ELECTROMAGNETIC AND MECHANICAL PROPERTIES OF THE CORNELL ERL INJECTOR CRYOMODULE*

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Abstract

This paper reports results of cold measurements characterizing the electro-mechanical properties of the Cornell ERL injector cryomodule, which houses five superconducting niobium elliptical 2-cell cavities developed for a high-current (100 mA) low-emittance electron beam. Each cavity is equipped with a blade tuner. The Cornell ERL blade tuner is a modified version of the INFN-Milano design, and incorporates 4 piezoelectric actuators and accelerometers enabling concurrent slow/fast cw RF frequency control and mechanical vibration measurements. The injector cryomodule cavities the microphonic-noise has been measured. The experimental data demonstrates the feasibility feedback control at microphonic-noise frequencies below ~100 Hz.

INTRODUCTION

Cornell University's Laboratory for Accelerator Based Science and Education (CLASSE) is developing the acceleratory technology for an Energy Recovery Linear accelerator (ERL) driven x-ray light source [1]. The RF amplitude and phase stability of the ERL superconducting RF cavities detuned by microphonic-noise pose a fundamental limit to the RF power required to stabilize the cavity RF fields [2]. The accuracy and precision to which the cavity RF field amplitude and phase can be controlled determines:

- The reliability and availability of beam for experiments.
- The beam quality

Operating an accelerator in an energy recovery mode necessitates a small effective beam current, the difference in beam current between the accelerating and the decelerating beam. For CLASSE ERL operation the superconducting RF cavities are expected to have loaded-quality factors of ~1×10^8, and bandwidths of ~10 Hz. Cavity RF frequency variations which are at the level of or greater than the loaded-cavity bandwidths will significantly increase the RF power required to stabilize the cavity fields.

CLASSE is currently commissioning a prototype cryomodule for the ERL injector [3]. The injector cryomodule houses five 1.3 GHz superconducting two-cell cavities. This is not a cryomodule for the ERL main linac. Even so, it is an excellent resource for the initial characterization of the cavity microphonic-noise levels and for investigations of the cryomodule structure for the ERL cryomodule development. The implementation of

Table 1: Summary of the CLASSE ERL Injector Cryomodule Mechanical Coupling Characterization Measurements

Excitation Point	Excitation Force	Vibrations Detectable With Cavity Accelerometers?	Vibrations Measurably Detune the Cavities?
Coupler Waveguide	110 N (25 lbs)	No	No
Coupler	110 N (25 lbs)	No	No
Cryomodule Saw-Horse Support	110 N (25 lbs)	Yes	No
Helium Gas Return Pipe Support	110 N (25 lbs)	Yes	Yes
Beam Line	10 N (2 lbs)	No	No
Helium Supply/Return	110 N (25 lbs)	No	No

active tuning systems to compensate the microphonic-noise presented here can be found in [4].

This paper is separated into three parts. First, data characterizing the mechanical coupling strength of the coupled cavity-cryomodule system is presented and discussed. Second, the level and structure of the cavity microphonic-noise is presented. Finally, we close with a brief summary and a few comments.

CAVITY-CRYOMODULE MECHANICAL COUPLING

The work presented here is not intended to be an exhaustive study of the cavity/cryomodule mechanical system. However, the mechanical couplings between the main vibration sources and the cavity/cryomodule have been characterized and will be discussed here. For this paper there are four aspects of the cavity/cryomodule structure to keep in mind:

- The cavities hang from the helium gas return pipe.
- The helium gas return pipe is supported from the top of the cryomodule.
- The cryomodule is situated on two saw horses on either end.
- The cavities are sequential numbered from 1 to 5 with cavity number 1 on one end of the cryomodule and cavity number 5 on the other.

A detailed description of the CLASS ERL injector cryomodule can be found in [3].

Refer to Table 1 for a brief review of all tests. To characterize the coupling strength between the cavities and the cryomodule a Modal Shop 2100E11 modal shaker, a PCB Piezotronics, Inc., model 200B01 quartz

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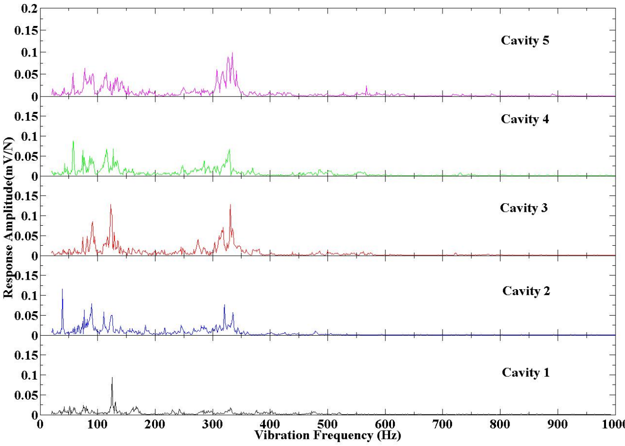

Figure 1: Characterization of the mechanical coupling strength between a cryomodule saw-horse support and the five cryomodule cavities.

