

# OPERATION OF AN SRF CAVITY TUNER SUBMERGED INTO LIQUID HELIUM.

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## Abstract

There are several projects is going at FNAL that required to tune bare (undressed) SRF cavities when they submerged into superfluid Helium. We have used LCLS II tuner [1] mounted on the special mechanical structure to tune single cell 1.3 GHz cavity.

To precisely control the resonance of 1.3GHz SRF cavities during testing at the FNAL's Vertical Test Facility, we install for the first time a double lever tuner and operate it when submerged into the liquid He bath. Both active components of the tuner: electromechanical actuator (stepper motor) and piezo-actuators are operated inside superfluid helium. Accuracy in controlling the SRF cavity resonance frequency will be presented. Specifics of the tuner operation when submerged into liquid He will be discussed.

## INTRODUCTION

Compact double lever tuner [1] designed for LCLS II project has been selected for tuning bare (undressed) single cell 1.3GHz cavity when submerged into superfluid ( $T=1.55\text{K}$ ) Helium. Special cage designed to mount tuner around cavity (figure 1). Cage manufactured from aluminum. One cavity flange (bottom) was attached to strong back plate of the cage. Tuner compressed/tuned cavity by applying forces on the top flange of the cavity.

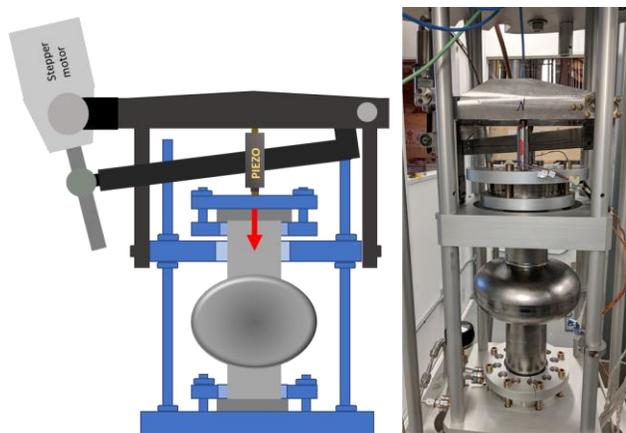


Figure 1: Picture (and schematics) of the tuner and single cell 1.3GHz cavity assembled in the cage.

Schematics and design specifics of the tuner presented previously [1]. Operational characteristics of the tuner mounted on Helium Vessel when it served the dressed 1.3GHz nine cell elliptical cavity measured and presented in several publications [1,2]. Standard operational environment for tuner is insulated vacuum and temperature of the stainless-steel frame and active components is typically near 20 Kelvins.

## WARM TUNER TESTING

According to ANSYS simulations single cell 1.3GHz cavity has value of frequency change vs cavity compression 2.3MHz/mm and stiffness  $\sim 23\text{kN/mm}$ .

LCLS II tuner that we used in our experiment has stiffness near 20kN/mm. This tuner was optimized to serve 9-cell 1.3GHz elliptical cavity with stiffness just 3kN/mm. Stiffness of the tuner close to the stiffness of the cavity will lead to low efficiency (below 50%) of slow& piezo tuner, but it was an issue for our experiment.

First test of the tuner was done at room temperature. We run stepper motor and monitor cavity frequency with network analyzer (NWA). At the first cycle we re-tuned cavity on  $\Delta F=160\text{kHz}$  or  $\sim \Delta X=70\mu\text{m}$ . Compressing warm cavity to 70um brought cavity to non-elastic deformation. During second cycle we limited range of slow tuner to 100kHz (or  $\Delta X=45\mu\text{m}$ ) (figure 2). Based on the kinematics scheme of the slow tuner for 1 step of the motor must deliver 5nm compression of the cavity, if all stroke will be delivered to cavity. The compression of the 1 cell cavity on 5nm must change frequency on  $\sim 10\text{Hz}$ . From the results presented on the figure 2 we can calculate slow tuner sensitivity (when cavity/tuner warm)  $\sim 3.3\text{Hz/step}$ . Efficiency of the warm cavity/tuner system is  $\sim 33\%$ .

