HOM MEASUREMENTS FOR CORNELL'S ERL MAIN LINAC CRYOMODULE*

F. Furuta†, R. Eichhorn, M. Ge, D. Gonnella‡, G. Hoffstaetter, M. Liepe, P. Quigley, V. Veshcherevich, CLASSE, Cornell University, Ithaca, New York, USA

Abstract

The main linac cryomodule (MLC) for a future energy-recovery linac (ERL) based X-ray source at Cornell has been designed, fabricated, and tested. It houses six 7-cell SRF cavities with individual higher order-modes (HOMs) absorbers, cavity frequency tuners, and one magnet/BPM section. All HOMs in a MLC prototype have been scanned in 1.8K. The results show effective damping of HOMs, and also agree well with simulation results and previous HOM scan results on one 7-cell cavity prototype test cryomodule. Here we present detailed results from these HOM studies.

INTRODUCTION

Cornell University has proposed to build an Energy Recovery Linac (ERL) as driver for a hard x-ray source because of its 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 1.3GHz, 2ps bunch length, 100mA average current in each of the accelerating and decelerating beams, normalized emittance of 0.3mm- mrad, and energy ranging from 5GeV down to 10MeV, at which point the spent beam is directed to a beam stop [1, 2]. For this type of high current machine, the suppression of high order modes (HOMs) excited by the beam in the SRF cavities is essential, because HOMs can lead a deflection of the beam. Especially the dipole modes, which can make a transverse kick on the beam bunch and start a bunch oscillation around the design orbit, need to be damped strongly to avoid resulting beam break up (BBU).

HOM ABSORBER IN MLC

MLC

Figure 1 (Top) shows an image of the Cornell ERL main linac cryomodule (MLC) prototype. The design had been completed in 2012. It is 9.8 m long and houses six 1.3 GHz 7-cell superconducting cavities, three of them are stiffened cavity, another three are un-stiffened, with individual HOM beamline absorbers located between the cavities. Each cavity has a single 5kW coaxial RF input coupler, which transfers power from a solid-state RF power source to the cavity (the designed Q_{ext} is 6.0×10^{7}). Due to the high beam current combined with the short bunch operation, a careful control and efficient damping of higher order modes (HOMs) is essential. Therefore, HOM beamline absorbers are installed at the beam pipe

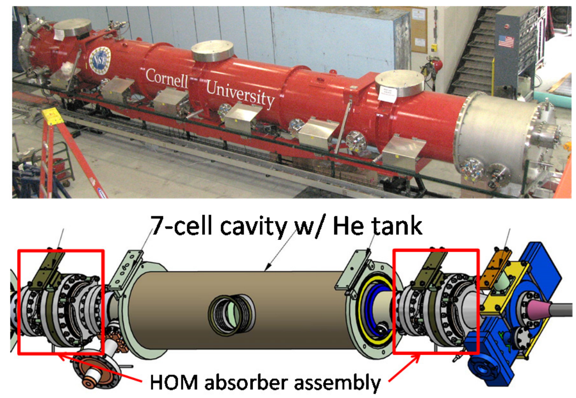

Figure1: MLC prototype (top), and 3D image of a one-cavity section of the string assembly (bottom).

ends of each cavity (Fig. 1, bottom). The specification values of the 7-cell cavities in the MLC are Q_0 of 2.0×10^{10} for the fundamental mode at 16.2MV/m, 1.8K. The fabrication and testing of MLC components (cavity, high power input coupler, HOM dampers, tuners, etc.,) and assembly of MLC cold mass have been completed in 2014 [3, 4, 5]. Initial cool down and RF tests have been performed in 2015, and reported in reference [6].

HOM Absorber

Figure 2 shows a cross section view of the production version of the Cornell HOM absorber. For these production versions, the absorbing material is Silicon Carbide, SC-35® from Coorstek [7]. Two prototypes where initial-

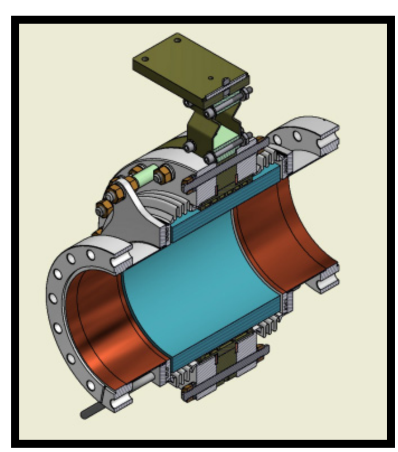

Figure 2: Cornell's HOM beamline absorber used in the main linac cryomodule (MLC). The absorbing material is SC-35 from Coorsteck, shrink-fitted into a Ti cylinder.