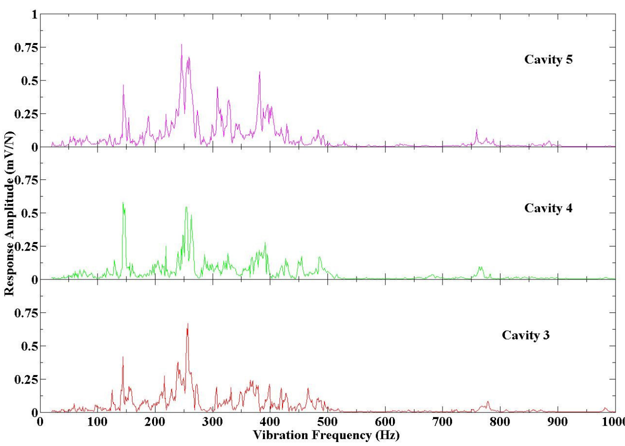

Figure 2: Characterization of the mechanical coupling strength between the cryomodule HGRP, the cavity support, and three of the cryomodule cavities.

force sensor, and several custom Noliac piezoelectric accelerometers rigidly connected to each of the cavities were used.

Figure 1, characterizes the mechanical coupling strength between a cryomodule saw-horse support and the superconducting cavities, measuring the ground motion coupling to the superconducting cavities. This measurement was performed with the modal shaker laterally exciting the cryomodule saw-horse support below cavity 5. The dynamic sinusoidal force exerted by the modal shaker on the cryomodule support was chosen to be 110 N significantly exceeding typical ground motion amplitudes at 100 Hz of ~1 nm [5]:

$$Force = m \cdot a = m \cdot \omega^2 \cdot \Delta x$$

$$\Delta x = 110N / (5440kg \cdot 4 \cdot \pi^2 \cdot 10000/s)$$

$$\Delta x = 50nm$$

where the injector cryomodule weights 5440 kg.

The modulation frequency of the applied force was swept from 20 Hz to 1000 Hz in 1 Hz steps while simultaneously measuring the force applied to the cryomodule and the vibrations measured with the accelerometers mounted on each cavity. The ratio of the cavity accelerometer signal and the applied force are graphed in figure 1 for all five injector cryomodule cavities. The horizontal axis is the vibration frequency in hertz, and the vertical axis is the response amplitude in millivolts per Newton of force applied. Note that each cavity is unique and the mechanical coupling strength between the excited support and cavity 1, the cavity furthest from the excitation source, is much lower than the rest of the cryomodule. While shaking the cryomodule saw-horse support no detectable detuning could be correlated with the modal shaker induced vibrations.

Figure 2, graphs the mechanical coupling strength between the top support for the helium gas return pipe (HGRP,from which the cavities hang), which is located above cavity 5, and three of the injector cryomodule cavities. There is no data characterizing cavities 1 and 2. First, notice that the response amplitude is approximately five times greater here than for vibrations introduced through the cryomodule support. This is due to the relatively stronger coupling between the cavities and the HGRP, to which the cavities are rigidly coupled. Next, notice that the coupling strength is inversely proportional to the distance between the excitation (cavity 5) and the cavity location. Cavities 4 and 3 are, in this order, farther away from the excitation. The section of the HGRP they hang from is decoupled from the section excited though a formed bellows.

Shaking the top support for the HGRP measurably detuned the cavities, contrary to inducing vibrations in the cavity couplers, coupler waveguides, beam pipe, cryomodule saw-horse supports, and helium supply lines. The peak cavity 5 detuning was 1.3 Hz. From this an upper limit can be established for the minimum detectable ground motion which detunes the cavities:

$$\frac{Saw\ Horse}{HGRP\ Vibration} * \Delta f_{cav} = \frac{9.85e-5\ V/N}{7.714e-4\ V/N} * 1.3Hz = 0.17Hz$$

INJECTOR CRYOMODULE MICROPHONIC-NOISE

The observed structure of the injector cryomodule superconducting cavity microphonic-noise has not been constant. Three different time domain samples are shown in figure 3. These three data sets were collected before a warm-up to ~80 K (upper trace), a cooldown to 1.8 K (middle trace), and a cycling of the pumping system for the entire injector cryomodule cold-mass (lower trace).

The structure of the cavity ringing has not changed but the repetition rate of the impulse driving the cavity ringing has changed. The root cause of this repetitive disturbance is unknown. To cure the impulsive ringing the valve to the sub-atmospheric pumps is cycled (difference between the middle trace and the lower trace). This strongly seems to implicate the cryogenic system but further study is required.

