PROGRESS ON SUPERCONDUCTING RF WORK FOR THE CORNELL ERL*

M. Liepe†, F. Furuta, M. Ge, D. Gonnella, Y. He, G. Hoffstaetter, T. O'Connell,
S. Posen, P. Quigley, J. Sears, E. Smith, M. Tigner, N. Valles, V. Veshcherevich
CLASSE, Cornell University, Ithaca, NY 14853, USA

Abstract

Cornell University is developing the superconducting RF technology required for the construction of a 100 mA hard X-ray light source driven by an Energy-Recovery Linac. Prototypes of all beam line components of the 5 GeV cw SRF main linac cryomodule have been fabricated and tested in detail. This work includes an optimized 7-cell SRF cavity, a broadband HOM beamline absorber, a cold frequency tuner, and a 5 kW CW RF input coupler. A one-cavity test cryomodule has been assembled for a first full cryomodule test of the main linac cavity. In this paper we give an overview of these extensive R&D activities.

INTRODUCTION

A multi-GeV superconducting RF linac operated in continuous wave (CW) mode is a key technology for several particle accelerators envisioned for the future. Cornell University's Laboratory for Accelerator based Sciences and Education is currently conducting an extensive R&D program to fully develop the SRF technology for a 5 GeV, 100 mA Energy-Recovery Linac (ERL) [1]. This work includes a short SRF section in the ERL injector as well as a multi-GeV main linac operated in CW mode in the ERL loop. The main challenges for these SRF sections arise from the CW operation of the cavities and from supporting very high beam currents.

The following two sections of this paper discuss the SRF cryomodules for these two SRF linacs separately, giving an overview of key challenges and solutions found.

ERL INJECTOR SRF

The Cornell ERL SRF injector section will host 12 SRF 2-cell 1.3 GHz cavities [2] providing a total energy gain of up to 15 MeV. A 5 cavity prototype version of this cryomodule has been developed [3] and fabricated at Cornell, and is now under operation in the Cornell high current ERL prototype [4]. Key parameters of this cryomodule are listed in Table 1. As reported previously, extensive tests of the ERL SRF injector module have shown that it meets and exceeds specifications for cavity performance, coupler performance, cavity alignment, HOM damping, and field stability [5]. Recently, the injector SRF module was operated successfully with a CW beam current of 50 mA, setting a new record for this type of SRF linac operation. Temperature measurements at the HOM absorbers showed

only small temperature increases at 50 mA beam current, as expected from absorbing the HOM power excited by the beam. Temperature sensors mounted on the shielded bellow sections in the HOM beamline absorbers and elsewhere on the beamline showed no significant temperature increases. During 50 mA operation, 50 kW of RF power per SRF cavity were coupled into each cavity by twin input couplers and transferred to the beam. Details of the high current module operation are presented in [6].

ERL MAIN LINAC SRF

The 5 GeV Cornell ERL main linac will have 384 7-cell SRF cavities, running CW at 16.2 MV/m accelerating gradient. Each cryomodule will host 6 SRF cavities. Key parameters of the main linac cryomodule are listed in Table 1. Major challenges that need to be addressed in the main linac cryomodule include: (1) Efficient CW cavity operation with high intrinsic quality factors $Q_0 \geq 2 \times 10^{10}$, (2) supporting high beam current ERL operation with up to 2x100 mA with short (2 ps) bunches, and (3) operating the SRF cavities at a high loaded quality factor $Q_L \geq 6.5 \times 10^7$ while still achieving excellent RF field stability.

Main Linac Cavity

The 7-cell main linac cavity is optimized for a high R/Q of the fundamental mode and for strong HOM damping by optimizing the shape of the end and center cells [7]. Robustness of the obtained cavity design to small shape imperfections was verified by calculating HOMs in deformed cavity shapes, resulting in a tolerance specification for the cavity cell shape of ± 0.25 mm. Beam-break-up (BBU)

Table 1: Injector and main linac cryomodule specifications.

|	injector	main linac
Number of cavities	5	6
Number of cells per cavity	2	7
Accelerating gradient	5-15MV/m	16.2MV/m
Fundamental mode frequ.	1.3GHz	1.3GHz
R/Q (circuit definition)	111Ω	387Ω
Loaded quality factor	4.6×10^4	6.5×10^7
RF power per cavity	120kW	5kW
Required amp. stab. (rms)	1×10^{-4}	2×10^{-4}
Required phase stab. (rms)	0.1°	0.1°
Design beam current	100mA	2x100mA

Figure 1: Main linac prototype cavity.

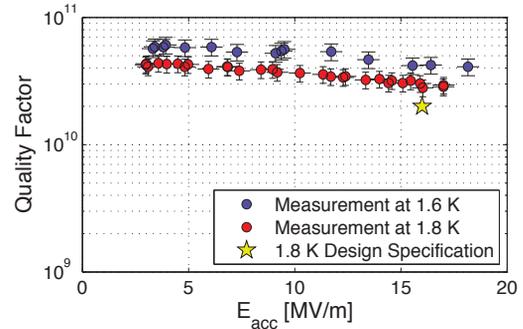Figure 2: Horizontal Test Cryomodule with ERL main linac prototype cavity inside.

