ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI061



# CORNELL'S MAIN LINAC CRYOMODULE FOR THE ENERGY RECOVERY LINAC PROJECT*

R. Eichhorn#, F. Furuta, Y. He, G. Hoffstaetter, T. O'Connell, P. Quigley, D. Sabol, J. Sears, E. Smith, M. Liepe, B. Bullock, B. Elmore, J. Kaufman, J. Conway, V. Veshcherevich
Cornell Laboratory for Accelerator-Based Sciences and Education, Cornell University
Ithaca, NY 14853-5001, U.S.A

*Abstract*

Cornell University has been designing and building superconducting accelerators for various applications for more than 50 years. Currently, an energy-recovery linac (ERL) based synchrotron-light facility is proposed making use of the existing CESR facility. As part of the phase 1 R&D program funded by the NSF, critical challenges in the design were addressed, one of them being a full linac cryo-module. It houses 6 superconducting cavities- operated at 1.8 K in continuous wave (CW) mode - with individual HOM absorbers and one magnet/ BPM section. Pushing the limits, a high quality factor of the cavities ($2*10^{10}$) and high beam currents (100 mA accelerated plus 100 mA decelerated) are targeted. We will present the status of the main linac cryomodule (MLC) fabrication and the findings on the cavity performance and component testing.

## INTRODUCTION

The concept and the application range of Energy-Recovery Linacs (ERLs) have expanded dramatically over the past years, the LHeC [1] and the ENC/EIC [2] are just two of the mayor projects. Cornell University has proposed an ERL as a driver for hard x-ray sources because of their ability to produce electron bunches with small, flexible cross sections and short lengths at high repetition rates, allowing us to pioneer the design and hardware for such an ERL based light-sources [3].

As a phase 1 R&D, critical design issues were addressed, like building a high brilliant, high current injector [4]. As goals for the SRF cavity performance were also set high, part of that R&D program was building a linac cryo module, based on 1.3 GHz cavities, optimized for a high BBU-limit with extraordinary high quality factors to reduce operating cost.

## MAIN LINAC CRYOMODULE

The general layout of the Main Linac Cryomodule (MLC) prototype is shown in Fig. 1. It houses six superconducting 7-cell cavities and has an overall length of 10 m. The design has been guided by the ILC Cryomodule while necessary modifications have been made to allow CW operation. In addition, we decided to align all components inside the module by reference surfaces on the helium gas return pipe (HGRP). As a consequence, the coldmass as a whole will shrink during cooldown, requiring the power couplers to flex.

Due to the high beam current combined with the short bunch operation a careful control and efficient damping of the HOMs is essential, leading to the installation of dampers next to each cavity [5]. Details of the design have been reported earlier [6,7].

## CAVITY PRODUCTION AND RESULTS

The almost 10 m long module houses 6 superconducting cavities, operated in CW mode at 1.8 K. These 7-cells, 1.3 GHz cavities with an envisaged Q of $2x10^{10}$ will provide an energy gain of 16 MV/m.

All 6 cavities have been produced in-house starting from flat metal niobium sheets. The steps doing this have been subject of another publications [8]. Figure 2 shows a photograph of the finished cavities. For the MLC, we decided to build 3 unstiffened cavities as well as 3 cavities with stiffening rings.

For the surface preparation we choose to stay with buffered chemical polishing (BCP). Starting after fabrication, the damage layer was removed by bulk BCP (100 μm). The hydrogen degassing was done at 650 C for 4 days while we monitor the hydrogen residual gas inside

