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COMPLECTION OF THE CORNELL HIGH Q CW FULL 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 individual HOM absorbers and one magnet/ BPM section. In pushing the limits, a high quality factor of the cavities ($2\bullet10^{10}$) and high beam currents (100 mA accelerated plus 100 mA decelerated) were targeted. We will review the design shortly and present the results of the components tested before the assembly. This includes data of the quality-factors of all 6 cavities that we produced and treated in-house, the HOM absorber performance measured with beam on a test set-up lessons learned during assembly.

INTRODUCTION

Energy-Recovery Linacs (ERLs) can provide beams with high currents, small emittances, and low energy spread. The current can be as large as typically in rings, 100mA in the case of Cornell's x-ray ERL, while the emittances and the energy spread can stay as small as only possible in linacs. While the current limit for conventional linacs is determined by the available acceleration power, ERLs recapture the energy of the spent beam and the current then becomes limited by other effects like higher order mode (HOM) heating and beam-break up (BBU). Cornell University has started an extensive R&D program to address these questions and proposed an ERL as a driver for hard x-ray sources [1].

One part of that R&D program was building a linac cryo-module, based on 1.3 GHz cavities, optimized for a high BBU-limit and good HOM damping, with extraordinary high quality factors to reduce operating cost. This module, show in Fig.1, has been completed recently which allows us to highlight our findings within this paper.

CRYOMODULE CONCEPT

The Main Linac Cryomodule (MLC) prototype 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

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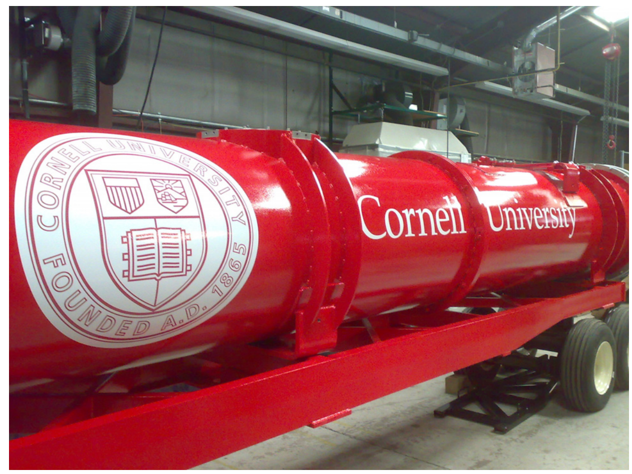

Figure 1: Cornell's Main linac cryo-module.

surfaces on the helium gas return pipe (HGRP). As a consequence, the cold-mass as a whole will shrink during cool-down, 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. There are more comprehensive details on the design in [2-5].

CAVITY PRODUCTION AND RESULTS

For the cavities, a 7-cells, 1.3 GHz design was made while an envisaged Q of $2x10^{10}$ was targeted at a gradient of 16 MV/m. All 6 cavities for the MLC module have been produced in-house starting from flat metal niobium sheets. To investigate microphonics, we decided to build 3 unstiffened cavities as well as 3 cavities with stiffening rings. All cavities were tested vertically, the summary of these test are given in Fig. 2. 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 $4.3*10^{10}$[6]. It should be noted that the Q we measured on the prototype cavity at 1.8 K was 2.5 $*10^{10}$ in the vertical test, but $6*10^{10}$ in the horizontal test where magnetic shielding is more efficient [7].

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.

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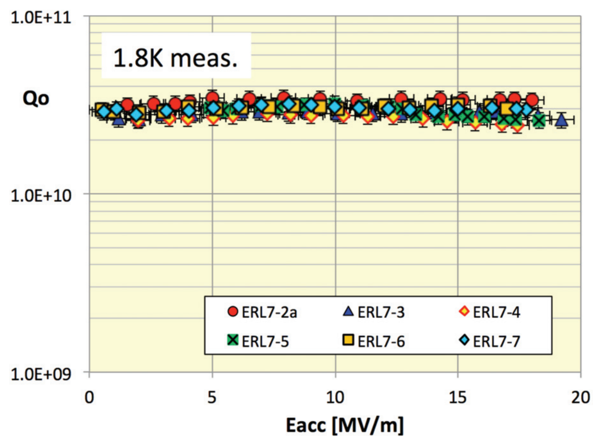

Figure 2: Vertical test results for all 6 ERL cavities. All cavities exceeded the design specifications for the ERL ($Q=2*10^{10}$ at 1.8 K). The reproducibility of the results, gained without any reprocessing of a cavity, is remarkable. The cavities were not N-doped!

