FIRST COOL-DOWN OF THE CORNELL ERL MAIN LINAC CRYO-MODULE

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Abstract

Cornell University has finished building a 10 m long superconducting accelerator module as a prototype of the main linac of a proposed ERL facility. This module houses 6 superconducting cavities- operated at 1.8 K in continuous wave (CW) mode with a design field of 16 MV/m and a Quality factor of $2\cdot10^{10}$. We will shortly review the design and focus on reporting on the first cool-down of this module. We will be giving data for various cool-down scenarios (fast/ slow), uniformity and performance.

INTRODUCTION

To drive a diffraction limited, hard x-ray sources, Cornell University has proposed to build an Energy Recovery Linac (ERL) because of the ability to produce electron bunches with small, flexible cross sections and short lengths at high repetition rates. The proposed Cornell ERL is designed to operate in CW at 1.3 GHz, 2 ps bunch length, 100 mA average current in each of the accelerating and decelerating beams with normalized emittance of 0.3 mm-mrad, and energy ranging from 5 GeV down to 10 MeV, at which point the spent beam is directed to a beam stop [1, 2].

Within this R&D program, the design of a main linac prototype cryo-module (MLC) was commenced and had been completed in 2012. This accelerator module is 10 m long and houses six 1.3 GHz, 7-cell superconducting cavities with individual HOM absorbers. It also has space for a quadrupole/ BPM section which was omitted in the prototype we built. Each cavity has a single coaxial RF input coupler which delivers power to the accelerating cavity[3].

For the superconducting cavities, an unloaded quality factor of $Q_0 = 2\bullet10^{10}$ at 1.8 K at a field of 16.2 MV/m was targeted. Quality factors as high as this can only be achieved if the ambient magnetic field is extremely small. For that reason, the MLC has three layers of magnetic shielding: the vacuum vessel made from carbon steel, an 80 K magnetic shield enclosing the cold mass, and finally a 2 K magnetic shield around each cavity, individually.

All components within the cryo-module are suspended from the Helium Gas Return Pipe (HGRP). This large diameter (280 mm) titanium pipe will return the gaseous helium boiled off the cavity vessel to the liquefier and act as a central support girder. The HGRP is suspended from the vacuum vessel by 3 support post. The central post is fixed in position while the two outer posts are designed to slide by 7 and 9 mm respectively during the cool-down to accommodate the shrinkage of the cold mass. More details on the design are given in [4].

The fabrication and testing of MLC components like cavities, high power input coupler, higher order mode dampers and tuners were successfully conducted in 2014. Results are published in [5]. With the final installation in the testing area, completed in September 2015 (see Fig. 1), preparations for the first cool-down commenced, resulting in a successful cryogenic testing campaign. This paper will concentrate on reporting these findings.

