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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 1.3 GHz 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 1.3 GHz cavity when submerged into superfluid (T=1.55 K) Helium. Special cage designed to mount tuner around cavity (Fig. 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.

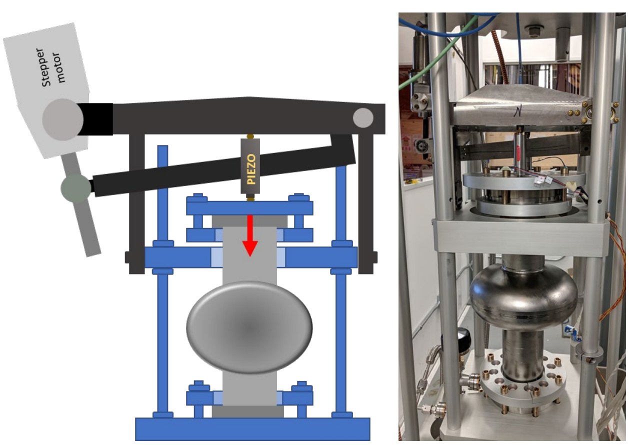

Figure 1: Picture (and schematics) of the tuner and single cell 1.3 GHz cavity assembled in the cage.

Schematics and design specifics of the tuner presented previously [1]. Operational characteristics of the tuner mounted on Helium Vessel when it served the dressed 1.3 GHz 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 1.3 GHz cavity has value of frequency change vs cavity compression 2.3 MHz/mm and stiffness ~23 kN/mm.

LCLS II tuner that we used in our experiment has stiffness near 20 kN/mm. This tuner was optimized to serve 9-cell 1.3 HGz elliptical cavity with stiffness just 3 kN/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 ΔF = 160 kHz or ~ ΔX = 70 um. Compressing warm cavity to 70 um brought cavity to non-elastic deformation. During second cycle we limited range of slow tuner to 100 kHz (or ΔX = 45 um) (Fig. 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 ~10 Hz. From the results presented on the Fig. 2 we can calculate slow tuner sensitivity (when cavity/tuner warm) ~3.3 Hz/step. Efficiency of the warm cavity/tuner system is ~33%.

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

TUNER TESTING INSIDE SUPERFLUID HELIUM

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 K) cavity detuning with slow tuner presented on the Fig. 4. Slow tuner tuned

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cavity on ΔF = 500 kHz, as required by experiment specifications. Slow tuner sensitivity when operated at superfluid He (T = 1.4 K) was measured as 5 Hz/step. Slow tuner efficiency when tuner/cavity cold is ~50%.

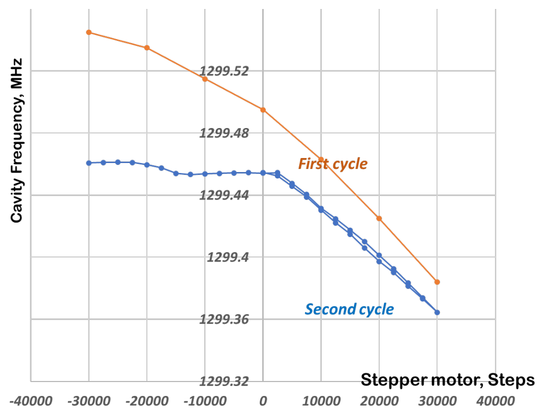

Figure 2: Warm slow tuner response.

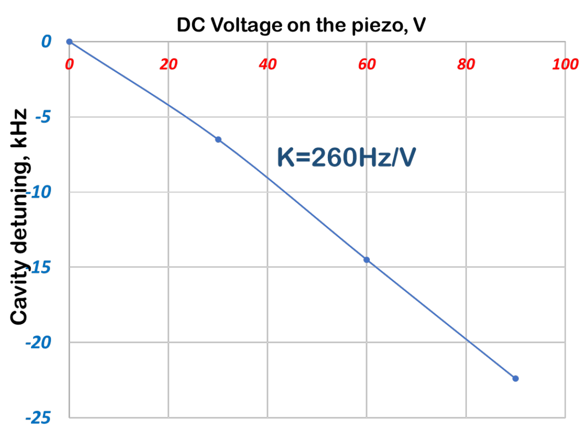

Figure 3: Piezo tuner response (warm measurements).

On the Fig. 5 presented results of the measurements of the short-range slow tuner response. Motor run in the range of the +/-1000 step with 100 steps increments. As measured previously Phytron electromechanical actuator has backlash ~30 steps [1]. Expected slow tuner hysteresis must be ~150-200 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 ΔF ~1.4 MHz. Slow tuner was able to retune single cell 1.3 GHz cavity ΔF ~1.4 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 ~8 kN. This excessive force could damage piezo-actuator.

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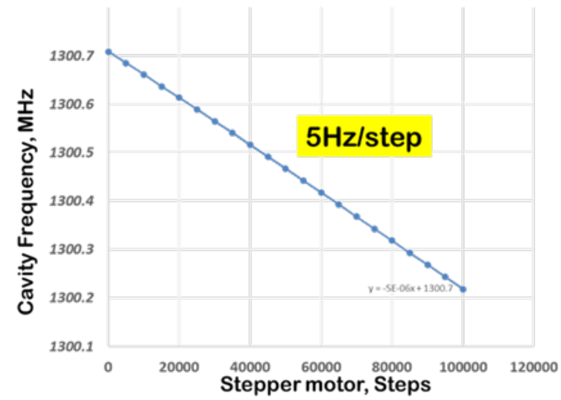

Figure 4: Tuning sensitivity with the slow tuner (cold, T=1.4K).