To evaluate response of the cavity on the piezo-tuner DC voltage up to up to  $V=90\text{V}$  applied to the both piezo-actuators (figure 3). Cavity frequency was measured with NWA. The sensitivity of the warm piezo-tuner was measured  $\sim 260\text{Hz/V}$ . Taking into account that stroke of the warm piezo-actuator is  $\sim 0.3\mu\text{m/V}$  and of the cavity detuning sensitivity is 2.3kHz/um we could estimate piezo-tuner efficiency  $\sim 38\%$ .

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## TUNER TESTING INSIDE SUPERFLUID HELIUM

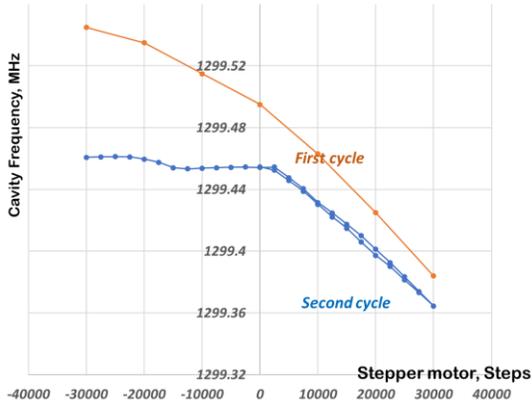


Figure 2. Warm slow tuner response.

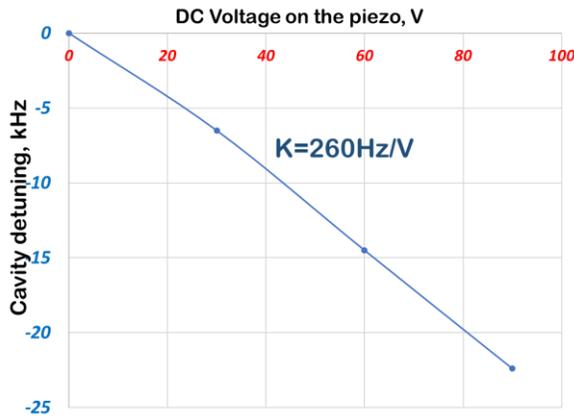


Figure 3. Piezo tuner response (warm measurements).

### Slow Tuner Measurement

During assembly of the tuner on the cavity/frame both piezo actuators were pre-loaded by slightly compressing cavity. We were expecting additional preload of the cavity/tuner system during cool-down process. Cage (fig.1) made from aluminium that contracted during cool-down more than Nb cavity. Cold (at  $T=1.4\text{K}$ ) cavity detuning with slow tuner presented on the figure 4. Slow tuner tuned cavity on  $\Delta F=500\text{kHz}$ , as required by experiment specifications. Slow tuner sensitivity when operated at superfluid He ( $T=1.4\text{K}$ ) was measured as  $5\text{Hz/step}$ . Slow tuner efficiency when tuner/cavity cold is  $\sim 50\%$ .

On the figure 5 presented results of the measurements of the short-range slow tuner response. Motor run in the range of the  $\pm 1000$  step with 100 steps increments. As measured previously Phytron electromechanical actuator has backlash  $\sim 30$  steps [1]. Expected slow tuner hysteresis must be  $\sim 150\text{--}200\text{Hz}$ . If experiment required control of the cavity resonance in the level of 1 Hz it could be accomplished with piezo-actuator in addition to slow tuner.

During other experiment requirement for slow tuner range was large. Slow tuner must be able to tune cavity on

$\Delta F \sim 1.4\text{MHz}$ . Slow tuner was able to retune single cell 1.3 GHz cavity  $\Delta F \sim 1.4\text{MHz}$ , but during this experiment both piezo-actuators was replaced with stainless-steel block. Otherwise forces on the each piezo-ceramic stack will be reached  $\sim 8\text{kN}$ . This excessive force could damage piezo-actuator.