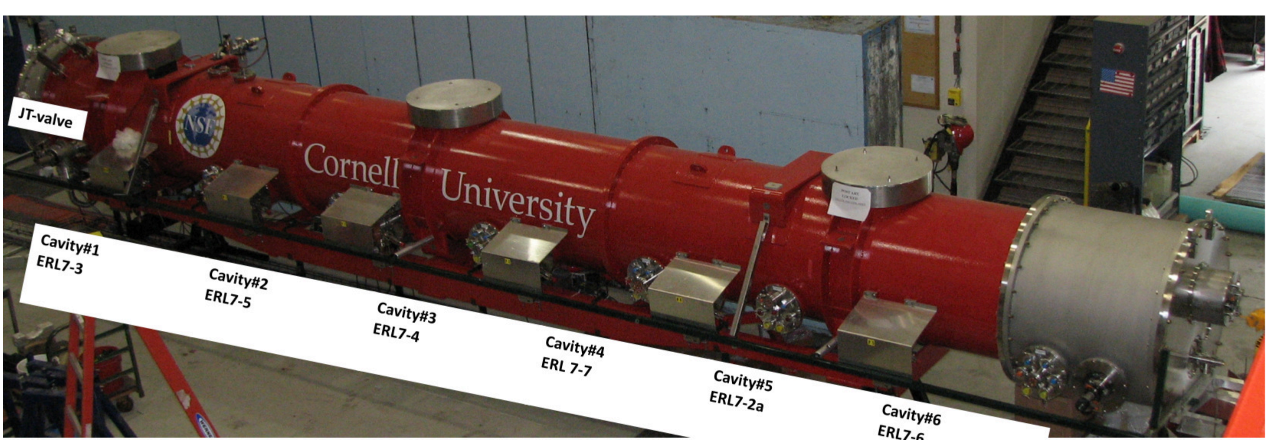

Figure 1: Cornell's Main linac cryo-module during the installation in Wilson Lab. Positions of the cavities are also depicted.

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ISBN 978-3-95450-147-2

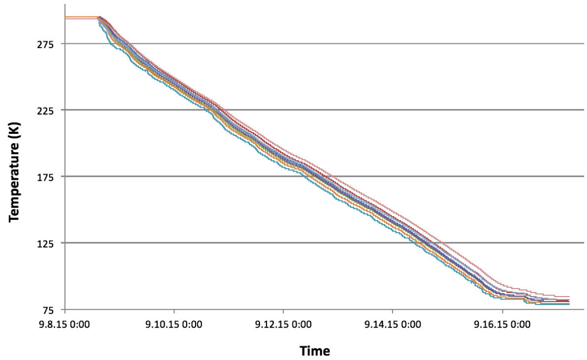

Figure 2: Temperatures on the thermal shield during the cool-down. Due to the design of the thermal shield the temperature spread across the shield had to stay below 20 K, leading to a cool-down rate of ~1.25 K/h.

INITIAL COOL-DOWN

In order to facilitate a smooth and controlled cool-down, a new heat exchanger can was built. It allows to add a warm stream of gas to the 80 K cold helium forwarded to the cold-mass, resulting in a very controlled cool-down, as shown in Fig. 2. This was mandatory as the thermal shield is cooled by conduction only with an extruded pipe running just along one side. As a result, the cool-down of the shield is asymmetric and we calculated stress limits on the aluminium transitions which required us to keep the temperature spread across the shield below 20 K. In the initial cool-down we maintained 10 K, becoming 15 K below 200 K with an average cool-down rate of 1.25 K/h. More details on the heat exchanger can which we found extremely convenient are in [6].

During cool-down, we also monitored the movement of the two outer, sliding support posts. In contrast to the ILC our cryo-module is aligned via the helium gas return pipe, made out of titanium, being suspended from the vacuum vessel by three support posts. The central post is fixed while the two outer posts are sliding, allowing the cold-mass to shrink. Figure 3 gives the movement of these posts as the temperatures on the cool-mass go down. The movement was as expected and deviations from the predicted position was considered an abort criterion.

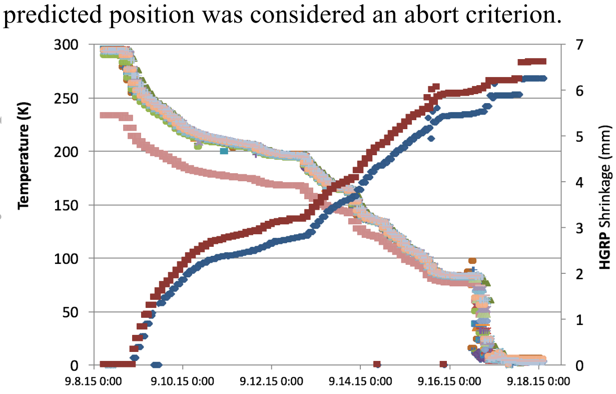

Figure 3: Movement of the outer (sliding) support posts: as the temperature of the HGRP goes down the posts move inwards. The movement was as expected.

