MEASUREMENT OF THE MECHANICAL PROPERTIES OF SUPERCONDUCTING CAVITIES DURING OPERATION*

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Abstract

The Horizontal Test Cryostat (HTC) contains the first prototype 7-cell 1.3 GHz superconducting cavity for the Cornell ERL main linac. In this paper, experimental measurements of the cavity's mechanical properties are presented. The mechanical resonances were studied using a Dynamic Signal Analyzer, which measured the transfer function from the fast piezo tuner to itself and the cavity frequency. The microphonics detuning of the cavity was measured, and found to satisfy the specification that the maximum detuning be below 20 Hz, even without feedback from the piezos. Correlations were studied between the microphonics detuning and the helium pressure, piezo sense signal, and the ground vibrations. The Lorentz force detuning (LFD) coefficient was also measured. The frequencies of the mechanical resonances were compared to simulation. In addition, the performance of the frequency tuners was evaluated. Both the mechanical tuner and the piezo were found to be highly linear with very little hysteresis even on small scales.

INTRODUCTION

The main linac of the Cornell ERL is planned to require 384 1.3 GHz 7-cell cavities to accelerate electrons to 5 GeV. The first horizontal test a prototype main linac cavity was recently completed in the Horizontal Test Cryostat (HTC), shown in Fig. 1. This first prototype was constructed with no stiffening rings, following one approach to minimizing df/dp, as shown in [1]. The results from the horizontal test exceeded specifications for quality factor and accelerating gradient (see [2] for details). In addition to these specifications, there are several requirements that must be satisfied related to the cavity frequency detuning and the tuners. They are presented here.

LORENTZ FORCE DETUNING

The Lorentz Force detuning (LFD) coefficient of the cavity was determined by measuring the frequency of the cavity as the field was changed over a large range, as shown in Fig. 2. The coefficient K_{LFD} was measured to be 1.5 Hz/(MV/m)^2, which is in the expected range for an unstiffened cavity.

MICROPHONICS DETUNING

Due to the high Q$_L$ of the cavity, it is very sensitive to detuning. Even microphonics, disturbances on the order of a few tens of Hz from helium pressure fluctuations and ground vibrations, would cause huge increases in the power required to keep the cavity at the design gradient. The detuning of the cavity was measured over 500 seconds, while simultaneously recording the pressure in the helium bath on a fast transducer, the voltage on one of the piezos, and the signal from an accelerometer on the ground next to the cryostat, with all signals at 2 kHz. Fast Fourier transforms of the signals are shown in Fig. 3.

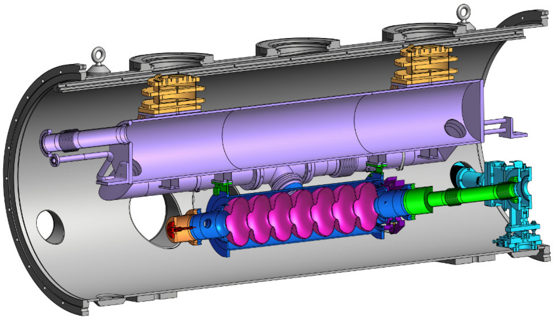

Figure 1: Section view of Cornell's Horizontal Test Cryomodule.

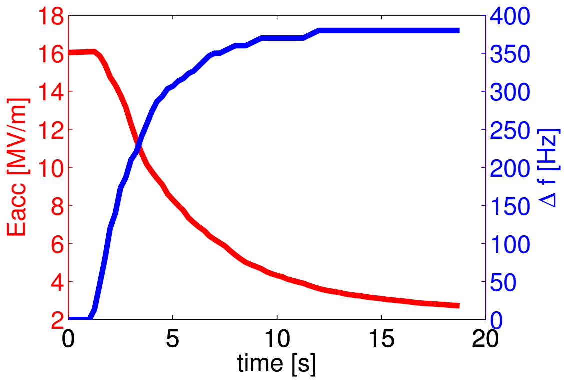

Figure 2: Lorentz Force Detuning of the first prototype main linac Cornell ERL cavity.

Note that the cavity detuning signal has strong lines that correlate to strong lines in either the piezo or the accelerometer signals or both. The pressure signal shows mostly 60 Hz noise and harmonics, without even lines near 30 Hz or 59 Hz, the approximate frequencies of the pumps. This indicates that there is probably an issue with the pressure signal conditioner. It will be improved for future tests.

