A Closed Cycle Cryogenic System for Testing Superconducting RF Cavities

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Abstract

Construction of particle accelerators with large numbers of superconducting RF cavities requires that adequate facilities be available to perform efficient cryogenic cavity testing. A closed cycle helium cryogenic system supplying multiple vertical test cryostats has been constructed at CEBAF. System design, instrumentation, and control features permit secure automated filling, cooldown to < 2 K, and fast warm-up. Description and operational characteristics of the system are presented.

I. INTRODUCTION

Construction of CEBAF requires installation of 338 niobium SRF cavities. Because of the large investment in assembly effort, provision is made to performance test all cavities prior to insertion into the horizontal cryostats used in the accelerator. A closed cycle cryogenic system has been designed and constructed at CEBAF to accommodate the testing of these cavities and to provide a durable facility available indefinitely for possible rework.

The Vertical Test Area is a test facility with 8 vertical dewars for LHe at 4.2 to 1.5 K to test single production cavities, cavity pairs, cavity components, and to perform RF and cryogenic diagnostics and R&D. The system allows computer process operation and also manual control.

II. SYSTEM CONFIGURATION

a) Cold Helium Supply

The cold helium is supplied from a remote refrigerator in the Cryogenic Test Facility (CTF) to the Vertical Test Area (VTA) junction box in three concentric transfer lines. The inner line provides 3.5 to 4.5 K, 2.8 bar He, flow-controlled from the CTF with a JT-valve. The other two lines carry the 40 K, 4.0 bar shield cooling gas supply and approx 55 K, 1.4 bar, 10g/s return. The transfer line is extended from the junction box to the central valve box, where the inner supply line is ramified into eight branches to feed all dewars. The shield cooling line is looped back inside the valve box and returns to the refrigerator. It is used to cool the shield, and to heat-station all valves and penetrations in the valve box.

The valve box contains two He shut-off valves, eight JT-valves, temperature diodes, pressure sensors, reliefs, and two 7/8" bayonet couplings. Unshielded transfer lines connect each JT valve in the valve box to the respective dewar. At the end of the dewar transfer lines, there are isolation valves which also act as 150 psi line pressure reliefs. The calculated losses for the section between the bayonet can and one single dewar is <15 Watts.

A 3800 liter LHe-storage dewar provides an emergency supply of LHe to enable the completion of ongoing tests in the event of a temporary failure of the CTF. This dewar can be filled from the CTF refrigerator and is connected to the VTA valve box which can supply all dewars.

See Figure 1 for an overall system schematic.

b) Dewars

There are eight special open-neck low-loss dewars in different sizes. They were specified without shield cooling to simplify the design and to reduce the warmup times. Six dewars are inserted into radiation shielded pits. Two dewars are not radiation shielded. Table 1 gives the main dimensions and the measured heat loads at 4.2 K for each dewar.

The CTF can normally provide a peak filling rate of 240 l/hr (8.3 g/s) at 4.3K for a continuous period of 12 hrs. One trial was performed filling a dewar at 2 K at a rate of 160-170 l/hr with a cavity pair insert. This mode of operation is normally not required, and no optimization has been done yet. Care must be taken in this mode to avoid underpressurizing the supply line in the valve box as the potential exists to open leaks through the bayonets.

The filling lines of all dewars allow LHe transfer between any dewars in the system. The transfer efficiency is > 80% if the receiving dewar is precooled. If the interconnecting transfer lines are warm, then approximately 50 LHe liters will be lost before LHe is collected in the receiving dewar.

Table 1
Dewar Characteristics

Dewar #	ID (cm)	Height (cm)	Usable Vol (liters)	Heat Load (Watts)
1	41	183	136	0.6
2	41	183	136	0.7
3	71	275	648	1.2
4	71	275	648	1.2
5	86	336	1197	1.2
6	41	275	212	0.7
7	71	336	812	1.3
8	71	336	812	1.3

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Each dewar is equipped with:

- pressure sensors (capacitance manometers 0-1000 Torr, Piranis 10E-3 to atm, and local dial instruments)
- diode temperature sensors 1.5 to 400 K
- LHe level sensors (CEBAF type)
- internal heaters (variable power up to 160 W)
- cold and warm helium supply lines (from the central valve box)
- warm gas return and pumping lines (to the manifolds)
- guard vacuum on the top plate
- outside heaters to reduce frost buildup
- isolation valves for guard vacuum, evacuation, He gas return, He purge gas, cold He supply, and pressure control valves for He pumping
- pressure control valves
- pressure reliefs (first level relief into the return line: set at 1.25 bar; second level relief is to atmosphere: set at 1.6 bar for dewars 1,2,4,5,6, and at 1.4 bar for dewars 3,7,8.)
- spare pumping port
- vent to air valve
- magnetic shielding on 6 dewars
- compensation coil wiring wound over the magnetic shielding to reduce magnetic fields inside of the dewars to < 9 mGauss.