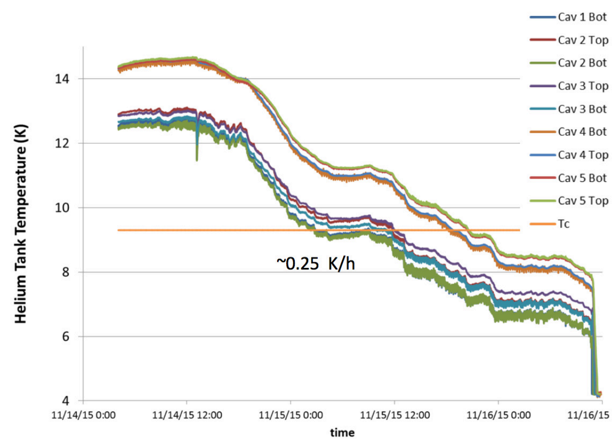

Figure 4: Slow cool-down cycle performed in order to measure cycle dependant impacts on the cavity performance. For the slow cool-down we were able to get 0.25 K/h relatively uniform over the cryo-module.

DIFFERENT SPEED THERMAL CYCLES

Recent findings have indicated that the performance of an SRF system also depends on details of the cool-down process. Findings at Cornell indicate that for conventionally treated cavities a slow cool-down leads to a higher quality factor of the cavity [7]. We were able to explain this finding by describing the role of thermo-currents that are excited at the material transitions between the niobium (cavity) and the titanium (enclosing helium vessel), driven by temperature gradients [8].

However, it has been found that large grain cavities as well as so-called nitrogen-doped cavities, seem to require a fast cool-down. It was found that this helps expelling residual magnetic field more efficiently than a slow cool-down [9]. We therefore went through a total of 5 thermal cycles, trying very slow and extremely fast cool-downs. Results are given in Figs. 4 and 5. We found that for a slow cool-down some cavities went through transition several times with some unwanted warm-up in between. This was hardly controllable but the transition speed was pretty uniform over the whole module. We also learned that on the fast procedure the final cool-down speed depended on the cavity position, especially how close the cavity was in relation to the Joule-Thompson valve.

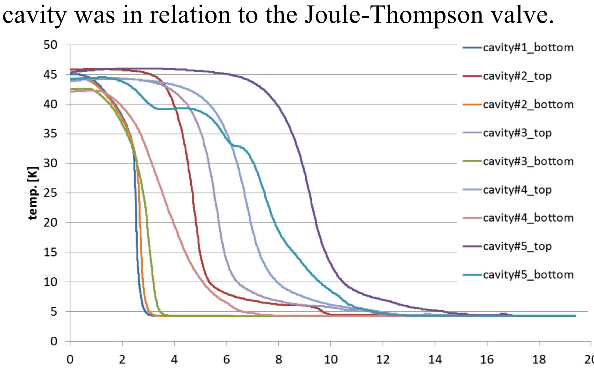

Figure 5: Cavity temperatures during the fast cool-down resulting in a speed of 0.5 K/min to 2 K/min, depending on how close the cavity was to the JT valve.