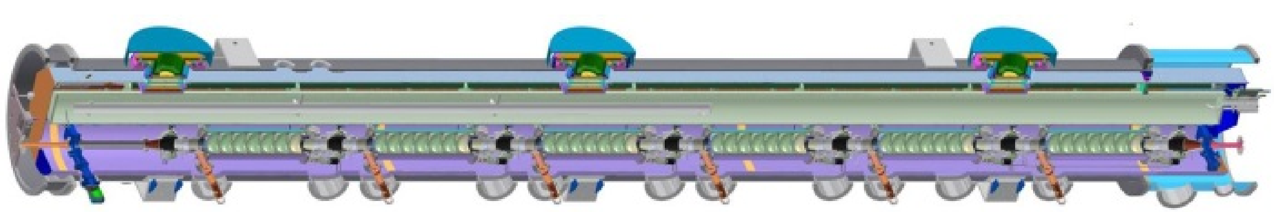

Figure 1: CAD model of the Cornell ERL Main Linac Cryomodule (MLC) prototype. It has 6 cavities (7-cells, 1.3 GHz, BBU-optimized shape) and beam line higher order mode absorbers.

#r.eichhorn@cornell.edu

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI061

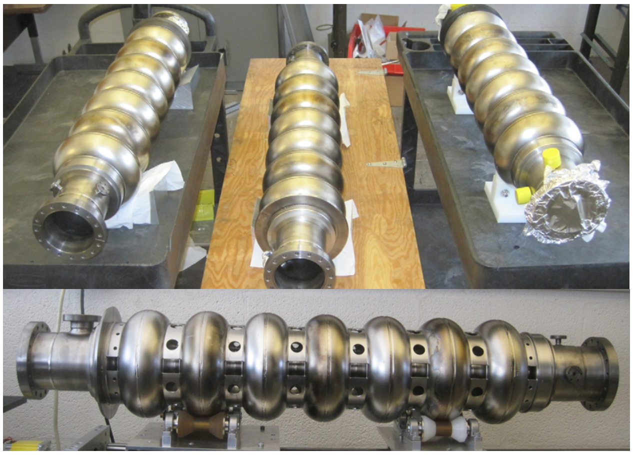

Figure 2: Picture of the superconducting cavities for the MLC. Six were built in-house, three of them have stiffening rings.

the furnace. We also found that a higher temperature (850 C) seems to remove more hydrogen while the softening of the cavity was still acceptable. The last production cavity (ERL 7-2a) was treated such and displayed a higher Q (compared to the other ERL cavities) at 1.6 K.

The degasing was followed by a frequency/ flatness tuning and an optical inspection. As final preparation step we did a light BCP (10 µm), a low temperature bake (120 C, 48 hrs), and an HF rinse. Each chemistry step was followed by an ultra-sonic cleaning and a high pressure rinsing. All cavities were tested vertically, the summary of these test are given in Fig. 3. All six cavities exceeded the design quality factor, averaging to $2.9*10^{10}$ at 1.8K. at 2 K, the average Q was $1.8*10^{10}$ , at 1.6 K we found $4.3*10^{10}$ .The reproducibility of the Q versus E curves for all cavities is remarkable, also the fact that none of the cavities needed additional processing.- giving a 100 % yield.

During the cavity fabrication process we learned that

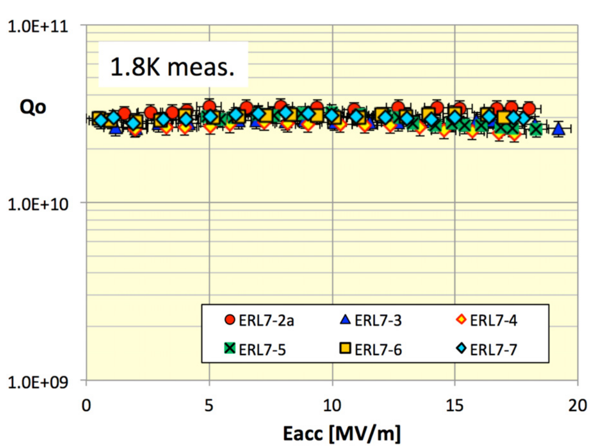


Figure 3: Vertical test results for all 6 ERL cavities. All cavities exceeded the design specifications for the ERL ($Q=2*10^{10}$ at 1.8 K). The reproducibility of the results, gained without any reprocessing of a cavity, is remarkable.

