BNL 703 MHz SRF CRYOMODULE DEMONSTRATION*

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Abstract

This paper will present the preliminary results of the testing of the 703 MHz SRF cryomodule designed for use in the ampere class ERL under construction at Brookhaven National Laboratory. The preliminary cavity tests, carried out at Thomas Jefferson Laboratory, demonstrated cavity performance of 20 MV/m with a Qo of $1x10^{10}$, results we expect to reproduce in the horizontal configuration. This test of the entire string assembly will allow us to evaluate all of the additional cryomodule components not previously tested in the VTA and will prepare us for our next milestone test which will be delivery of electrons from our injector through the cryomodule to the beam dump. This will also be the first demonstration of an accelerating cavity designed for use in an ampere class ERL, a key development which holds great promise for future machines.

INTRODUCTION

The BNL 5 cell accelerating cavity[1] has been designed for use in our high average current Energy recovery linac (ERL). The ERL is a test-bed for superconducting RF components designed for use in future machines such as next generation light sources as well as the RHIC upgrade path known as eRHIC, the electron heavy ion collider.[2] The 5 cell cavity has been tested to greater than 20 MV/m with a Qo of $1e^{10}$, the design specification for the cavity, in the Vertical Test Area (VTA) at Jefferson Laboratory.[3] The cavity has since been built into a hermetic string assembly and then a constructed into a cryomodule and installed in our ERL facility. This paper will cover the string assembly and cryomodule construction and will then look at the initial cool-down of the cryomodule and subsequent RF tests of the cryomodule.

STRING ASSEMBLY

The string assembly was carried out in the class 100 cleanroom at Jefferson Lab and included the installation of all of the beamline components that are located between the isolation valves on either end of the string. Figure 1 shows the completed string assembly which is effectively symmetric about the 5 cell cavity. The key components shown moving away from the cavity are the 5 K liquid helium cooled thermal transitions with dual bellows, the beam position monitors, the water cooled Ferrite higher order mode (HOM) dampers, a beamline step reduction section with 20 l/s ion pumps and burst disks and finally the all metal seal valves.

Upon completion of the string assembly the cavity was shipped to BNL for cryomodule integration.

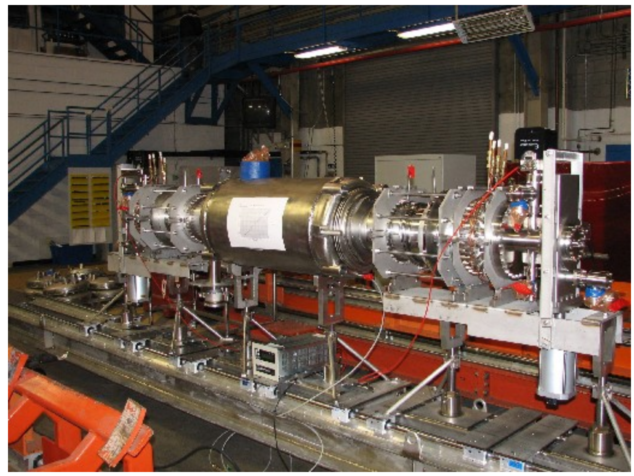

Figure 1: The ERL accelerating cavity hermetic string assembly shown before installation into the cryomodule.

CRYOMODULE INTEGRATION

The string assembly was built into a standard SRF cryomodule including two layers of magnetic shielding, multi-layer super insulation, a liquid nitrogen shield, installation of the cavity tuner mechanism which resides inside the vacuum space and finally the vacuum shell. The tuner mechanism is composed of a coarse mechanical stepper motor which was designed to provide 400 kHz of tuning range, as well as a piezo-electric drive for fine adjustment which provides 9 kHz of tuning range. Due to safety concerns the coarse tuner adjustment was limited to 100 kHz of tuning range, which is still more than adequate for our prototype ERL.

Following the cryomodule construction the unit was moved to the ERL facility and positioned under the liquid helium ballast tank, designed to provide operational liquid helium at 2 Kelvin. Figure 2 shows the cavity installed in the blockhouse and attached to the related helium and vacuum vent lines. Due to the fact that a liquid helium refrigerator was not part of the original plan the cryomodule was designed with the aforementioned ballast tank. For operations the system is filled with LHe and then a liquid ring pump is used to reduce the pressure over the Helium and provide stable operation at 2K.

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Figure 2: The cryomodule and liquid helium ballast tank installed in the ERL blockhouse.

CRYOMODULE CRYOGENIC TESTING

Once the associated systems were installed and tested a preliminary cryogenic test was carried out to determine the operational parameters of the cryostat. The goal of the test was to operate the four 5 K liquid helium intercepts to pre-cool the cavity, followed by introduction of LHe into the system to establish 4 K and then 2 K operational readiness.

The initial cooldown was very successful with all subsystems working as designed. The cavity was cooled to 4 K and then left to measure the static heat load from the system. The measured value was ~30 W, which was within approximately 15% of the expected static load. After this measurement the cavity was cool down to 1.8 K to test the operation of the liquid ring pump and ensure all of the associated systems operated correctly. The cool-down to 1.8 K was monitored closely to optimize the liquid helium loss and resulted in ~30% reduction in liquid level. The normal operation of the ERL requires 2 K operation, however the system was tested to 1.8 K as this pump will be used with other cavity testing dewars which may require lower temperature for cavity studies. Figure 3 shows the data recorded during the cryogenic operation.