HOM ABSORBER

For the MLC, the design of the HOM absorber has been finalized and 7 full assemblies were built [8]. Figure 3 shows an isometric view of the Cornell HOM Absorber and a picture taken during string assembly inside the clean room. The centre assembly consists of the absorbing cylinder, which is shrink fit into titanium cooling jacket and flange. The cooling jacket and flange locate, support, and provide cooling at 80 K to the absorbing cylinder using a cooling channel inside the titanium. The absorbing material is Silicon Carbide, SC-35® from Coorstek.

Initial reservations against the material could be cleared up: After a careful cleaning we saw not particulation during the mounting procedure. In addition, no Q degradation of the cavity mounted next to the absorber in a horizontal test cryo-module was observed. In addition, we ran a 25 mA beam through the absorbers, in particular defocussed and off axis, and saw no charge-up the material[9].

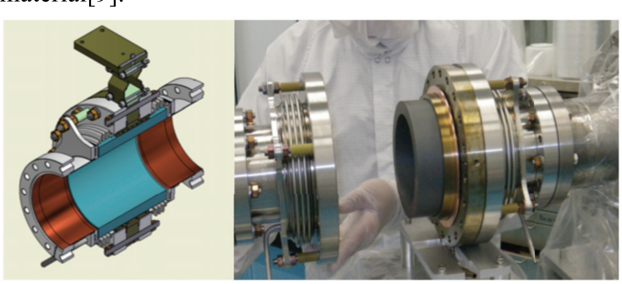

Figure 3: Cornell's higher order mode absorber.

HGRP AND ALIGNMENT

The alignment concept of the cryomodule relies on the helium gas return pipe, a 30 cm ID titanium pipe, acting as a strong-back of the module. Suspended by 3 composite post assemblies from the outer vessel, it provides precision surfaces for all cavity mounts and beam line components,

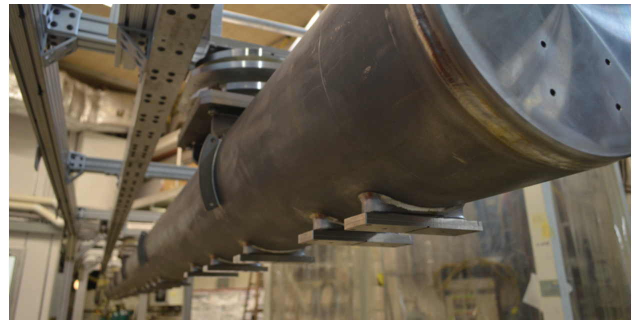

Figure 4: Assembly frame, supporting the HGRP which acts as a strongback for all beam line components, hung under the precision machined mounting feet.

as can be seen in Fig. 4.

The position of these surfaces where surveyed upon receiving the pipe, displaying larger than the specified +/-1 mm accuracy. However, when preloaded with the approximate weight of the cold-mass alignment was within specs. This data is given in Fig. 5. The sagging on the right end of the module will be hindered in a module string by the support of the adjacent module.

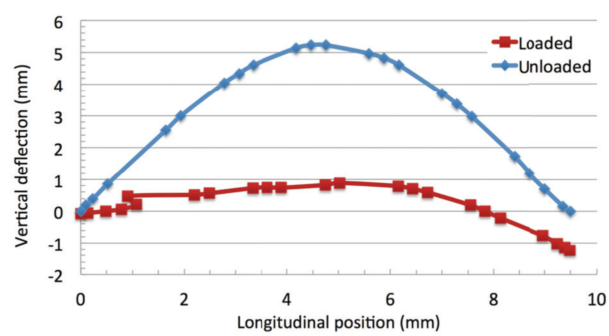

Figure 5: Vertical position of the reference surfaces on the helium gas return pipe defining the positions of all beam line components. In a module string, the right end will receive more support resulting in a better vertical positioning.

MODULE ASSEMBLY

While production of components started earlier, the virtual assembly began in March 2014, when the first cavities where connected to a string inside the cleanroom. For space reasons, two half strings, consisting of three cavities with attached cold section of the coupler and 4 HOM absorbers as well as a gate valve were assembled. Each substring was leak checked and connected to the other later on. In May, cold mass assembly continued outside the cleanroom. Mating the pre-aligned cavity string with the precision surfaces on the HGRP strong-back turned out to be not an issue at all. All bellows located at the HOM absorber package were able to compensate for deviations and only the longitudinal position of one HOM absorber had to be adjusted.

Installation of the cavity magnetic shield, the tuner, the thermal and magnetic shield, all cryogenic piping and jumpers, instrumentation and cabling as well as a wire

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Figure 6: Group photo taken after the successful completion of the module (Nov. 2014).

position monitor to track alignment during cool-down took 3 month. After a minor modification of the wheel, supporting the cold-mass on our rail system we were able to slide it into the vacuum vessel in September.

As final assembly steps we installed the warm portion of the couplers, feed-throughs and cryogenic valves. All circuits were leak checked and pressure tested. In November, the team could celebrate the completion of the module (group photo is shown in Fig. 6), which was achieved within time and budget.

