UPGRADE TO CRYOMODULE TEST FACILITY AT JEFFERSON LAB*

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Abstract

The cryomodule test facility (CMTF) was originally implemented in the late eighties for testing of a small fraction of the cryomodules during the production run for the Continuous Electron Beam Accelerator Facility [1]. The original system was built using a dedicated wiring scheme and a pair of 2 kW, 1497 MHz RF sources. This dedicated system made it difficult to test cryomodules and other RF structures of non-standard configuration. Additionally, due to a previously installed cyclotron, there were static magnetic fields in excess of 6 Gauss within the test cave, which limited the capability of the facility when measuring the quality factor of superconducting cavities. Testing of the Spallation Neutron Source cryomodules as well as future upgrades to the CEBAF accelerator necessitated that the facility be reconfigured to be flexible both with respect to RF source power and cryomodule wiring configuration. This paper will describe the implementation of a generalized wiring scheme that is easily adapted to different cryomodule configurations. It will also describe the capabilities of the LabView based low level RF controls and the related data acquisition systems currently being used to test cryomodules and related hardware. The high power RF source capabilities will be described. The magnetic shielding put in place in order to reduce the ambient magnetic file to levels below 50 mGauss will also be described.

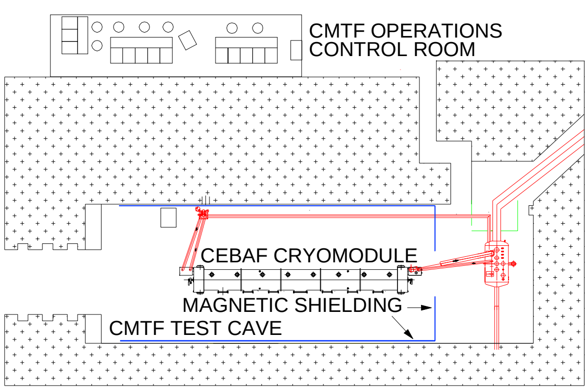

Figure 1: General layout of the Cryomodule Test Facility showing the test cave and control room.

GENERAL FEATURES

Figure 1 shows the general layout of the cryomodule test facility. The test cave is a 21 m by 7 m area with concrete shielded walls, floor, and roof. Access is gained either through a labyrinth or by lowering the 2.5 m thick concrete door. Analysis indicates that the shielding should be adequate for 12 GeV upgrade cavities operated at 28 MV/m. The control room is a 12 m by 3 m area with cable tray access to the test cave. The test cave and cabling scheme were laid out in anticipation of testing several different RF and cryogenic structures. Currently we are configured for testing SNS medium beta, SNS high beta, and CEBAF upgrade cryomodules.

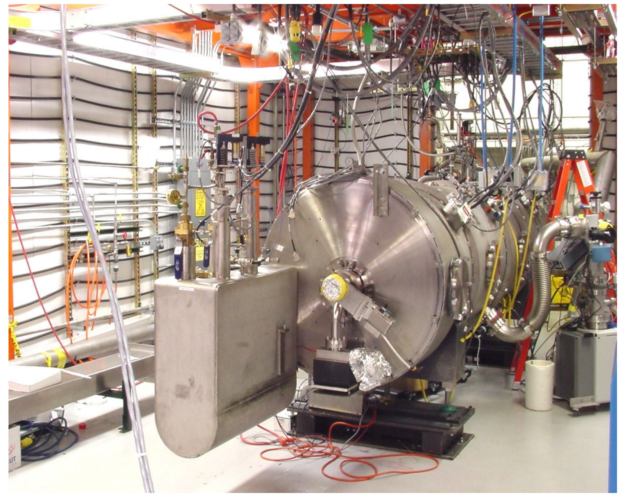

Figure 2: SNS medium beta cryomodule installed in the cryomodule test cave.

The facility is supported by three high power RF sources. Two pairs of 8 kW klystrons operated at 1497 MHz are combined to provide two 16 kW RF sources for testing of CEBAF-style cryomodules, windows, and other RF structures. Two 8 kW klystrons operated at 805 MHz are combined to provide a 16 kW source used for SNS testing. The third high power source is a 2.4 MW peak-power 60 kW average-power klystron with 1.3 ms maximum pulse width and an 8% duty cycle operated at 805 MHz. This klystron is shared with the SNS coupler test stand using manual waveguide switches, which allow the target systems to be quickly and safely changed.

The facility is supported cryogenically by the existing cryogenic test facility. It is a closed cycle helium system, which is shared between the CMTF and the vertical test facility [2]. The 4.17 K supply is limited to 15.5 gm/sec by the capacity of the recovery compressor. There are two 8 gm/sec process vacuum pumps, and the liquefier has a steady state capability of 5.5 gm/sec. Additionally, the system is tied into the CEBAF central helium liquefiers in order to better handle peak loading conditions.