* Work is supported by NSF awards NSF DMR-0807731 and NSF PHY-1002467
† ff97@cornell.edu
‡ Now at SLAC National Accelerator Laboratory

ly built using the same absorbing ceramics and tested together with a prototype 7-cell cavity in the Cornell one-cavity Horizontal-Test-Cryomodule (HTC). Within the HTC, a 7-cell ERL cavity was placed between two HOM absorbers. HOM measurements demonstrated excellent higher order mode damping, and a successful high current (40mA) beam test was done. More details about the beam test results can be found in reference [8, 9].

MLC HOM SCANS AND ANALYSIS

HOM Scans

HOMs in the MLC were scanned via S21 Network analyzer measurements at cavity temperature of 1.8K. Scans were completed for three of six 7-cell cavities (#1, #2, and #5) in the MLC. HOM absorber and bellows sections of the HOM assemblies were kept at 80K by 80K Helium gas line and thermal anchors. The beam tubes of the HOM assemblies were cooled by 5K supply lines. The high power RF input couplers were used as input port and field pick up probes were used as output. The scanned frequency range was 1.5GHz to 6GHz with the frequency step (df) of 125Hz. A Matlab GUI was programmed for the scan. Figure 3 shows the set-up for the HOM scans. with the MLC. Figure 4 shows the measured S21 curves from 1.5 to 6GHz for three of the cavities.

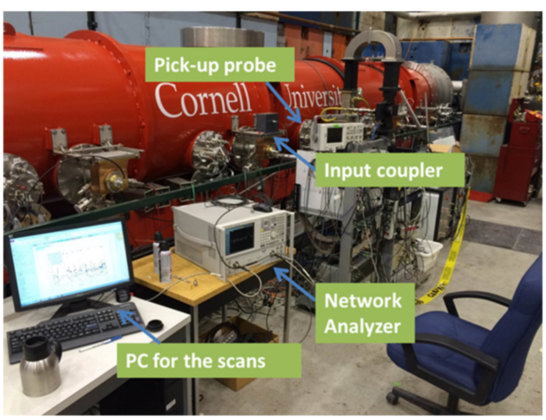

Figure 3: HOM scan set-up for the MLC.

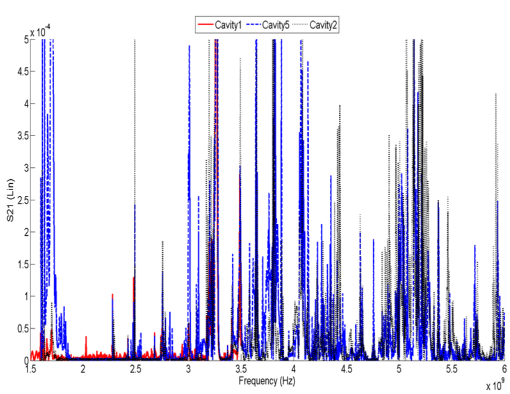

Figure 4: Measured S21 resonances for 3 cavities from 1.5 to 6GHz. Cavity#1 and #5 are un-stiffened cavities. Cavity#2 is a stiffened cavity.

HOM Analysis

The measured S21 curves showed resonant modes (HOMs) in the cavities. Those modes can be divided into two groups. The first group are monopole modes which have a single peak for each mode. Loaded quality factors (Q_L) were extracted by fitting the individual S21 resonance curves using Eq. (1) [10]. Figure 5 shows an example a fit together with the measured S21 resonance curves.

$$|S_{21}|(f;a,\,b,\,f_0)=\frac{10^{-a}}{\sqrt{10^{-2b}+\left(\frac{f}{f_0}-\frac{f_0}{f}\right)^2}} \quad (1)$$

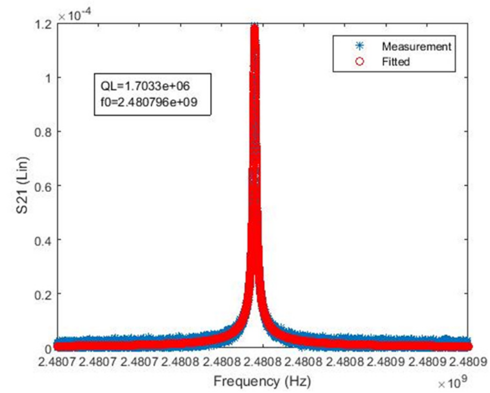

Figure 5: An example of a measured S21 curve fit with a single resonance curve.

