# FAST PIEZOELECTRIC ACTUATOR CONTROL OF MICROPHONICS IN THE CW CORNELL ERL INJECTOR CRYOMODULE*

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*Abstract*

The RF power required to phase-stabilize the Cornell University ERL main linac cavities is expected to be driven by microphonic-noise. To reduce the required RF power we are exploring the possibility of active compensation of cavity microphonic-noise with the cavities in the Cornell ERL injector cryomodule. The Cornell ERL injector cryomodule houses five elliptical 2-cell SRF cavities developed for the acceleration of a high current (100mA) ultra-low emittance beam and is currently undergoing extensive testing and commissioning. Each of the five cavities is equipped with a blade tuner; each blade tuner integrates 4 piezoelectric actuators and vibration sensors for the active compensation of cavity detuning. This paper presents first results of active frequency-stabilization experiments performed with the Cornell ERL injector cryomodule cavities and their integral blade/piezoelectric fast tuners.

## INTRODUCTION

Cornell University's Laboratory for Accelerator based Science and Education (CLASSE) is developing the technology required for an x-ray light source driven with an Energy Recovery Linear accelerator (ERL) [1]. An injector cryomodule with five superconducting-niobium two-elliptical-cell cavities is being commissioned [2] for the injector of the ERL. The injector cryomodule does not operate in an energy recovery mode and has to provide up to 100 kW of RF power to the beam per cavity, easing the phase and amplitude stability requirements relative to the main ERL linac cavities. Even so, the injector cryomodule provides a unique test bed for the development of the technology required to operate the ERL main linac cavities.

The main linac of the CLASSE ERL requires cryomodules with superconducting cavities to efficiently recover the decelerating-beam energy and accelerate the fresh-beam. The ERL superconducting cavities must be operated with stable amplitude and phase-locked to both the accelerating and decelerating beam bunches [3] with:

- An amplitude stability of $3\text{x}10^{-4}$ rms
- A phase stability of $0.06^0$ rms

Microphonic-noise is expected to be the dominant limitation to achieving these goals. Here we present the results of using active fast mechanical tuners to control the cavity RF phase and amplitude errors caused by microphonic-noise. With optimal coupling the required RF power is proportional to the maximum cavity detuning [3, 4]:

$$P_{\max} \propto \Delta f_{\max}$$

By introducing, with a fast mechnical tuner, a controllable RF frequency variation which cancels the microphonic-noise the required power is reduced.

This paper will describe the fast mechanical tuning system employed here and present initial results characterizing the system performance. First, we describe the hardware. Second, we present results characterizing the dynamic compensation of microphonic-noise: Lorentz detuning and low-frequency non-resonant mechanical vibrations, microphonic-noise. We close with a brief summary.

## ACTIVE PIEZOELECTRIC TUNING

Four low-voltage Noliak piezoelectric stacks we added to each injector cryomodule cavity's blade tuner and spaced $90^0$ apart, figure 1 [5, 6]. On one side the blade tuner attaches to a helium vessel flange rigidly attached to the cavity beam pipe. On the other side the blade tuner is decoupled from the helium vessel flange though the four piezoelectric stacks. The cavity is constantly under compression and actuating the piezoelectric stacks or the slow blade tuner stepping motor changes the level of compression. The blade tuner and the piezoelectric fast tuner act on the cavity in series, where the total cavity displacement is equal to the combined displacement of the blade tuner (slow tuner) and the piezoelectric stacks.

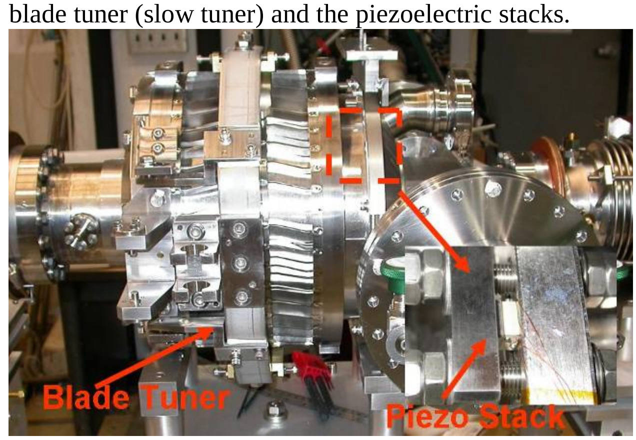


Figure 1: The blade tuner with integral piezoelectric stacks.

