pumps in the warm sections. The ion pump power supplies are interlocked to these gauges to prevent turn on at atmospheric pressure.

b. The fast valves which protect the system against catastrophic failures are now required to have a simultaneous pressure fault ($> 10^{-7}$ torr) on two adjacent ion pumps. It has been observed that 1 ms vacuum excursions (do to sparking, for example) have caused erroneous trips.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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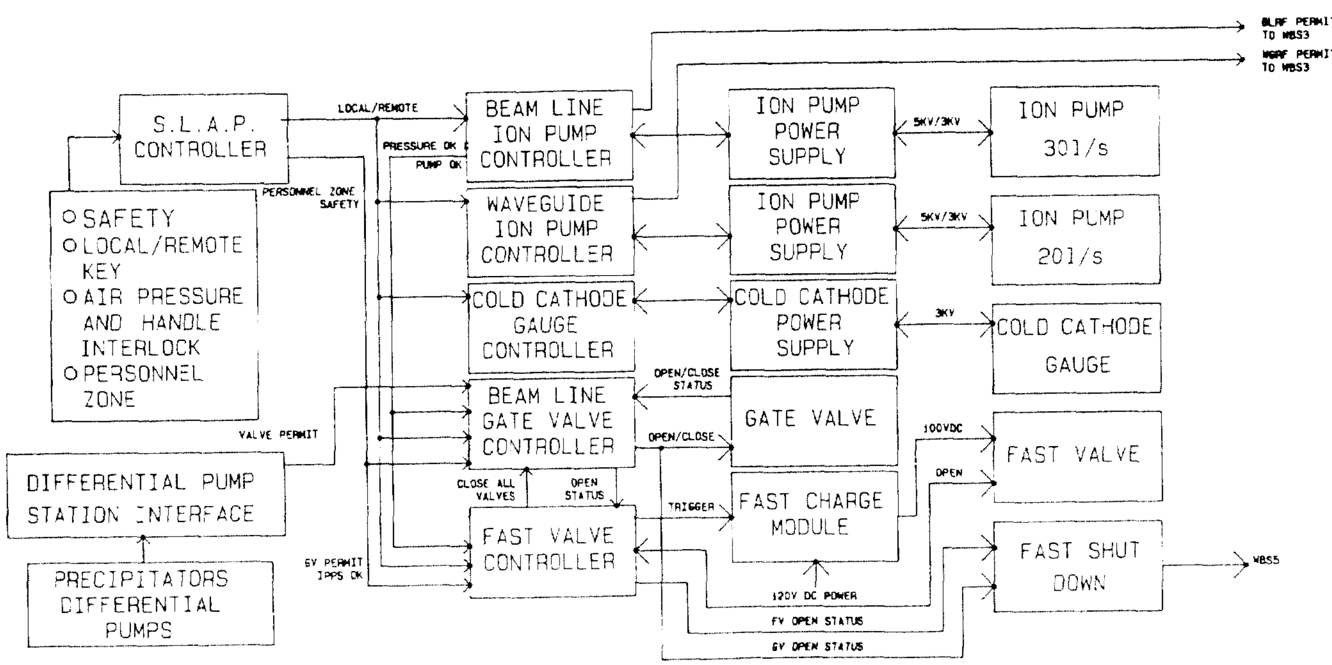

Figure 2. System Block Diagram.