Table 1: Cavity fabrication accuracy achieved on the second batch of cavities after improving the procedure. The target length refers length as built the design length is the envisaged post tuning length. ERL7-6 & ERL7-7 were designed short intentionally to compensate the excessive length of the first 3 cavities built.

| | Target Length (mm) | Design Length (mm) | Length Post-Tune (mm) | ΔLength (mm) |
|---|---|---|---|---|
| **ERL7-006** | 1157.84 | 1159.0 | 1159.09 | **0.09** |
| **ERL7-007** | 1157.39 | 1159.0 | 1159.3 | **0.3** |
| **ERL7-002a** | 1161.66 | 1160.0 | 1160.08 | **0.08** |

the initial cavities all came out to be long (by ~1.5 mm),triggering a careful analysis of all production and QA processes. Details of our findings have been described in [9]. The result of the improvements made are summarized in Table 1: the last 3 cavities where produced to match the length (tuned to final frequency) with a mean deviation of less than .2 mm. Currently, all cavities are connected to form the cold mass string. Figure 4 gives the status as of Mai 2014.

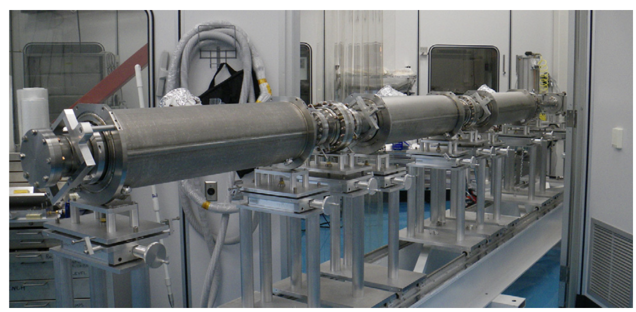

Figure 4: String assembly inside the cleanroom- 3 cavities being already connected.

## MODULE FABRICATION

All major sub-systems have been fabricated, each required special technical challenges. The cylinder of the vacuum vessel is a rolled longitudinally welded carbon steel (A516 GR70) pipe. Due to vendor's limited capability of final machining of the entire length of the vessel in a single setup, the vacuum vessel is made from three spool pieces. The spools are bolted with pins for alignment, and then welded together from the inside of the joining flanges to make up the full length. All precision required surfaces are machined in a single spool piece setup. Dowel pins and reference surfaces on the end flanges are used for the alignment to meet the GD&T requirements of the final vessel (see Fig. 5). Both the interior and exterior steel surfaces are painted, the interior being painted with PSX 700 Engineered Siloxane while a marine paint was chosen as the exterior paint.

The Helium Gas Return Pipe (HGRP) is fabricated from a rolled and welded Grade 2 Titanium cylinder. Being the reference for the alignment of the beam-line string, the surfaces of the HGRP top and bottom supports

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRI061



Figure 5: Vacuum vessel received by Cornell.

are precision machined with a single machine tool setup at the final stage after all welding is done. During test fit of the baffle sub-assembly (which is needed in the prototype to guide the cold helium gas stream through the full length of the HGRP which lags the downstream flow from an adjacent module) in the Ti pipe, it was noticed that the baffle tube was flexible and the spoke support rods did not all make contact to the Ti pipe. This was solved by extending the support rods to ensure a tight fit with an extra pressure. See Fig. 6 for details. The final acceptance tests include: leak checking, dye penetrant testing, CMM measurement, and vibration stress relieving. The fabrication of the 40 K thermal shield and magnetic shield, being attached to each other, are handled by the same vendor, to ensure they fit well at pre-mounting. Due to a limited furnace size for the hydrogen annealing after forming of the Mu-metal sheet, the magnetic shield sections are consists of many small patches in 1 m x1.2 m, with overlaps at joints. Enough clearance is ensured between sections and the joints, to account for differential thermal contractions between the magnetic shield (Mu-metal) and the thermal shield (Al1100-14).

CMM measurement was performed for the acceptance of the support posts. Cooling pipes are pre-bent, with some loops to allow thermal contractions. Most of other components such as instrumentation cabling, beam-line supports, wire position monitors (WPM), etc. are made in house. Provision is made that no magnetic materials are used inside the cold mass, including all fasteners.