### *Piezoelectric Fast Tuner Dynamic Response*

To characterize the fast tuner performance the correlation between the amplitude and the frequency of the piezoelectric fast tuner drive signal and the amplitude and relative phase of the cavity RF frequency modulation is measured. The measurement was performed by sweeping the frequency of the sinusoidal signal driving the fast tuner and simultaneously recording the relative

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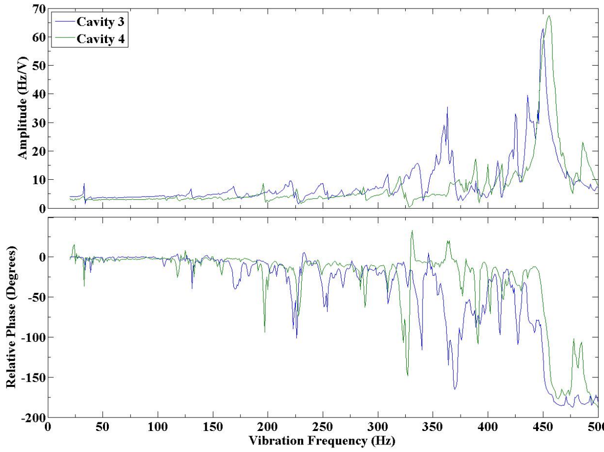


Figure 2: The piezoelectric fast tuner transfer function for two different cavities. The top trace is the amplitude and the lower trace is the relative phase shift.

phase and amplitude modulation of the driven cavity RF frequency modulation. The amplitude of the correlation measurement and the relative phase between the cavity RF frequency modulation and the piezoelectric fast tuner drive signal is graphed in figure 2 for two out of five of the injector cryomodule cavities. This amplitude and phase graph is the fast tuner transfer function.

The horizontal axis of the piezoelectric fast tuner transfer function is the amplitude modulation frequency of the electrical signal used to drive the piezoelectric fast tuner, referred to as the vibration frequency. The upper graph is the amplitude of the transfer function, defined as the ratio between the amplitude of the sinusoidal cavity RF frequency modulation and the amplitude of the sinusoidal modulation of the piezoelectric drive signal. The lower graph is the phase difference between the cavity RF frequency modulation and the piezoelectric drive signal amplitude modulation. The piezoelectric fast tuner transfer functions can be used to predict the coupled cavity fast tuner response to an arbitrary voltage waveform driving the piezoelectric actuator, e.g. a feedback loop.

In figure 2 notice, at low-frequencies, no strong mechanical eigenmodes of the mechanically coupled cavity and fast tuner system are excited. While relatively strong mechanical resonances are excited at 350 Hz in cavity 3 and at 450 Hz in cavity 4 (cavity 3 also has a strong mechanical resonance here). This allows for the closed-loop compensation of low-frequency non-resonant microphonic-noise below a few tens of hertz in these cavities, albeit different feedback gains and filters parameters are required for each cavity.

This result is exploited to damp low-frequency RF phase perturbations, e.g. Lorentz detuning and microphonic-noise; where microphonic-noise is the single largest contributor to RF phase errors in the injector cryomodule cavities. Next, we present the active compensation of Lorentz detuning due to step changes in the cavity RF field amplitude. Then results characterizing the active compensation of microphonic-noise, independent from Lorentz detuning will be presented.

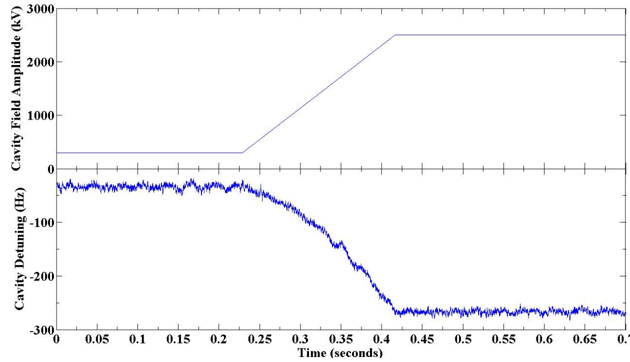


Figure 3: Lorentz detuning without active compensation.

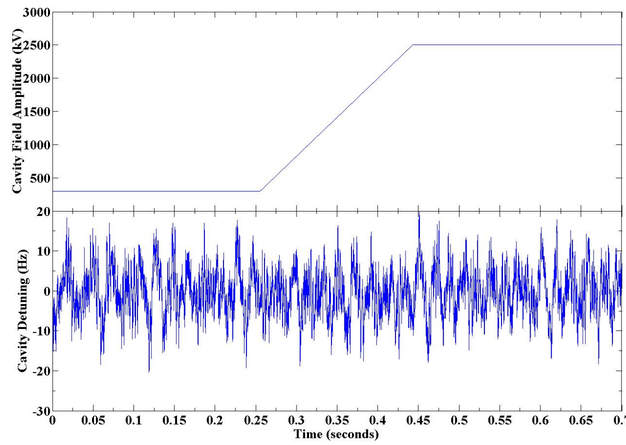


Figure 4: Actively compensated Lorentz detuning.

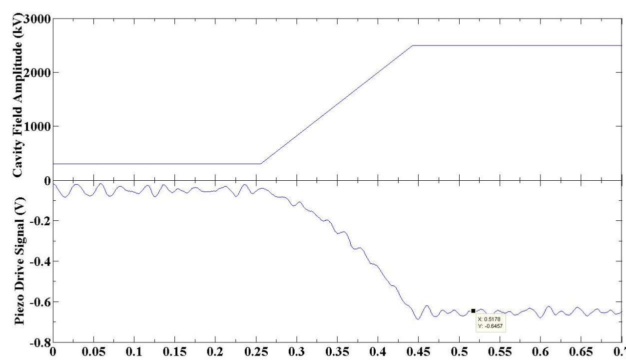


Figure 5: The piezoelectric fast tuner drive signal during active compensation of Lorentz detuning.