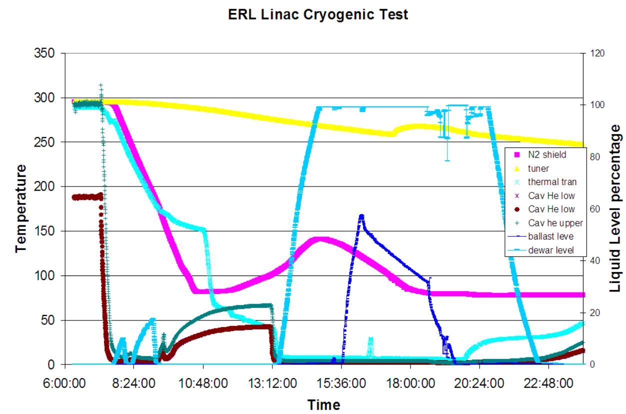

Figure 3: A summary of some of the relevant data from the first cryogenic cool-down of the cryostat.

FUNDAMENTAL POWER COUPLER RE-CONDITIONING

The FPC was originally conditioned 2 years prior to it's insertion into the hermetic string. As such, there was concern that it may require re-conditioning prior to operation. It was decided to carry out this operation at room temperature to conserve liquid helium in the event the conditioning process took more than an hour or two. The FPC is designed to operate at 10 kW power during routine cavity operation. The RF transmitter is designed to operate up to 50 kW, and as such the full range of the transmitter was used for conditioning. The cavity was at 150K when the conditioning was carried out, and there were no arcing events or vacuum trips during the conditioning operation. The power was raised to 47 kW without incident and the processes declared a success. The vacuum level in the cavity was 1e^{-9} Torr as measured on two cold cathode gauges on the flange of the FPC as well as measured by the beamline cold cathode gauge in the warm section of the cavity beampipe. The vacuum pressure only rose slightly due to thermal heating of the FPC antenna to 1.8e^{-9} Torr at 47 kW. The temperature of the ceramic window was monitored by an RTD mounted to the flange on which the ceramic is brazed. The temperature of the flange rose 20 K during the conditioning operation and peaked at 308 K. The FPC inner conductor is water cooled and the vacuum side outer conductor is cooled by LHe, or in this case LN_2, while the ceramic window itself is maintained at 15° C to avoid ice-ball formation or excess thermal stress on the window.

CRYOMODULE RF TESTING

The first test of the performance of the cavity in the cryomodule was carried out in April, 2009. The preliminary results are very encouraging, and all subsystems worked as designed. The cavity was operated at both 4K and 2K and a gradient of ~20 MV/m was measured at 2 K. This value is inline with the design specification for the system and agrees well with the data collected during the vertical cryogenic testing (VTA) of the cavity. Figure 4 presents the data from this test along with the data acquired in the VTA. The current test data reached a similar gradient as in the VTA, but the Qo of the cavity was considerably lower. The reason for this decrease in Qo is still under investigation, but is likely attributed to the low level RF (LLRF) system calibration as well as the method of calculating Qo. For this test the gradient was calculated using our calibrated pick-up probe via equation 1.

$$Eacc = \sqrt{Q_{ext2} * P_{trans} * \frac{(r/Q)}{L}} \qquad (1)$$

The Qo of the cavity was then calculated based on equation 2 which relies on an accurate measurement of the power lost, $P_{loss} = P_{inc} - P_{ref} - Pt_{rans}$, in the cavity.

$$Q_0 = \frac{E_{acc}^{\ 2}}{P_{loss}} * \frac{L}{(r/Q)} \qquad (2)$$

In the current calculations the power loss calculation is based on the incident, reflected and transmitted power, and does not rely on the preferred calorimetric measurement traditionally used in cryomodule tests. As the analysis is ongoing, calorimetry values will be obtained and further data analysis conducted.

Analysis of the radiation levels monitored ~1 meter downstream of the end of the cryomodule gate valve show signs of a multipacting barrier at 10-12 MV/m, also seen in the VTA, as well as significant field emission above this gradient. The field emission will require further analysis and possible implementation of He processing to overcome.

The cavity test duration was limited to one day due to the amount of helium available. With the ballast tank design, filled via transfer dewars, and the static load of ~20-25 watts the cavity can operate for approximately 4 hours before requiring the addition of more helium. Due to the time constraints it was not possible to process the cavity completely, so the abovementioned field emission and multipacting will require further investigated during the next test.

In addition to the RF data described above, several other important steps were carried out during this test, including testing the operation of the LLRF system, the phase lock loop, and the tuner drive mechanism. Additionally vibration measurements were taken with multiple accelerometers placed on a variety of location on and around the cryomodule to better understand potential sources of noise and how this may impact operations. Additional vibration measurements were collected through the tuner mechanism.

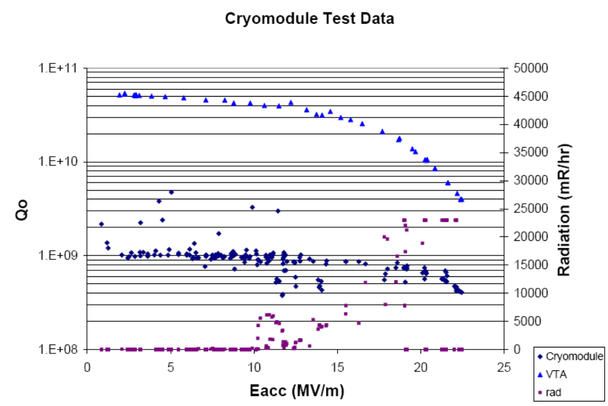

Figure 4: The preliminary test data from the cryomodule including radiation measurements presented along with the previous VTA measurements.

CONCLUSIONS

The overall performance of the system is very encouraging and has set the program off to a very good start. Further testing and analysis is required, and future tests with the balance of the ERL components are highly anticipated.

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