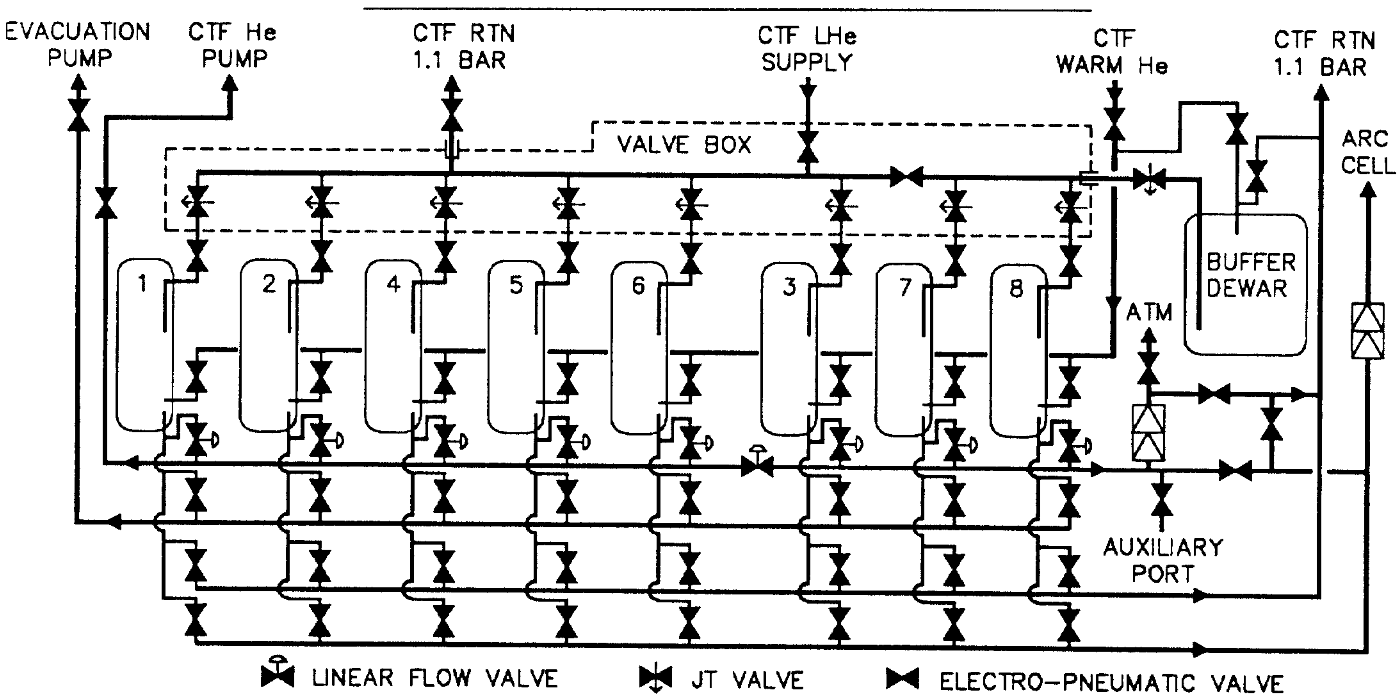

Figure 1. Eight-Dewar Closed Cycle Cryogenic System Schematic (Not all valves shown).

c) Helium return to the CTF

There is no cold gas return to the refrigerator. When the dewars are operating at 4.3 K, the helium is returned at approximately 300 K and 1.1 bar directly to a recovery compressor. This recovery compressor sends the helium via a purifier to the closed loop refrigerator system.

To lower the temperature of the helium in any dewar, it is necessary to pump via a 12" manifold to a large vacuum pump located in the refrigerator building (CTF pump). This pump is shared by all users in the CEBAF Test Lab and has a Helium pumping capacity of 10 g/s at 20 Torr.

Three dewars dedicated to production testing (#3,7, and 8) can also be pumped by two separate vacuum pumps (VTA pumps), each rated at 1.2 g/s at 30 Torr He. These dewars have the redundant pumping ability to ensure a more independent operation for the testing of the high priority production cavities, and also to allow the pumping of additional auxiliary dewars which are filled from standard commercial helium dewars. These contaminated dewars do not send the boiloff gas to the refrigerator. Selective valving at the output of the VTA pumps allows to direct the gas to either the recovery compressor (via oil filters), or to atmosphere.

d) Contamination monitoring and Warm-up

The cleanliness of the helium at each dewar, at the discharge of the VTA He pumps, and also at the discharge of the CTF recovery compressors is checked with a nitrogen contamination monitor (Arc Cell). The dewars are cleaned by repeatedly evacuating and backfilling with clean gas from the CTF (2 to 4 cycles are typically required to reach the clean condition). The contamination levels during operation of the dewars are typically lower than 5 ppm. The upper limit set for the contamination of the return gas before the purifier is 20 ppm.