Figure 3: Intrinsic quality factor vs accelerating field curve at 1.6K and 1.8K for the prototype ERL main linac cavity installed in the test cryomodule.

simulations were done taking into account the strongest dipole modes found in HOM calculations for the 7-cell cavity with realistic RF absorber materials and cell shape imperfections, giving a BBU current of ≥ 300 mA, well above the 100 mA design specification [7]. A first Niobium prototype cavity was fabricated at Cornell; see Fig. 1. Detailed measurements of the cell shape during various stages of the cavity fabrication confirmed that the shape errors are within the ± 0.25 mm specification. Following fabrication, the cavity received a bulk buffer-chemical polish (BCP) of 150 μm, was heat treated at 800C for two hours, received a final 10 μm BCP, two eight-hour high pressure rinses, and then was baked under vacuum at 120C for 48 hours. In a vertical test, the prototype cavity then met design specifications ($Q_0 = 2 \times 10^{10}$ at $E_{acc} = 16.2$ MV/m and 1.8K). Following the successful vertical test of the prototype cavity, a helium jacket was welded to the cavity. After a final high pressure rinse but no additional chemistry, the cavity was installed in a one-cavity Horizontal Test Cryomodule (HTC) for a first horizontal cryomodule test of the cavity. Fig. 2 shows the fully assembled test cryomodule. During this first cryomodule test of the cavity, beam line higher-order mode (HOM) absorbers were not present, and the cavity was equipped with a high external Q input coupler. HOM absorbers and a high power RF input coupler will be in place in subsequent HTC assemblies and tests. The performance of the cavity installed in the test module significantly exceeded specifications, reaching quality factors at $E_{acc} = 16.2$ MV/m of $Q_0 = 3 \times 10^{10}$ at 1.8K and $Q_0 = 4 \times 10^{10}$ at 1.6K; see Fig. 3. At lower fields, the quality factor even reached $Q_0 = 6 \times 10^{10}$ at 1.6K. For details refer to [8].

The mechanical design of the cavity was optimized to support operation of the cavity at high loaded quality factors by reducing microphonics [9]. Good agreement between simulated mechanical properties of the main linac cavity and values measured during the HTC test was found [10]. The peak cavity detuning over periods of several minutes was measured to be less then 20 Hz, meeting Cornell ERL specifications for cavity operation at a loaded quality factor of $Q_L = 6.5 \times 10^7$ with 5 kW RF power per cavity. In addition to measurements of the fundamental mode, higher-order modes frequencies and quality factors were measured during the first HTC test of the prototype cavity. The results show good agreement with simulations, and confirm excellent damping of dipole modes in the optimized cavity shape [11].

Currently, three additional main linac 7-cell cavities are under fabrication at Cornell, and will be tested vertically in the fall of 2012.
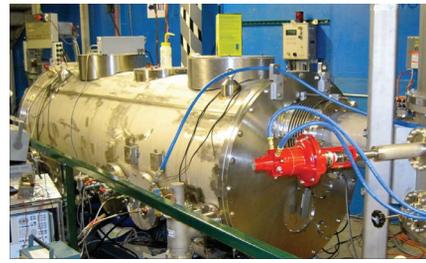
Frequency Tuner

A frequency tuner based on the Saclay I tuner design [12] was developed for the ERL main linac cavities . An illustration of the tuner is shown in Fig. 4 together with the first prototype installed on the prototype 7-cell cavity in the HTC. The tuner was optimized for high stiffness and small backlash. Only non-magnetic materials are used to support cavities with high intrinsic quality factors. The tuner enables slow frequency control via a stepping motor driven lever arm, and fast, piezo driven frequency control.

The prototype tuner was tested extensively during the first HTC test. The slow and fast tuners exceeded requirements for linearity, hysteresis, and tuning range (400 kHz for the slow tuner and 2 kHz for the fast tuner) [10]. The backlash in the slow tuner is ≈ 20 Hz only.

RF Input Coupler and Source

The ERL main linac input couplers must deliver up to 5 kW CW RF power to the main linac cavities. At this CW power level, active cooling of the inner conductor is required. The design of the ERL main linac coupler is based on the TTF-III and Cornell ERL injector couplers [13], see Fig. 5. To simplify the input coupler, it has fixed coupling with a nominal Q_{ext} of 6.5×10^7. Coupling adjustability can be achieved using three-stub tuners in the feed-transmission line to have a coupling range of 2×10^7 to 1×10^8. Two sets of bellows are placed on the warm por-
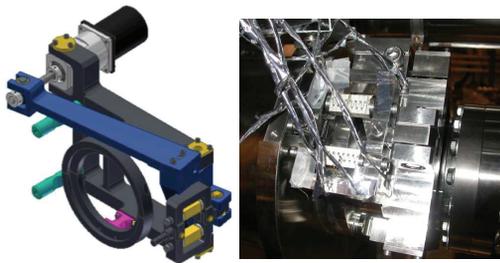
Figure 4: Main linac cavity frequency tuner. Left: CAD model. Right: Prototype on 7-cell ERL main linac cavity.

tion of the coupler, on both the inner and outer conductor, to allow for significant lateral motion of the cavities during cool down while keeping the cold antenna fixed relative to the cavity coupler port. A first prototype of the input coupler was fabricated, see Fig. 5, and was tested successfully to 5 kW CW RF power under full reflection without any conditioning required to reach this power level. A 5 kW solid state RF amplifier was used during the coupler test.