MAGNETIC SHIELDING

The test lab building at Jefferson formerly housed a cyclotron, which magnetized the building steel such that the DC magnetic fields in the test cave exceed 6 Gauss

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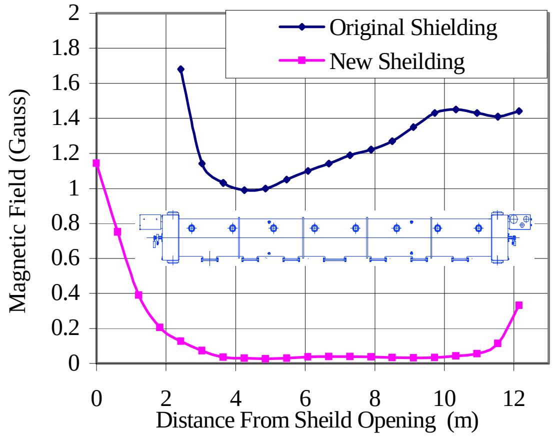

Figure 3: Measured magnetic fields before and after replacement of the magnetic shielding. The location of a CEBAF cryomodule is shown in blue.

along the cryomodule beam line. This exceeds the design value for a cryomodule by a factor of ten. Vitatech Engineering, of Springfield VA [3] was contracted to design and install a magnetic shielding system for the test cave. Their design consisted of 12 overlapping layers of 0.63 mm silicon steel, which were sandwiched between two layers of 6 mm low-carbon steel plate. The design included degaussing coils, which will be used when the system becomes magnetized after several years. The final shielding was a five-sided box of dimension 12.5x5.5x3.2 m. As shown in Figure 3, the new shielding provides <0.2 Gauss in the area where the cryomodules are tested.

CONTROLS HARDWARE

The block diagram for the low level RF (LLRF) and cryogenic controls as well as the data acquisition hardware is shown in Figure 4. The number of signals going to each subsection is indicated in the drawing. In order to maintain long-term flexibility, trunk cables were routed from the control room into the cave. This allows us to change both the instruments within the control room and connections to the structures inside the test cave without routing new cables. Two paths were chosen for the cable routing. The first was used for low noise and RF cables. The second was used for medium current and high noise cables. The cables include 46 multi conductor cables which have a capacity of 640 signals, 20 RF cables, 4 eight-pair thermocouple cables, 40 coaxial cables, and 8 triaxial cables.

Slow Data Acquisition

A Windows-based computer running LabView data acquisition software controls the slow data acquisition subsystem. The computer interfaces to a VME crate, a PXI chassis, a SCXI chassis, several GPIB power supplies, two RS232 based vacuum gauges, and an Allen Bradley programmable logic controller (PLC). Additionally, the computer acquires selected cryogenic plant process variables from the EPICS system through an Active-X channel access interface. The system collects and processes approximately 250 signals once a second and records them to a data file at a user specified rate. Additionally, the software has provisions for controlling the liquid helium heaters, coupler heaters, as well as multiple graph capabilities so that the user may track process trends as required.

In the SNS fundamental power couplers, the outer conductor transition is cooled by a flow of gaseous helium.[4] Without mitigation, condensation forms on the stainless steel flange which can damage the coupler and instrumentation. The condensation is eliminated by a pair of resistive film heaters which are mounted to the flange. A PLC was chosen for this function due to its reliability and ability to recover from temporary power failures. Additionally, this PLC monitors the coupler cooling water flow and temperature.

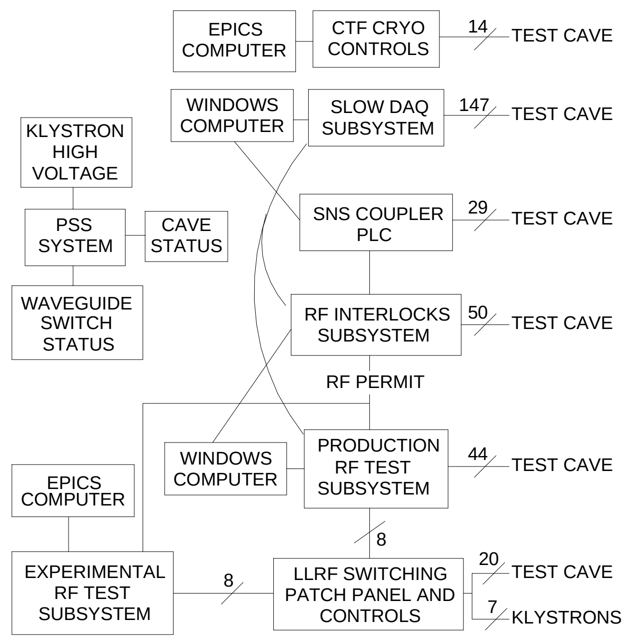

Figure 4: Bock diagram of the data acquisition and LLRF controls systems.