By using warm purge gas from the CTF and a regulated and interlocked heater in the dewar, it is easy to warmup the dewars overnight. The actual time depends on the dewar size, the internal heater setting, and the gas flow tolerated by the CTF recovery system.

III. INSTRUMENTATION & CONTROLS

The cryogenic control system is designed so that multiple, nominally independent users can reliably purge, fill, pump down, and warm up a dewar with a minimum amount of training. The electronic controls are designed to coordinate the operation of 73 electro-pneumatic valves, nine JT valves, 14 linear flow valves, 30 pressure sensors, 38 temperature sensors, and 8 liquid level sensors. Each dewar has its own set of interlocks, controls, and displays. A block diagram of the control system for a typical dewar is given in Figure 2. Shared resources are controlled by an additional subsystem which is interfaced with the CTF. Each subsystem may be operated manually subject to interlock supervision, or routine procedures may be automated by computer control. Interlocks may only be overridden by the use of a keyed switch.

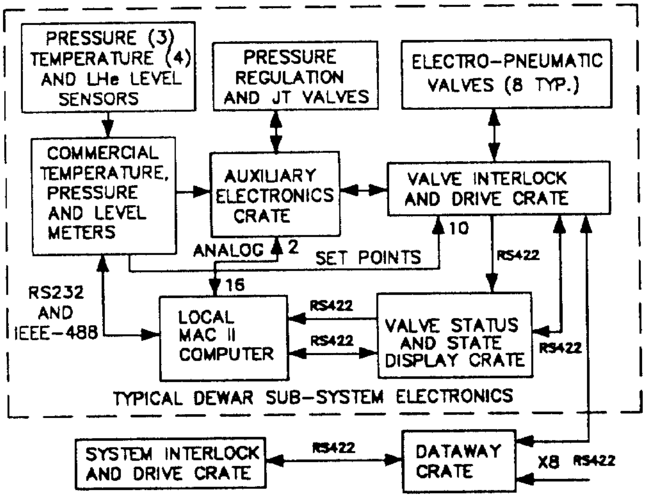

Figure 2. Control and Interlock Block Diagram.

In the interlocked manual mode of operation, valves are opened and closed using switches which send requests to the appropriate valve interlock modules. In the interlocked computer controlled mode, the switches are repaced by digital output from a Macintosh IIx computer. In each of the interlock modules, two or three programmable logic devices operate as a clocked state machine to open or close a valve based on the request and the status of required conditions (dewar clean, dewar pressure, the status of other valves, etc.). This implementation allows all valves to use the same interlock module hardware with differing firmware.

The output of the interlock module drives the input of a solenoid valve or control valve driver module. The solenoid valve modules drive electro-pneumatic valves via solid state relays. Micro-switches on each the valve supply signals to the drive modules indicative of the valve's position. The state of these feedback switches is converted to logic levels and distributed to the rest of the system as required. Additionally, if the valve position does not agree with the requested position, an alarm sounds warning the operator of a fault.

Interconnecting backplanes were constructed for the interlock crate and the display crate. About 90% of the roughly 600 interconnections of the 190 to 210 signals per dewar are made on each pair of these double layer printed circuit boards. System revisions are accomodated by all nodes having been left accessible for wire-wrap connections. An expansion capability of about 20% was built-in.

Communication of data between crates is accomplished using serial communication modules. The same modules provide interdewar communication via a central dataway crate. These microcontroller based modules each use a RS-422 serial interface to exchange 80 digital signals (40 in each direction). By changing the firmware, one of the modules in each interlock crate acts as a "state" module which tracks the overall condition of the dewar (open to air, sealed, clean and cold, etc.) and drives the indicator lamps on a dewar state panel. The artwork on this panel has the form of a flow chart. Using this flow chart, the operator tracks the dewar's current status and may determine what options are currently available.

IV. SOFTWARE

A unique method was developed for the programing of the imbedded controllers used to control state and timing functions. A list processor was created for the micro-controllers which can process sum-of products logical equations. These equations are generated by a parser written in C. The inputs to the parser are two text files, one each from a spreadsheet and a schematic capture program containing the equations and the netlist respectively. The output is in the form required by the list processor. Thus, the entire process of writing the assembly language code has been automated and is free of coding errors.

Extensive use of software tools was used for QA and troubleshooting. Using LabVIEW® and test fixtures, each PC board and completed assembly was fully exercised. This same software can be easily modified to create a simulator for use in operator qualification.

All information and controls available to the operator are also available to the computer system. Any control output of the computer is subject to the same interlock constraints as manual operation.

This arrangement enables the software to control all normal operations with a minimal amount of operator intervention. It also makes provision for automatic logging of all relevant cryogenic data that the experimenter may require. Computer control has been tested pumping down a dewar while maintaining level. In this mode, the computer was in direct control of the JT valve and two pressure control valves. It adjusted these valves based upon He level in the dewar, dewar pressure, and transfer line temperature.

VII. ACKNOWLEDGEMENTS

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