HOM Beamline Absorber

A CAD model of the ERL main linac beamline HOM load is shown in Fig. 6. The design is based on the ERL injector HOM beamline load, but with significant simplifications. The load has a graphite loaded SiC RF absorber as a unitary cylinder brazed into a metal sink, and stainless-steel bellows for flexibility of flange alignment. The RF absorber cylinder is extending along the bellows to shield the bellows from the beam and to damp high-frequency trapped modes in the bellow sections. Graphite loaded SiC material has strong, broadband losses and sufficient DC conductivity to avoid charging up by the beam. Cleaning tests of this material have shown very good performance. A first prototype of the absorber has been fabricated, see Fig. 6, and is currently under testing.
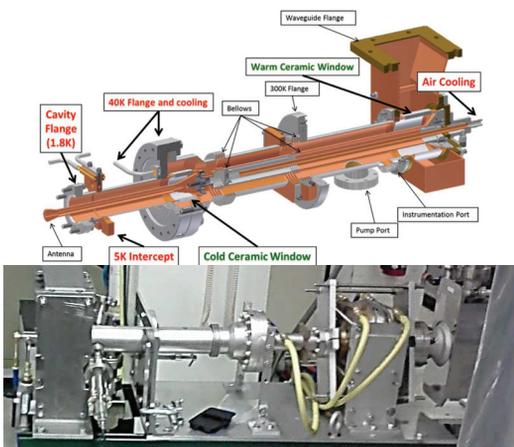

Figure 5: Cornell ERL main linac RF input coupler. Top: CAD model. Bottom: Prototype on a coupler test setup.
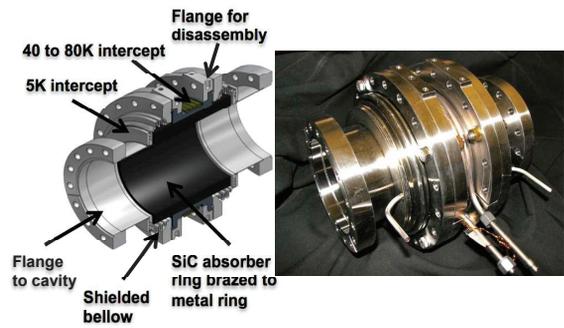

Figure 6: Cornell ERL main linac HOM beamline absorber. Left: CAD model. Right: Prototype.
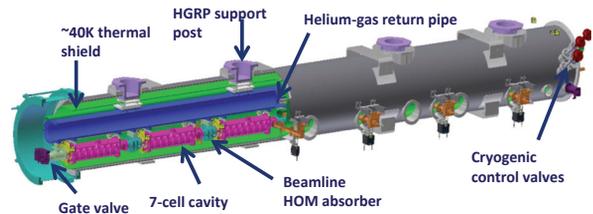

Figure 7: Cross-section of the ERL main linac module with six SRF cavities and HOM beamline absorbers in between.

Cryomodule

The main linac module design is based on the successful injector module, employing many of its innovations. A longitudinal cross section of the main linac module is shown in Fig. 7. The cryogenic 1.8K, 5K, and 40K systems of the module were optimized for the high dynamic loads in the main linac; see [14] for details. A full prototype of the main linac cryomodule will be assembled in 2013 and RF testing of the module at Cornell in planned for 2014.

REFERENCES

[1] C. Mayes et al., PAC 2011, New York, NY, USA (2011).

[2] V. Shemelin, et al., PAC 2003, pp. 2059-2061 (2003).

[3] M. Liepe et al., PAC 2005, Knoxville, TN, USA (2005).

[4] B. Dunham et al., IPAC 2012, New Orleans, USA (2012).

[5] M. Liepe et al., PAC 2011, New York, NY, USA (2011). M. Liepe et al., SRF 2011, Chicago, IL, USA (2011).

[6] M. Liepe et al., IPAC 2012, New Orleans, USA (2012).

[7] N. Valles, M. Liepe, PAC 2011, New York, USA (2011). N. Valles, M. Liepe, SRF 2011, Chicago, IL, USA (2011).

[8] N. Valles et al., "Testing of the...", IPAC 2012 (2012).

[9] S. Posen et al., "Minimizing Helium ...", IPAC 2012 (2012).

[10] S. Posen et al., "Measurements of ...", IPAC 2012 (2012).

[11] N. Valles et al., "HOM Studies ...", IPAC 2012 (2012).

[12] Bosland, P. and B. Wu, Technical Report CARE-Note-2005-004- SRF, DAPNIA-CEA Saclay (2005).

[13] V. Veshcherevich et al., SRF 2009, Berlin, Germany (2009).

[14] E. Smith et al., IPAC 2012, New Orleans, USA (2012).