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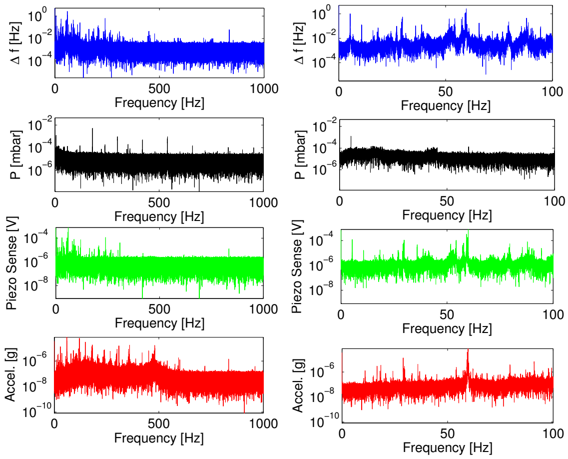

Figure 3: FFTs of the cavity detuning signal, the helium pressure, the piezo sense, and the ground vibration; both full range (left) and zoomed in (right) are shown.

A histogram of the 10^6 frequency detuning measurements is shown in Fig. 4. The peak detuning was 17.8 Hz, smaller than 20 Hz, the maximum that the power supplies can compensate for, even without piezo feedback. The RMS detuning was 4.6 Hz.

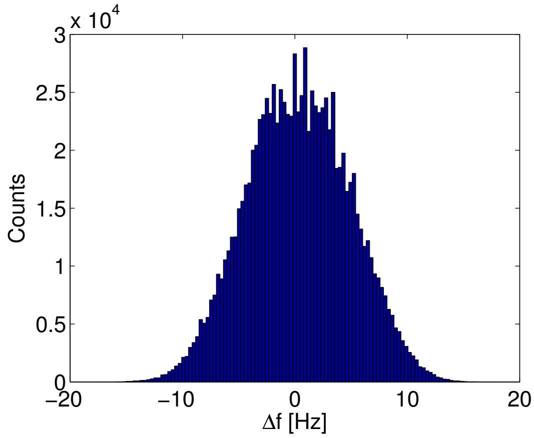

Figure 4: Histogram of the cavity detuning over 500 s, with 10^6 samples. The peak detuning was 17.8 Hz and the RMS detuning was 4.6 Hz.

TUNER PERFORMANCE

The frequency tuner of the HTC cavity consists of a large-range slow frequency tuner in series with a short-range fast frequency tuner. The slow frequency tuner is a modification of the Saclay I design [3]. Compared to the original design, it has increased stiffness, uses bushings instead of bearings, and is made from only non-magnetic materials. The fast tuner consists of 2 15×15×34 mm piezoactuator stacks. Both tuners show excellent linearity with minimal hysteresis, as shown in Fig. 5.

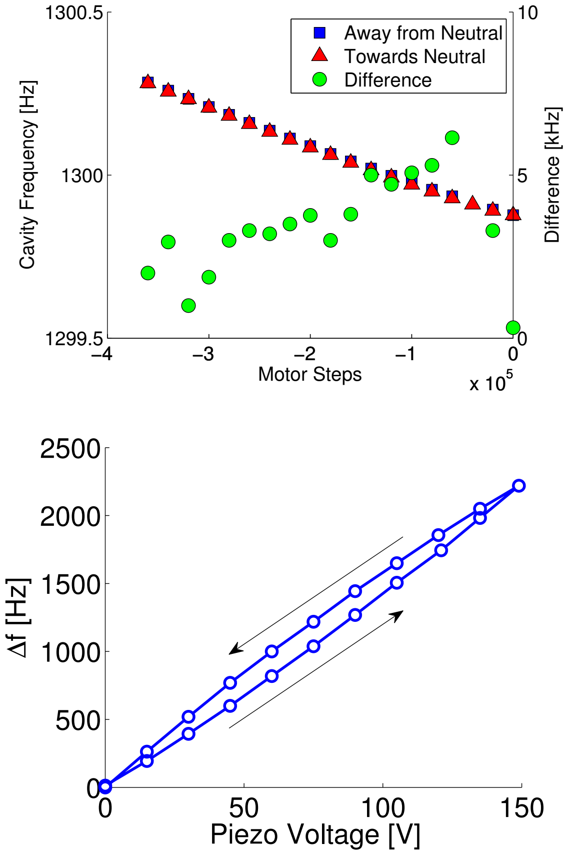

Figure 5: Measurements showing excellent linearity and small hysteresis in the slow tuner (top) and the fast piezo tuner (bottom).

Fig. 6 shows that the slow tuner has exceptionally small hysteresis for small numbers of steps. The fast tuner has >2 kHz range, which, given the operating gradient of 16.2 MV/m, should be more than enough to compensate LFD of $K_{LFD} \times E_{acc}^2 = 384$ Hz.

