FIRST TEST OF THE CORNELL SINGLE-CAVITY HORIZONTAL CRYOMODULE *

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Abstract

A single-cavity horizontal test cryomodule (HTC) has been designed and fabricated recently at Cornell University for ERL project. This cryomodule is a shortened version of the full injector cryomodule, housing five superconducting cavities. It serves as a test bench for new design features and for testing fully dressed two-cell ERL injector cavities. The cryostat design has been optimized for precise cavity alignment, good magnetic shielding, and high cryogenic loads from the RF cavities, input couplers, and HOM loads. The HTC was made long enough so in the future it can accommodate longer, multicell cavities of the ERL main linac. In this paper we report on results from the first full test of the HTC, including RF system and superconducting cavity performance, cryomodule studies and operation of a new 2 K cryogenic system.

INTRODUCTION

Cornell University is developing a future X-ray light source based on the Energy Recovery Linac (ERL) concept [1]. The 5-GeV low-emittance beam will have average current of 100 mA. For the energy recovery to be efficient, the linac has to be superconducting (SC). Another SC linac serves as an injector to this ERL [2]. Unlike main linac, it does not energy recover and has to provide up to 100 kW of RF power per cavity to beam. Different requirements to two linacs [3] dictate choice of the cavity designs: the injector cavity is a two-cell structure with two symmetric input couplers [4] while the main linac cavity will have seven cells and only one low power input coupler. Cryogenically though the injector cryomodule (ICM) [5] and the main linac cryomodule will be very similar.

The cryomodules are among the most challenging components of ERL. They have to accelerate a high current CW beam without diluting its very low emittance. This puts high demands on the cavities, RF input couplers, higher-order mode loads and cryostat. While all these components are fabricated and tested individually, the ultimate test of the design approaches is the horizontal test of a “fully dressed” cavity. A one cavity horizontal test cryostat was designed [6] and built for such tests. In this paper we report results from the first test of a two-cell ERL injector cavity in HTC.

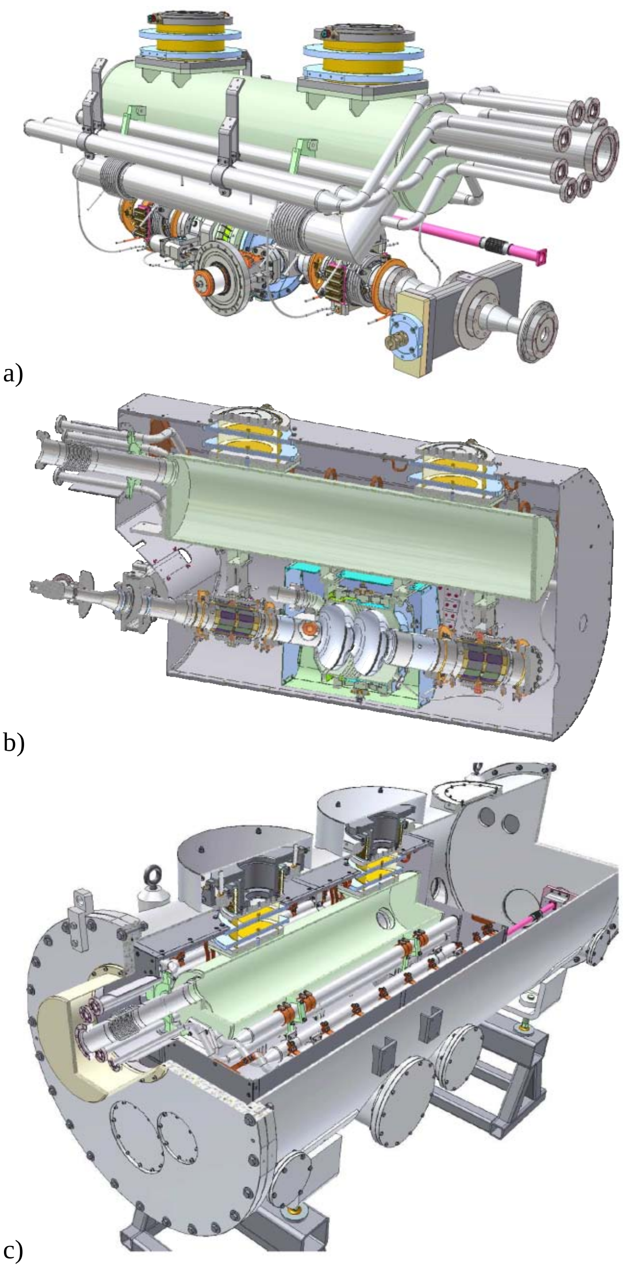

Figure 1: 3D views of the Horizontal Test Cryomodule: a) the SC cavity string attached to the helium gas return pipe; b) the HGRP assembly inside the 80 K shield; c) the cryomodule vacuum vessel with the cold mass inside.