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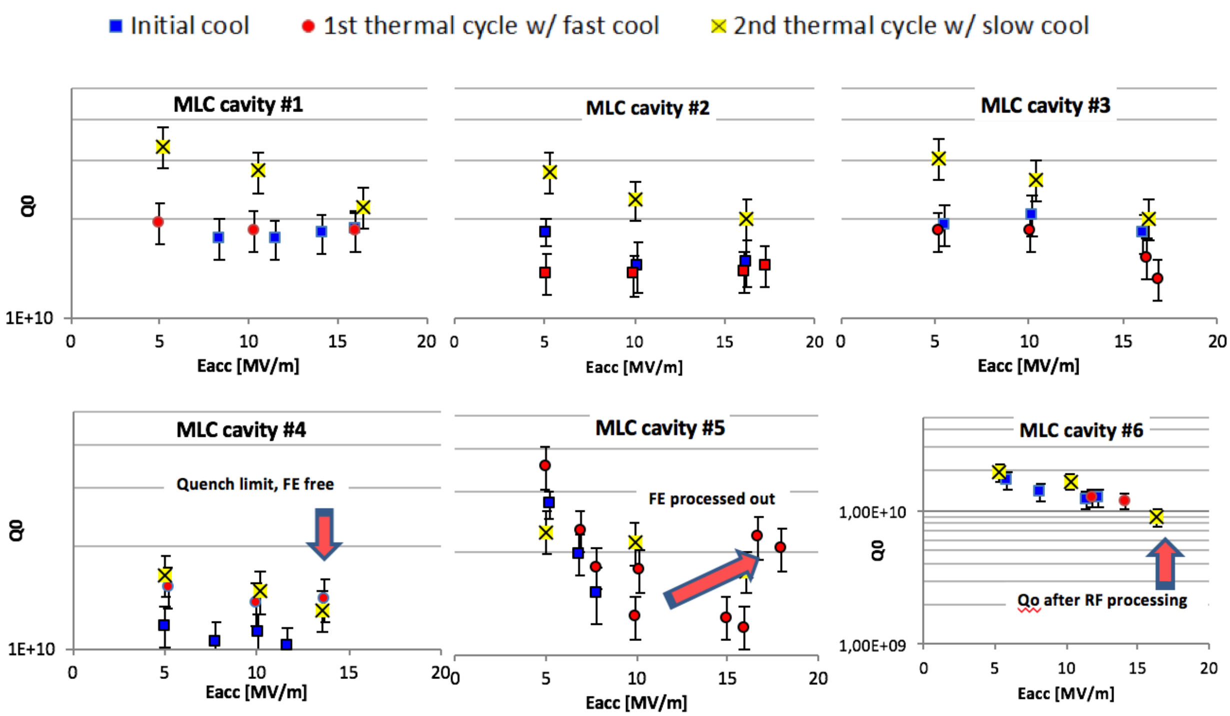

Figure 6: Summary of the cavity performance. All data were taken at 1.8 K. Two cavities had to be RF processed to increase the field and to remove field emission. Cavity #4 is still limited by an early quench, but administrative procedures (for now) prevented us from processing this cavity harder.

CAVITY RESULTS

Test results from all 6 cavities are summarized in Fig. 6 After some initial processing 5 of the 6 cavities perform close to their design specifications. One cavity is currently limited by a premature quench which we hope to overcome by a thermal cycle and pulse processing. Even so the quality factors are slightly lower than the design, the cavities (except #4) easily reach the design gradient. From Fig. 6 one could also conclude that in our case the cool-down speed did not significantly affect the cavity performance. However, the data shows slightly higher Qs for the slow cool-down. This might indicate that we have a slightly higher residual magnetic field inside the MLC (as compared to our short test module HTC).

MODULE PERFORMANCE AND COMISSIONING

During the initial testing period, we also performed tests on the tuning system, the fundamental power couplers, measured the spectrum of the higher order modes and started investigating microphonics. In summary, we were able to tune all cavities to the common resonant frequency of 1.3 GHz, we ran all coupler to 5 kW and the HOM spectrum measured on the first cavity we measure so far was indicating no dangerous undamped modes[10]. More details can also be found in [11].

In that sense everything worked as expected. Currently we are tracking down sources of microphonics, as the detuning we observed exceeds the designed bandwidth of 10 Hz. It should be mentioned that the pressure stability of the 2 K system is better than 0.1 mbar when the JT valve is set to a fixed position while the He-level is controlled by boil-off using an electrical heater.

ACKNOWLEDGMENTS

Cornell's work has been supported by DOE grant DE-ACO2-76SF00515 and NSF grants PHY-1002467 and DMR-0807731.

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ISBN 978-3-95450-147-2