During periods of relatively stable operation, the lower trace of figure 3, the structure of the microphonic noise

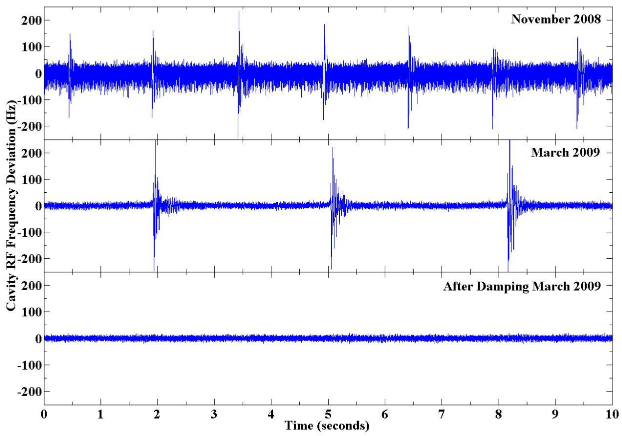

Figure 3: Changes cavity # 2's RF frequency deviation over time. The top trace is before a warm-up of the cryomodule coldmass. The middle trace is after cool-down to 1.8K after the warmup. The lower trace is after cycling the helium vacuum pump valve between the cryomodule and the vacuum pumps.

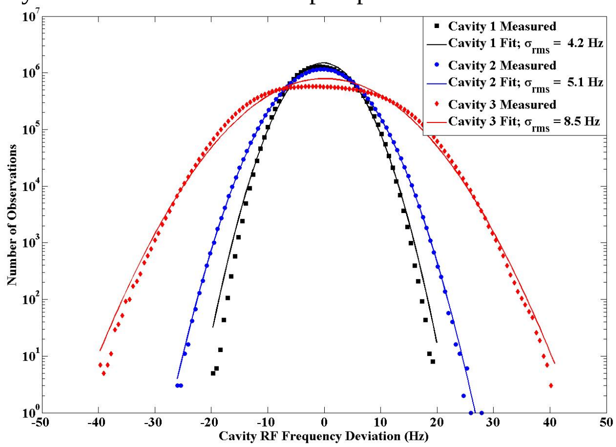

Figure 4: Cavity RF frequency deviation density.

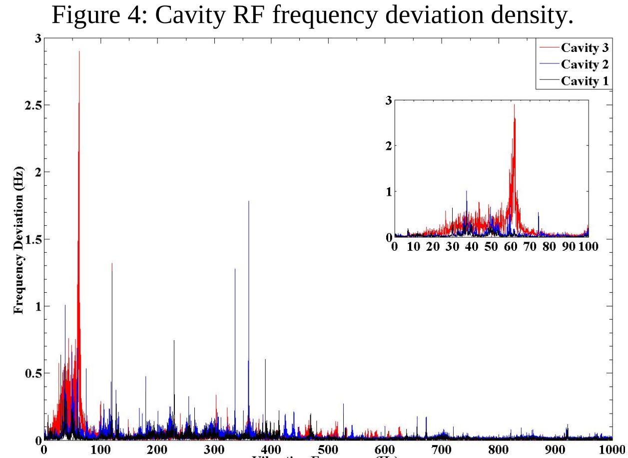

Figure 5: Cavity RF frequency deviation spectrum.

was characterized. First, probability densities for the RF frequency deviations for three of the injector cryomodule cavities are shown in figure 4. Each trace was calculated with forty minutes of cw data with the cavities operated at an accelerating gradient of 2.5 MV/m and fit to a Gaussian curve. Notice that cavity 3 is not Gaussian, demonstrating that the detuning is not completely random. The peak outliers observed over the forty minute sampling period differ by approximately 5σ from the mean for all cavities. The other 2 injector cryomodule cavities are still not fully characterized but preliminary measurements indicate that the level of detuning is greater than shown here.

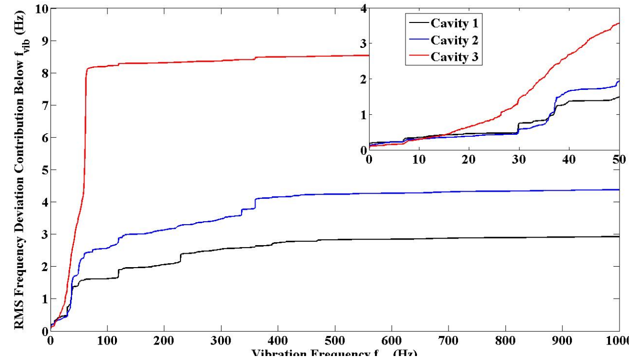

Figure 6: The integrated microphonic spectrums.

The spectrum of the cavity RF frequency deviation is shown in figure 5, for cavities 1, 2, and 3. The x-axis is the cavity mechanical vibration frequency while the y-axis is the amplitude of the frequency deviation in the cavity RF frequency due to the mechanical vibrations.

Figure 6 shows the integrated spectrum of cavity detuning which demonstrates that most of the cavity vibration is due to low-frequency phenomena, e.g. helium pressure fluctuations. Note, greater than 97% of cavity detuning below 1 kHz is due to vibrations below 400 Hz.

SUMMARY

Microphonics tests on the CLASSE ERL injector cryomodule have been performed in a real accelerator environment. The results show that the cavities do not couple to relatively low-frequency (500 Hz) ground motion, with a detuning detection limit of 0.17 Hz. Eliminating the cavity ringing by cycling the sub-atmospheric pumping valve and the lack of detectable coupling from ground motion strongly imply that helium pressure fluctuations are the likely contributor to cavity microphonics. Work investigating the coupling of the helium system to the cavities is ongoing.

ACKNOWLEDGEMENTS

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