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*Work supported by NSF Grant PHY 0131508

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HTC DESIGN

The design of the HTC [6] closely follows the design of the ERL injector cryomodule [5], but hosts only one SC cavity. Its vacuum vessel is made long enough to accommodate either a two-cell injector cavity or a seven-cell main linac cavity in future tests. The cryomodule design is based on the well established TTF cryomodule [7], with the beam line components supported from a large diameter helium gas return pipe (HGRP) nd all cryogenic piping located inside the cryomodule. The TTF type cryomodule has been significantly re-designed to meet the specific requirements of ERL and to include several innovations [5]. Figure 1 shows 3D views of HTC.

TEST RESULTS

The HTC test set up in the RF processing area used many of the components that have later become part of the ERL injector facility: a cryogenic heat exchanger box with associated cryolines, a pumping skid, waveguide assemblies and a klystron. Details of the cryogenic controls and HTC instrumentation can be found in [8]. The cryogenic system performed well during the test allowing for quick cool down to 1.6 K – 2.0 K and warm up to 4.2 K. The cryostat pressure stability at 1.8 K was typically 0.02 mbar rms. Figure 2 shows temperature evolution at several points inside the cryostat during cool down to 80 K. The cold mass shift during cool down was monitored using a wire position monitor. The measured shift was within ±0.1 mm of the predicted number. While leaky JT valve prevented us from making precise measurements of the static heat leak, it was estimated to be several watts more than the design value.

RF layout was similar to one of the ICM RF channels described in [9], with an adjustable hybrid power split between two input couplers and a waveguide three-stub phase shifter. The input couplers were tuned for $Q_{ext} = 4.9\times10^5$ to minimize RF power demand. No coupler processing was necessary up to 12.2 kW with the cavity off resonance and only minor pulse processing (above 10 kW) was performed with the cavity on resonance. RF loss measurements low cavity intrinsic quality factor of $\approx1.5\times10^9$ at 1.8 K (Figure 3), about one order of magnitude below the expected value. The cavity field was limited to 9.5 MV/m in CW operation due to this high RF power dissipation. Fields above 13 MV/m were achieved in pulsed operation. X-ray radiation level was measured at a distance of 1 meter from HTC as a function of accelerating voltage (Figure 4).

Significant efforts were spent during the test trying to understand the cause of excessive RF losses. A warm up and fast cool down confirmed absence of *Q* disease. Shielding components with residual magnetic field did not have any effect on RF losses. Finally, quality factor measured at 4.2 K was consistent with the BCS theory prediction (Figure 3).

No high quality higher-order modes were found. All modes detected with a network analyzer had *Q* of few hundreds.

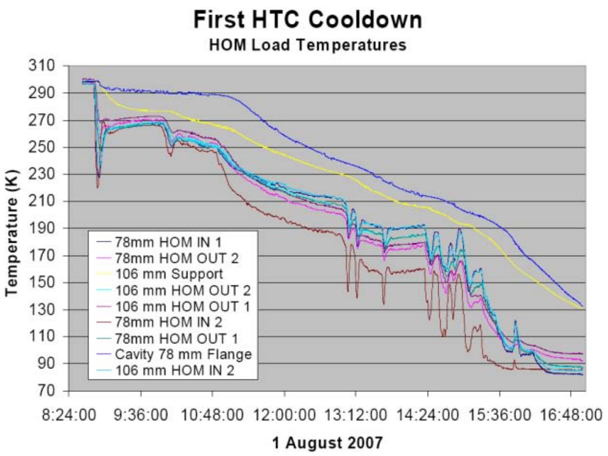

Figure 2: Temperatures during HTC cool down to 80 K.

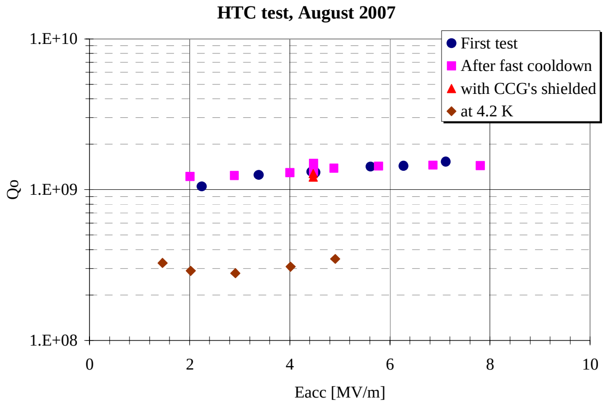

Figure 3: Q vs E_{acc} measured during HTC test.