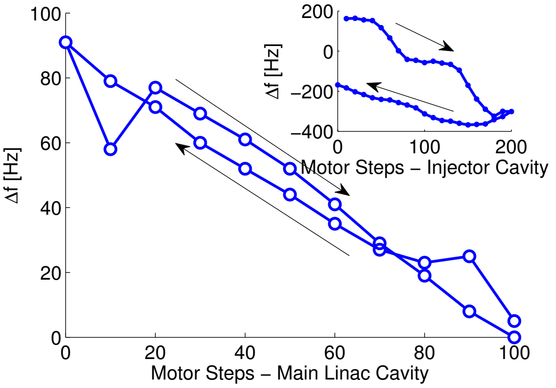

Figure 6: Short range slow tuner movement shows exceptionally small hysteresis. The inset shows short range movement from an injector cavity for comparison, which uses a blade-style tuner on the He vessel [4].

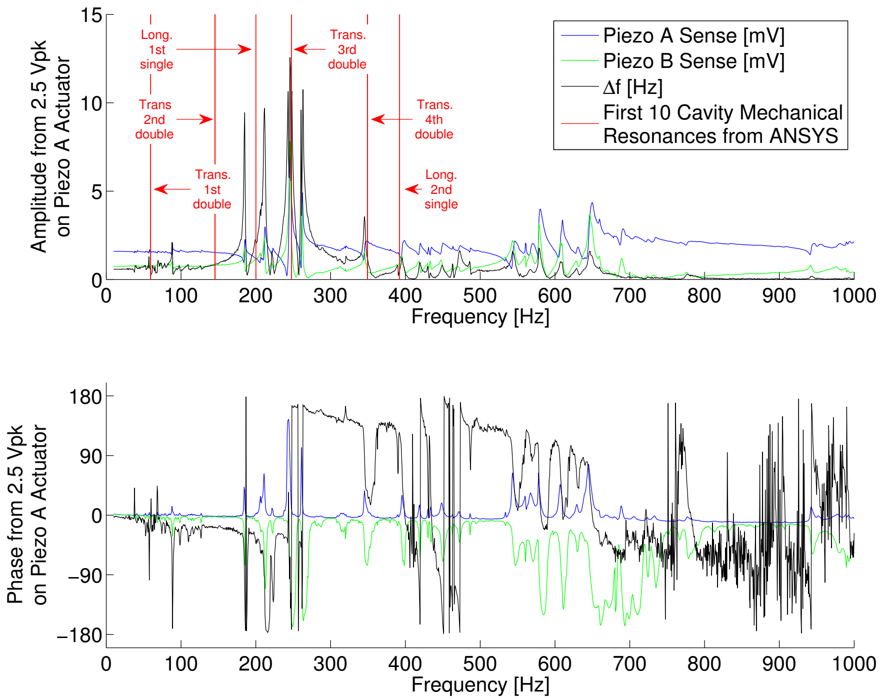

Figure 7: Piezo transfer functions and ANSYS prediction for mechanical resonances. Transfer functions are shown from piezo A actuator to piezo A sensor, from piezo A actuator to piezo B sensor, and from piezo A actuator to Δf. The phase of the Δf signal wraps through 2π several times.

TRANSFER FUNCTIONS

Transfer functions were measured from one piezo to itself, one piezo to another, and one piezo to cavity frequency, as shown in Fig. 7. The phase of the piezo to self and piezo to piezo transfer functions never crosses 180 even up to 1 kHz, as expected for having the actuator and sensor at the same location in the mechanical system. This suggests that stable feedback should be possible over large bandwidth with high gain. Also shown in the figure are the frequencies, orders, and types of first 10 mechanical resonances of the cavity as calculated in ANSYS [5]. They match up very well with the resonances in the transfer functions. Note that the first resonance that strongly couples to the piezos corresponds to the first longitudinal resonance in ANSYS, as expected for the way in which they act on the cavity. Additional resonances in the measurement should be from the tuner which was not included in the ANSYS simulations.

CONCLUSIONS AND OUTLOOK

Measurements related to the microphonics and frequency tuners were carried out on the Cornell HTCI. The slow and fast tuners exceeded requirements for linearity, hysteresis, and range. Correlations were found between the cavity detuning and the piezo and ground vibrations. For HTCII, the pressure signal will be improved so that correlations can be made with it as well. In addition, the transfer functions measured here will be used to inform the setup of feedback from piezo to piezo to actively reduce microphonics detuning.

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