The second group of modes are non-monopole modes such as dipole, quadrupole, etc. modes, having more than one peak for each mode type because of different polarisations. These modes have mode mixing issue, e.g. a dipole has two peaks mixed together (see for example Fig. 6), distorting their combined S21 curve. Eq. (2) was used for fitting Q_L for these modes [11].

$$S_{21}=\sqrt{\frac{D_1^2}{1+\Delta_1^2}+\frac{D_2^2}{1+\Delta_2^2}-\frac{2D_1D_2Cos(\pi-\theta)}{\sqrt{1+\Delta_1^2}\sqrt{1+\Delta_2^2}}} \quad (2)$$

where $\Delta= Q_L\left(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}\right)$.

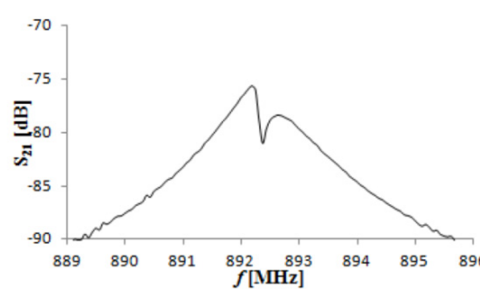

Figure 6: An example of a measured S21 curve, which had mode mixing.

ISBN 978-3-95450-169-4

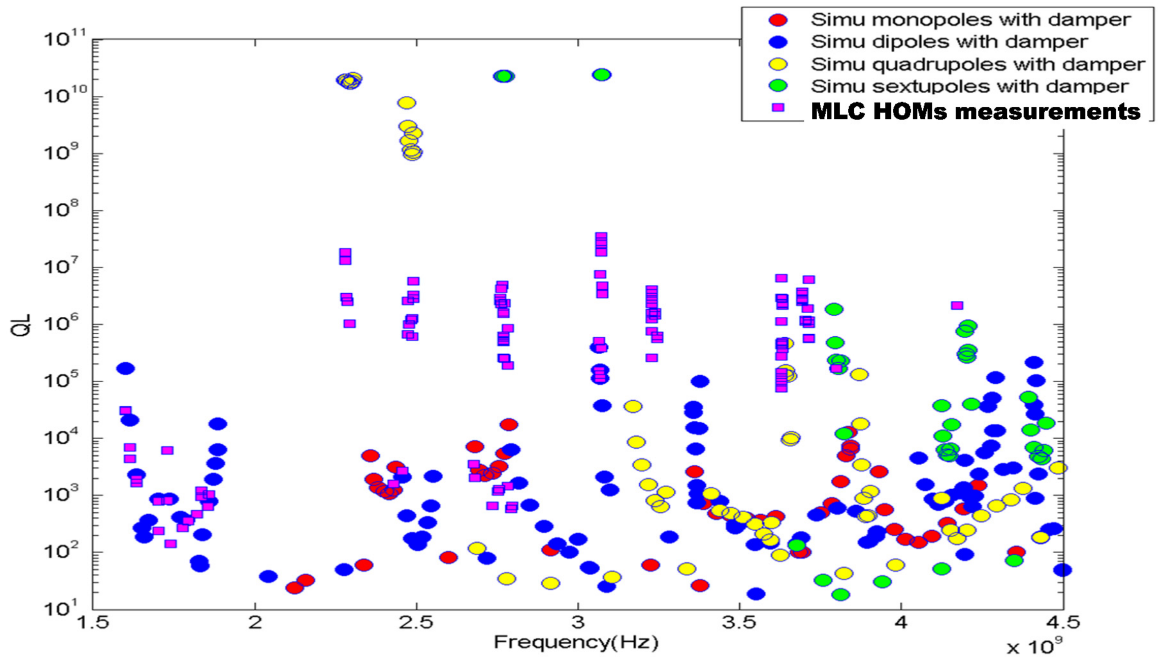

Figure 7: Comparison of MLC HOM measurement results and HOM damping simulation results.

HOM Simulations

For calculation of the higher order modes of the cavity with the dielectric HOM absorbers we used a full cavity model without the coupler and field probe ports. Without ports, it is axially symmetric and we used the 2D electromagnetic solver CLANS [12] for simulation of monopole modes and CLANS2 [13] for simulation of multipole modes. Simulations were made for absorbers having parameters: Re{ε} = 60, Im{ε} = 20, Re{μ} = 1, Im{μ} = 0. These numbers are close to average values of the real absorber material for a wide frequency range.