Interlocks

The system makes use of a modular interlock scheme. Each of the interlock functions is handled using separate hardware with an active low TTL daisy chained RF permit signal. Arc detectors, IR detectors, coupler vacuum, cavity vacuum, helium pressure and level are conditioned using custom VXI modules which, in addition to providing the interlock function, have built in data acquisition so that the status of both the analog and fault signals can be logged continuously during RF operations. Additionally, a PLC which controls the 1497 MHz waveguide switching is tied into the interlock chain so that it can inhibit RF operations while the switches are in an intermediate position.

The personal safety system (PSS) was also replaced when the facility was upgraded. The new system is PLC

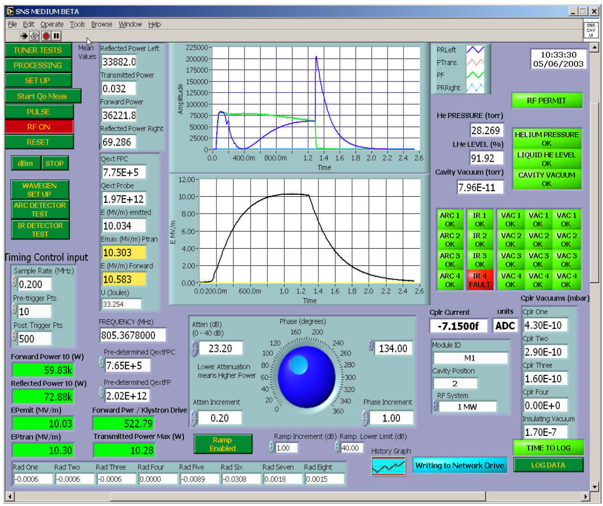

Figure 5: Screen image of the RF acquisition system configured for a SNS medium beta cryomodule.

based and uses the same architecture and many of the same components as those found in CEBAF.[6] The PSS operates independently of the low level RF, cryogenics and cryomodule protection interlocks. It monitors the status of the cryomodule test cave as well as the waveguides which feed the systems, and only provides a klystron high voltage permit when the system is properly configured for high power operation. Lockable waveguide shutter switches were installed near the terminus of each of the waveguides in the test cave to provide a mechanism to insure personnel safety by eliminating the possibility of an open waveguide.

Low Level RF Control and Acquisition

The system has three different provisions for the generation of RF drive signals for the klystrons. The first is custom VXI based VCO/PLL modules controlled by LabView Software.[5] These systems make use of I/Q modulation to control RF amplitude and phase. They also have provisions for external modulation through either a TTL signal or analog I/Q modulation controls. The second means is using an Agilent E442B signal source configured as a VCO/PLL using connectorized mixers, limiters, amplifiers, etc. This system has the advantage of precise amplitude modulation which is used for characterization of dynamic Lorentz force detuning.[6] The third option is to use an EPICS-based LLRF systems installed in the experimental RF subsystem.

The heart of the LLRF acquisition system is a pair of Boonton 4532 peak power meters. These meters allow us to acquire the RF waveforms with less than 2% nonlinearity over a 50 dB dynamic range at sample rates up to 2 MS/s. One of the difficult measurements for a strongly overcoupled cavity is measuring the stored energy, which is used to determine the electric field in the cavity. Using these instruments allows us to accurately determine the stored energy in the cavity. We use the reflected power waveform to calculate the stored energy using equation (1), where U is the stored energy, $(P_r)_i$ is

$$U = \sum_{i=k}^{N} (P_r)_i * \Delta t \qquad (1)$$

the i^{th} element of the reflected power data array, k is the index where the incident power is turned off, Δt is the sample time and N is the index of the final element of the data array. The two major contributors to the error in this measurement are the jitter in capturing the peak reflected power and the error in the RF power measurement. For sample times, which are hundreds of times less than the cavity fill time and 8% RF measurement errors, equation (1) yields stored energies, with an RMS error of approximately 10% and gradients with an RMS error of approximately 5%. Errors associated with Q_0 measurements are 20%, primarily due to errors in measuring the RF heat load.

In addition to recording waveform records on request, the system logs the cavity RF parameters, including RF power levels, peak gradients, stored energy, and coupler vacuum values every two seconds while the system is operating. This allows the user to review the operational characteristics of the cavities while they are being commissioned. Additionally, the system is set up to measure the cavity parameters parasitically to operation with experimental LLRF systems.

CONCLUSIONS

The modification to and capabilities of the cryomodule test facility located at Jefferson Lab have been presented. It a unique facility in that in which multiple cryomodule types as well as other RF structures may be tested. The cabling scheme implemented allows one to quickly change from one cryomodule type to another in a period of days. It has provisions for extensive diagnostics, which allow the users to investigate cryomodule design issues in a controlled environment.

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