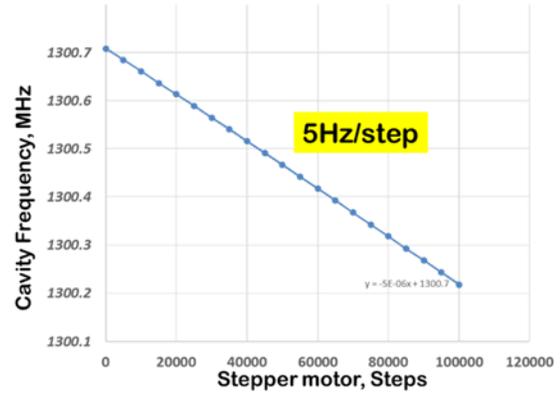


Figure 4. Tuning sensitivity with the slow tuner (cold,  $T=1.4\text{K}$ ).

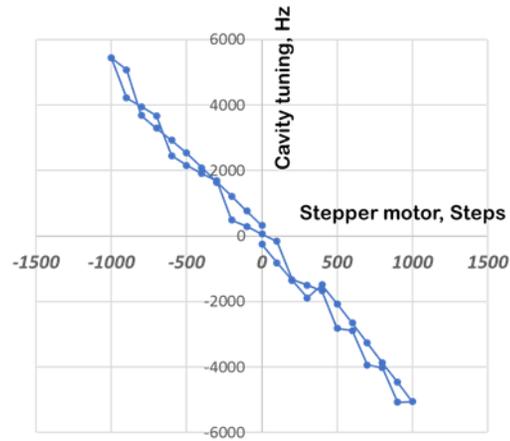


Figure 5. Slow tuner short range response (cold,  $T=1.4\text{K}$ ).

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### Fast/Piezo Tuner Measurement

There is limited experience of the piezo-ceramic actuators operations when submerged into superfluid Helium. One the major concerns was HV breakdown when piezo submerged at superfluid Helium and operated at significantly high voltage [3].

Even we are planning to operate our piezo-actuators below 10V we tested piezo up to 50V. So far, we do not experience any problems when we operated piezo-actuator submerged into superfluid Helium up to 50V. On the figure 6 presented response of the cavity when DC voltage up to 10V (with 1V increment) applied to both piezo-actuators. Piezo-tuner sensitivity, when operated inside superfluid Helium, is 55Hz/V. Per specifications of the PI P-885.51 piezo-actuator warm piezo stroke is  $\sim 0.3\mu\text{m/V}$ . At temperature near  $T=2\text{K}$  piezo stroke will decrease to  $\sim 0.03\mu\text{m/V}$  that must deliver  $\sim 70\text{Hz/V}$  if piezo-tuner will have 100% efficiency [4]. Estimated piezo-tuner efficiency is  $\sim 75\%$ .

We measured piezo-tuner sensitivity versus preload on the piezo-actuators. Preload on the piezo increased by tuning (compressing) cavity with slow tuner. We do not observe any changes in piezo stroke versus preload up to 4,5kN per piezo (table 1).

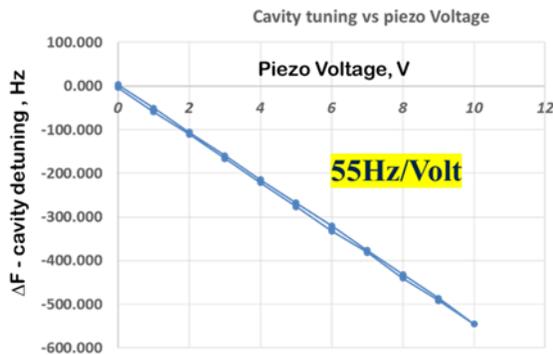


Figure 6. Piezo-tuner sensitivity (cold,  $T=1.4\text{K}$ )

Table 1.

Piezo-actuator sensitivity versus piezo preload.