Figure 7: The MLC crossing Cornell campus on a truck in preparation for testing at Wilson Lab.

PERPARATION FOR TESTING

In preparation for the testing of the MLC, the module was transported across the Cornell campus (see Fig. 7). No special damping frame was used. However, all movements were done with extreme care and transportation speed was set to 5 km/h max. In addition, we measured mechanical shocks using accelerometers. The data, given in Fig. 8, revealed a maximum g force of 2.3

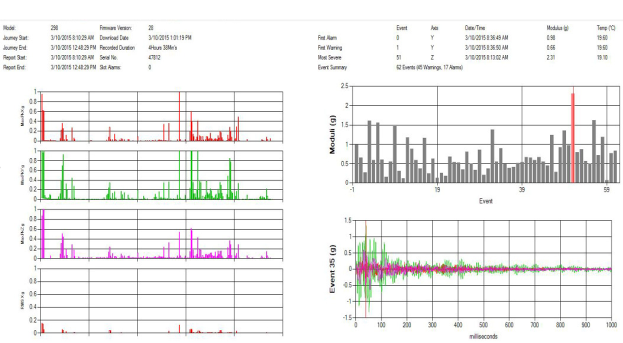

Figure 8: Accelerometer data taken during the transportation of the cryo-module.

(lasting less than 10 ms), which occurred while pulling the module (siting on its own wheels) in place after lifting it from the truck. During the road trip, max g-factors were below 1.5.

As of Mai 2015, preparations continue for the first cool-down being scheduled for late June.

REFERENCES

[1] M. Tigner et al. “Cornell Energy Recovery Linac: Project Definition Design Report”, www.classe.cornell.edu/ERL/PDDR

[2] R. Eichhorn, Y. He, G.H. Hoffstaetter, M. Liepe, T.I. O'Connell, P. Quigley, D.M. Sabol, J. Sears, E.N. Smith, V. Veshcherevich, “The CW Linac Cryo-module for Cornell's ERL”, Proc. of the 2013 Intern. Part. Acc. Conf., Shanghai, China (2013) 2444.

[3] R. Eichhorn, B. Bullock, Y. He, G. Hoffstaetter, M. Liepe, T. O'Connell, P. Quigley, D. Sabol, J. Sears, E. Smith, V. Veshcherevich, “Design and Construction of the Main Linac Module for the Superconducting Energy Recovery Linac Project at Cornell”, Advances in Cryogenic Engineering 59B (2013) 1837.

[4] R. Eichhorn, M. Ge, Y. He, G. Hoffstaetter, M. Liepe, T. O'Connel, P. Quigley, D. Sabol, J. Sears, E. Smith, V. Veshcherevich, “Cornell's Main Linac Cryo-module Prototype”, Proc. Of the 2013 North American Part. Acc. Conf, Pasadena, CA, USA (2013) 811.

[5] R. Eichhorn, B. Bullock, B. Elmore, B. Clasby, F. Furuta, Y. He, G. Hoffstaetter, M. Liepe, T. O'Connell, J. Conway, P. Quigley, D. Sabol, J. Sears, E. Smith, V. Veshcherevich, “The Cornell Main Linac Cryomodule: a Full Scale, High Q Accelerator Module for cw Application”, Physics Procedia (2014), accepted.

[6] R. Eichhorn et al., “Cornell's ERL Cavity Production”, Proc. of the 2013 Int. Conf. on RF Supercond., Paris, France (2013) 909.

[7] N.R.A. Valles, R. Eichhorn, F. Furuta, G.M. Ge, D. Gonnella, Y. He, K.M.V. Ho, G.H. Hoffstaetter, M. Liepe, T.I. O'Connell, S. Posen, P. Quigley, J. Sears, V. Veshcherevich, “Cornell ERL Main Linac 7-cell Cavity Performance in Horizontal Test Cryomodule Qualifications”, Proc. of the 2013 Intern. Part. Acc. Conf., Shanghai, China (2013) 2459.

[8] R. Eichhorn, J. Conway, Y. He, Y. Li, T. O'Connel, P. Quigley, J. Sears, V. Shemelin, “Higher Order Mode Absorbers for High Current ERL Applications”, Proc. of the 2014 Intern. Part. Acc. Conf., Dresden, Germany (2014) 4037.

[9] D.L. Hall, A. Bartnik, M.G. Billing, R. Eichhorn, G.H. Hoffstaetter, M. Liepe C. Mayes, P. Quigley, V. Veshcherevic, “Beam-based HOM Studies of the Cornell Energy Recovery Linac 7-cell SRF Cavity”, Proc. of the 2014 Intern. Conf. on Lin. Acc., Geneva, Switzerland (2014) 869.