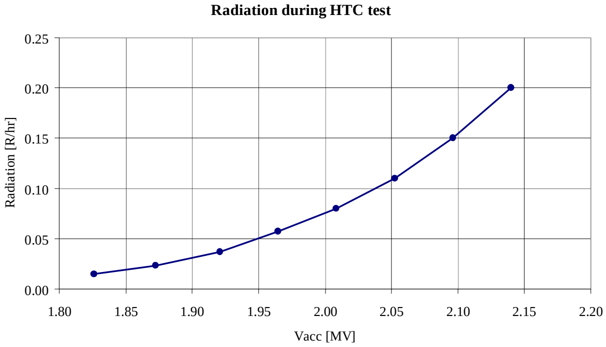

Figure 4: Radiation level at about 1 m from HTC.

HTC TEST FOLOW-UP

Upon disassembly of the cryomodule, it was found that two ferrite tiles broke of from the large diameter HOM load (see Figure 5) and small ferrite chips propagated into the cavity beam pipe. The ferrite tile was of TT2-111 type. Computer simulations indicate that a 1µm size ferrite particle near the cavity equator can cause factor of ten drop of the quality factor. To verify that the ferrite dust was indeed the cause of poor cavity performance, the cavity was re-tested on a vertical test stand. Firstly, the cavity was thoroughly rinsed with methanol. The *Q* factor improved, but did not recover completely. Secondly, it was high-pressure water rinsed and its performance recovered completely as one can see from Figure 6.

It is believed that the cause of the failure is too fast cool down rate of resulting in large temperature difference across the tiles and hence in excessive mechanical stress. It is therefore recommended that the injector cryomodule cool down rate should be kept below 10 K/hr. Following the HTC test all production series HOM loads were subjected to cryogenic testing and careful inspection. Several more broken tiles were found in the large loads. It was decided to replace all TT2-111 tiles in the large diameter HOM loads of the injector cryomodule with CO2Z tiles. Simulations show that this should not affect beam stability in the ERL injector.

Careful re-examination of the cryomodule design revealed that the source of extra static heat leak is due to HOM load support posts, which thermally connect the HOM load body kept at 80 K to HGRP operating at 2 K. Extra 5 K heat intercept is added to the support posts to reduce this parasitic heat leak.

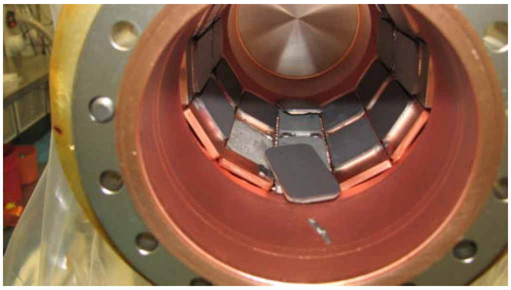

Figure 5: Photograph of the broken ferrite tile inside the large diameter HOM load.

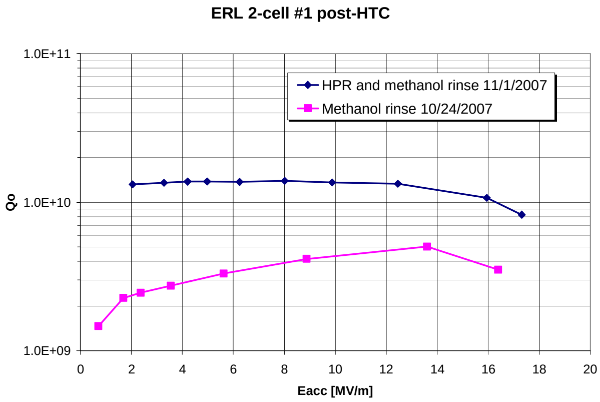

Figure 6: Results of re-testing HTC cavity on a vertical test stand.

SUMMARY

The first test of the one-cavity horizontal test cryostat was performed at Cornell recently. The assembly included the “fully dressed” two-cell ERL injector cavity with attached HOM loads and input couplers. The test verified soundness of the concepts for the injector cryostat design, cryogenic system and RF. The superconducting cavity reached exceeded minimal gradient specifications (5 MV/m), reaching 9.5 MV/m in CW mode. The field limit was due to excessive RF power dissipation caused by small ferrite particles from broken tiles. The cause of failure is understood and a fix for the injector cryomodule is implemented. High static heat leak was traced to HOM load’s support posts and a 5 K heat intercept was added to reduce parasitic heat load. The HTC test provided us with invaluable experience and, which was used to improve the injector cryomodule, which is installed and under commissioning at the time of writing [10].

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