Comparison of Measurements and Simulation

Figure 7 shows a comparison of the measured and simulated MLC HOM loaded quality factors (Q_L). The purple squares show the Q_L results from the HOM scans of cavity#5. The blue data points show Q_L values of dipole modes from the simulations for an MLC cavity with HOM dampers. The comparison indicates 1) scanned HOM frequencies agreed well with simulation results, and 2) Q_L of dipole HOMs of the MLC cavities are strongly damped below the target value of ~10^4. 3) the higher Q modes measured in the MLC are very likely from quadrupole and sextuple modes, as their frequencies line up very well with the simulated frequency bands for these modes, and high Q is expected for these. These mode types are not a concern for causing BBU. The results shown in Figure 7 also agree well with those from a previous HOM study on a prototype 7-cell cavity, which was an un-stiffened cavity in the Horizontal Test Cryomodule (HTC) [10]. The results from the HOM analysis in the HTC are shown in Figure 8.

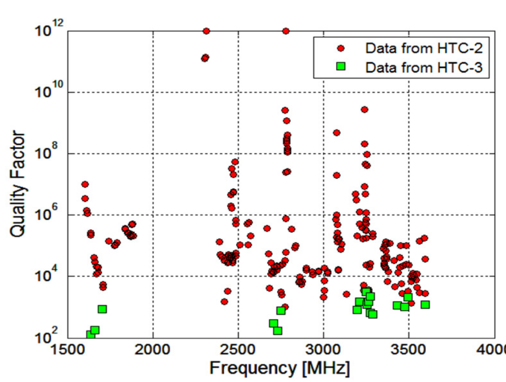

Figure 8: HOM scan and analysis results of one 7-cell cavity in the Horizontal Test Cryomodule ; HTC-2 has no HOM beamline absorbers and HTC-3 had HOM absorbers [9].

SUMMARY

The Cornell Main Linac Cryomodule prototype has been fabricated, assembled, and cooled down to 1.8K successfully. HOMs scans on the MLC cavities and loaded quality factors Q_L analysis has been performed. The results agree well with previous prototype test and simulation results. Extracted Q_L of dipole modes in the MLC cavities verified effective damping by the HOM absorbers. High performance and reliability of the HOM beamline absorber design during fabrication, installation, and cryomodule operation has been demonstrated for future SRF installations through the MLC work at Cornell. HOMs scans for the remaining three 7-cell cavities (#3, #4, and #6) in the MLC are planned for the future.

REFERENCES

[1] G. H. Hoffstaetter, S. Gruner, M. Tigner, eds., “Cornell Energy Recovery Linac Project Definition Design Report”, http://erl.chess.cornell.edu/PDDR

[2] C.E. Mayes *et al.,* “Cornell ERL Research and Development”, in Proceedings of the PAC2011, New York, NY, USA, 2011.

[3] R. Eichhorn *et al.,* “Design and Construction of the Main Linac Cryomodule for the Energy Recovery Linac Project at Cornell”, in Proceedings of the SRF 2013, Paris, France, 2013.

[4] R. Eichhorn *et al.,* “Cornell’s Main Linac Cryomodule for the Energy Recovery Linac Project”, in Proceedings of the IPAC2014, Dresden, Germany, 2014.

[5] R. Eichhorn *et al.,* “Completion of the Cornell High Q CW Full Linac Cryomodule”, in Proceedings of the IPAC2015, Richmond, VA (2015).

[6] F. Furuta *et al.,* “Performance of the novel Cornell ERL Main Linac prototype Cryomodule”, presented at LINAC’16, East Lansing, USA, Sept. 2016.

[7] www.coorstek.com

[8] R. Eichhorn *et al.,* “Higher Order Mode Absorbers for High Current SRF Applications”, in Proceedings of SRF2015, Whistler, Canada, 2015.

[9] D. Hall *et al.,* “Beam-Based HOM Studies of the Cornell Energy Recovery Linac 7-Cell SRF Cavity”, in Proceedings of LINAC14, Geneva, Switzerland, 2014.

[10] N. Valles *et al.,* “HOM studies of the Cornell ERL Main Linac cavity: HTC-1 through HTC-3”, in Proc. IPAC2013, Shanghai, China, 2013, paper WEPWO069, pp. 2462-2464.

[11] W. Xu *et al.,* “Improvement of the Q-factor measurement in RF cavities”, report BNL-98926-2012-IR, November 2012.

[12] D.G. Myakishev, V.P. Yakovlev, “The New Possibilities of SuperLANS Code for Evaluation of Axisymmetric Cavities”, in Proceedings of the 1995 Particle Accelerator Conference, Dallas, TX, 1999, pp. 2348-2350.

[13] D. G. Myakishev, “CLANS2--A Code for Calculation of Multipole Modes in Axisymmetric Cavities with Absorber Ferrites”, in Proceedings of the 1999 Particle Accelerator Conference, New York, 1999, pp. 2775–2777.

ISBN 978-3-95450-169-4