Force[kN]	dF[kHz]	Hz/V
1	0	54.6
2.25	250	55
3.4	500	56
4.5	700	56

### Microphonics measurements

To evaluate level of the microphonics we used Digital PLL (Phase Lock Loop) system deployed at the FNAL's Vertical Test Facility (VTS). Changes of the cavity frequency recorded with high rate logger recorded during several seconds intervals. Shift of the cavity frequency during 10 second interval and FFT of this signal presented on the figure 7. There are several lines in the noise spectrum in figure 7. Very likely that narrow peak around 60Hz is contributed by 110V AC power line. Measured level of microphonics on the cavity was  $\sim 3\text{Hz}$  (rms) (figure 8).

We conducted one more cavity vibration test. We excited mechanical vibrations in cavity by slightly tapping on the

VTS Top Plate with small wooden block. Vibrations transferred to the cavity, that hanging on the several 6-8 meters long metal rods below Top Plate (figure 9). Cavity detuning measured with the same VTS Digital PLL system. On the figure 10A and figure 10B presented cavity vibrations in time domain. And on the figure 10C is FFT of these signals.

Even we hit Top Plate quite gently, peak cavity detuning reached  $\sim 1000\text{Hz}$ . When cavity microphonics recorded (figure 7) peak detuning was less than 12Hz. It was interesting to compare two spectrums: microphonics and external vibration generated by intentional hits on VTS Top Plate (figure 11). First observation that main resonances lines concentrated in the range of 20-50Hz in the both tests. Second observation that there is no strong narrow line near 60Hz in the spectrum from wooden blocks hits. This is providing us with more confidants that 60Hz line in cavity microphonics is come from 110AC noise in our DAQ.

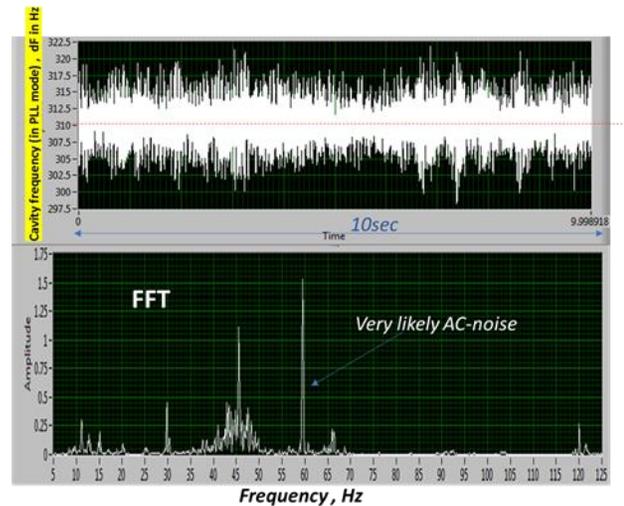


Figure 7. Cavity detuning caused by microphonics. Top: cavity frequency detuning during 10 second interval. Bottom: Spectrum of the microphonics (FFT of the top signal)

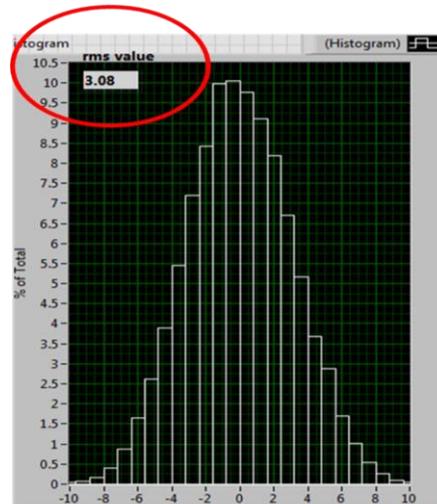


Figure 8. Cavity detuning histogram. 10 seconds of the data (figure 7). The 60Hz narrow line deleted from data.