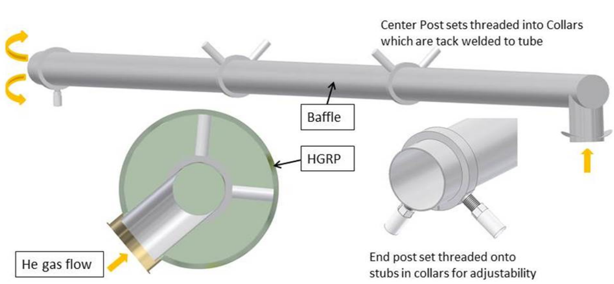

Figure 6: Baffle tube supported with spoke rods in HRGP, required for the prototype module, only.

## MODULE ASSEMBLY

The assembly process begins when assembled beam-line string is removed from the cleanroom, whereas the HGRP is suspended by three support posts to the assembly frame.

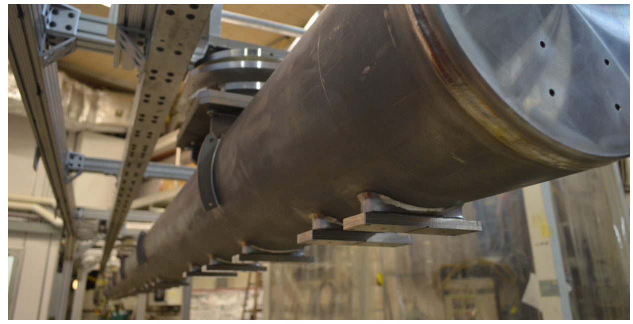
Figure 7: Assembly frame, supporting the HGRP which acts as a strongback for all beam line components, hung under the precision machined mounting feet.

The beam-line string is then connected underneath the HGRP, followed by welding of the 2-phase pipe (see Fig. 7) Afterwards, temperature sensors, cavity magnetic shields, tuners, cooling pipes, WPM, thermal and magnetic shields, and MLI are installed to form the cold mass. Once the cold mass is assembled, it will be rolled into the vacuum vessel on its rail system. The beam-line position relative to the vacuum vessel is surveyed and aligned properly through the adjustment screws on the three posts. Afterwards, the cryogenic valves, coupler warm portion, gate valve actuator, instrumentation feedthroughs, end shields, and end cans are installed. Finally, the end walls are installed, with the bellows units sealing the insulation vacuum space. The full cryomodule is expected to be assembled by the end of 2014.

## REFERENCES

[1] O. Bruening et. al., “The Large Hadron Electron Collider”, Mod. Phys. Lett.A 28 (2013) 133001.
[2] eRHIC web site: http://www.bnl.gov/cad/eRhic
[3] M. Tigner et. al. “Cornell Energy Recovery Linac: Project Definition Design Report”, www.classe.cornell.edu/ERL/PDDR
[4] B. Dunham et al., “Record high-average current from a high-brightness photoinjector,” App. Phys. Lett. 102 034105 (2013).
[5] R.Eichhorn et. al.,” Higher Order Mode Absorbers for High Current ERL Applications”, Proc. Of the IPAC 2014, Dresden, Germany.
[6] R. Eichhorn et. al, “Design and Construction of the Main Linac Cryomodule for the Energy Recovery Linac Project at Cornell”, Proc. of the SRF 2013 Conference, Paris.
[7] R. Eichhorn, et. al. “Design and Construction of the Main Linac Module for the Superconducting Energy Recovery Linac Project at Cornell”, Advances in Cryogenic Engineering 59B (2013) 1837.
[8] R. Eichhorn, et. al. “Cornell's ERL Cavity Production”, Proc. of the 2013 Int. Conf. on RF Supercond., Paris, France (2013) 909.
[9] R. Eichhorn, et. al.” Achieving High Accuracy in Cornell's ERL Cavity Production”, Proc. Of the 2013 North American Part. Acc. Conf, Pasadena, CA, USA (2013), in press.