## *Lorentz Detuning Compensation*

In operation, the CLASSE ERL superconducting cavity slow tuner will not be actively actuated. The piezoelectric fast tuner must actively compensate all cavity-detuning, including the Lorentz detuning due to changes in cavity field amplitudes. Lorentz detuning compensation is successful if the cavity detuning is limited to a small fraction of the loaded bandwidth while the field amplitude changes. The adiabatic Lorentz detuning coefficient (often referred to as the static Lorentz detuning) for the two-cell cavities used in the experiments reported on here is -2.1 Hz/(MV/m)$^2$, note that these cavities do not have stiffening rings which typically reduce Lorentz detuning. For example, the RF frequency of a cavity excited from a very low-field to 10MV/m will decrease by 210 Hz

Figure 3 and figure 4 demonstrate active Lorentz force compensation with the piezoelectric fast tuner. Figure 5 graphs the piezoelectric fast tuner drive voltage during active Lorentz detuning compensation. First, the cavity was excited to 300 kV, establishing a field and allowing the resonant frequency to be monitored. Then the cavity was excited to 2500 kV in 0.2 seconds, a ramp up time chosen to avoid exciting high-frequency mechanical modes of the cavity.

For all figures, the upper trace is the measured cavity field amplitude. In figures 3 and 4 the lower trace is the measured cavity detuning, while for figure 5 the lower trace is the piezoelectric fast tuner drive voltage. The horizontal axis is time, in seconds.

This data demonstrates that the piezoelectric fast tuner is fully capable of compensating Lorentz detuning in the two-cell injector cryomodule cavities. It is important to note that this compensation scheme was reproducible over several hours of testing. Data characterizing the main linac cavities will be collected after the cavities have been fabricated.

### *CW Microphonic-Noise Compensation*

This section discusses measurements where the piezoelectric fast tuner is used to damp the microphonic-noise of the cw operated injector cryomodule cavities. During cw operation of the injector cryomodule cavities we have encountered a repetitive impulse which drives broadband mechanical ringing in the cavities [5]. The simple PI controller used here cannot compensate the higher frequency ringing with the piezoelectric fast mechanical tuner. Even so, the piezoelectric fast tuner can damp low-frequency microphonic-noise.

First, a single injector cryomodule cavity and its integral piezoelectric fast tuner were operated in a closed PI feedback loop with a low-pass filter. The feedback loop used a DSP to monitor the cavity RF phase error signal and calculated the piezoelectric fast tuner drive signal.

Figure 6 graphs the spectrum of the cavity detuning with varying levels of feedback gain. The horizontal axis is the vibration frequency of cavity and the vertical axis is the peak cavity detuning at each vibration frequency. The proportional gain was set to half of the maximum value, above which the system goes unstable, the low pass filter -3 dB frequency is ~30 Hz and the integral gain is scanned. The integral gain values shown in figure 6 are not scaled. Notice at high proportional gains the low frequency microphonic-noise if damped by ~34 dB. This gives a 20 Hz maximum feedback bandwidth. Higher frequency cavity microphonic-noise is not damped, it is amplified, and this limits the overall operation of this tuner. An investigation into the source of this noise and into more advanced feedback schemes is on going. The microphonic-noise of the injector cryomodule cavities is presented in [6].

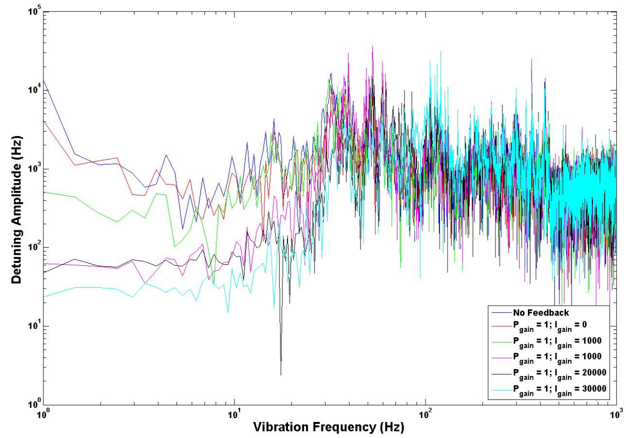


Figure 6: CW microphonic-noise compensation. Notice the 34 dB damping of low-frequency microphonic noise.

## SUMMARY

It was demonstrated that the piezoelectric fast tuner used here is useful for the compensation of Lorentz detuning and low-frequency microphonic-noise. This was carried out with the CLASSE ERL injector cryomodule cavities, providing a real operating accelerator environment for the demonstration of the piezoelectric fast tuner. This work represents the first step in the development of the cavity fast mechanical tuning system for the CLASSE ERL main linac. Future work will be focused on improving the high-frequency response of the coupled cavity and fast mechanical tuner system.

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