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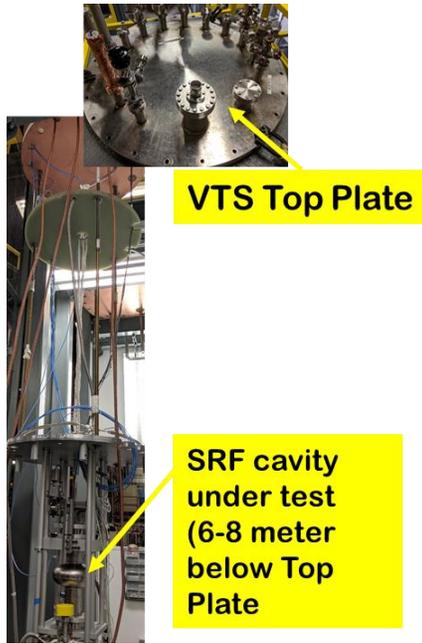


Figure 9. VTS Insert. Top Plate and long (8 m) insert with 1.3GHz single cell cavity (equipped with tuner).

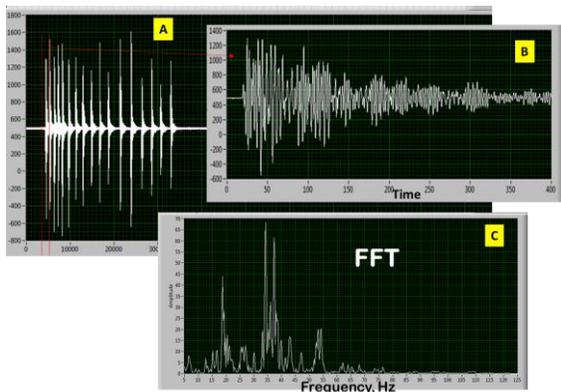


Figure 10. (A) Response of the cavity on the 18 hits on Top Plate with wooden block. Vertical axis is cavity detuning in Hz. (B) Zoomed in time: cavity vibrations from one hit. (C) -Spectrum of the vibrations: FFT of cavity response (B).

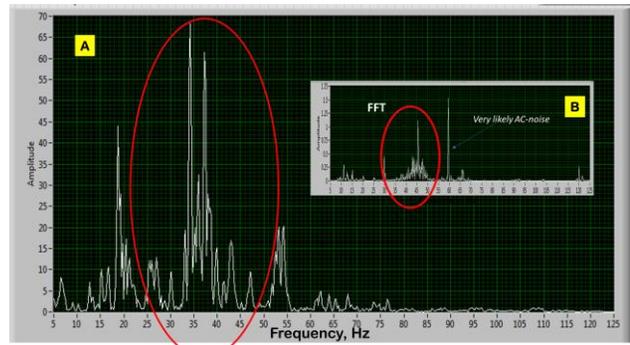


Figure 11. Two spectrums of the cavity vibrations. (A) Cavity response on the external (to Top Plate) hits. (B) Spectrum of the cavity microphonics.

external vibration generated by intentional hits on VTS Top Plate (figure 11). First observation that main resonances lines concentrated in the range of 20-50Hz in the both tests. Second observation that there is no strong narrow line near 60Hz in the spectrum from hits by wooden blocks. This is providing us with more confident that 60Hz line in cavity microphonics is come from 110AC noise in our DAQ.

## CONCLUSION

The first Tuner designed for operation inside insulated vacuum environment successfully operated inside superfluid He ( $T=1.4\text{K}$ ).

Both actuators: electromechanical (Phyton LVA 52-LCLS II-UHVC-X1) and piezo-ceramic (PI P-844K075) worked well. Piezo-actuator didn't experience any HV breakdown up to 50V. We do not test piezo above 50V.

Tuner range (with piezo-actuators installed) is  $\sim 800\text{kHz}$  and limited by allowable preload on the piezo. Without piezo-actuators (replaced with stainless-steel rods) tuner range is  $\sim 1.6\text{MHz}$ .

Level of the microphonics on the single cell 1.3GHz cavity, installed at FNAL VTS facility, was  $\sim 3\text{Hz}$  (rms). Main resonances were in the range of 20-50Hz. Using piezo-tuner with active compensation could suppress microphonics below  $\text{rms}=1\text{Hz}$  [5].

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