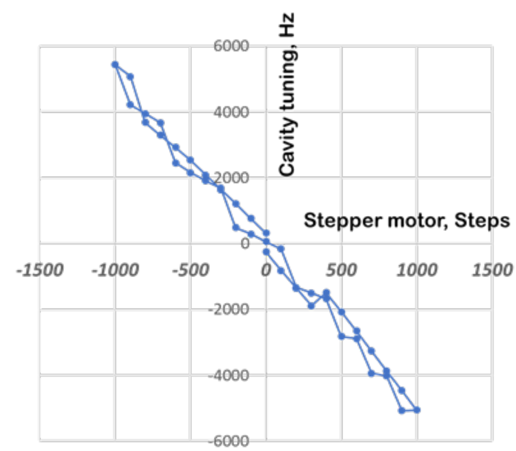

Figure 5: Slow tuner short range response (cold, T=1.4K).

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 10 V we tested piezo up to 50 V. So far, we do not experience any problems when we operated piezo-actuator submerged into superfluid Helium up to 50 V. On Fig. 6 presented response of the cavity when DC voltage up 10 V (with 1 V increment) applied to both piezo-actuators. Piezo-tuner sensitivity, when operated inside superfluid Helium, is 55 Hz/V. Per specifications of the PI P-885.51 piezo-actuator warm piezo stroke is ~0.3 um/V. At temperature near T = 2 K piezo stoke will decrease to ~0.03 um/V that must deliver ~70 Hz/V if piezo-tuner will have 100% efficiency [4]. Estimated piezo-tuner efficiency is ~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 4,5 kN per piezo (Table 1).

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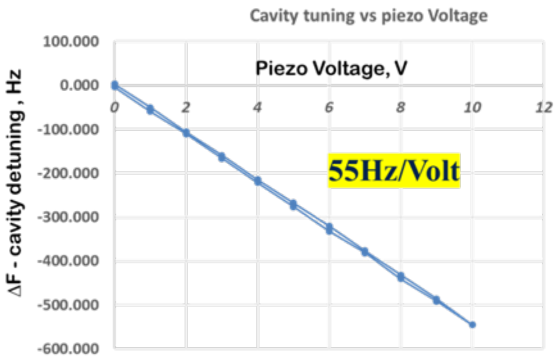

Figure 6: Piezo-tuner sensitivity (cold, T=1.4K).

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 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 Fig. 7. There are several lines in the noise spectrum in Fig. 7. Very likely that narrow peak around 60 Hz is contributed by 110 V AC power line. Measured level of microphonics on the cavity was ~3 Hz (rms) (Fig. 8).

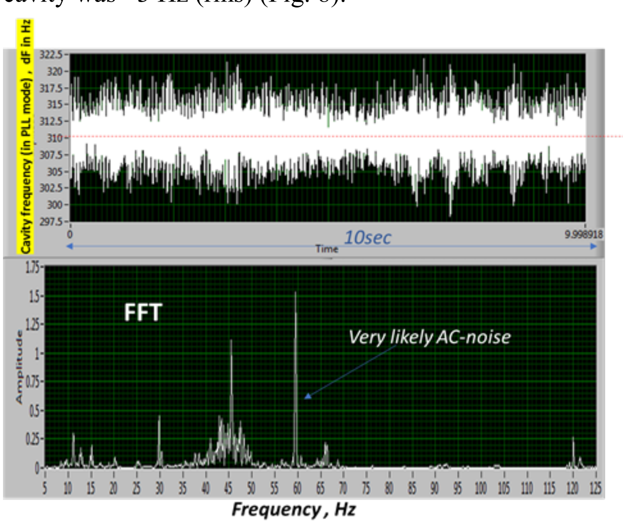

Figure 7: Cavity detuning caused by microphonics. Top: cavity frequency detuning during 10 second interval. Bottom: Spectrum of the microphonics (FFT of the top signal).

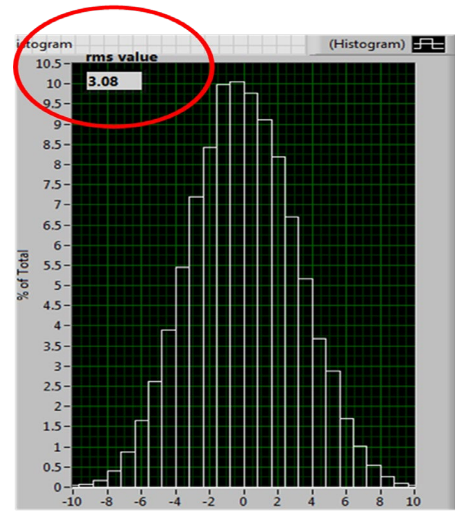

Figure 8: Cavity detuning histogram. 10 seconds of the data (Fig. 7). The 60Hz narrow line deleted from data.

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 (Fig. 9). Cavity detuning measured with the same VTS Digital PLL system. On the Fig. 10(A) and (B) presented cavity vibrations in time domain. And on the Fig. 10(C) is FFT of these signals.

Even we hit Top Plate quite gently, peak cavity detuning reached ~1000 Hz. When cavity microphonics recorded (Fig. 7) peak detuning was less than 12 Hz. It was interesting to compare two spectrums: microphonics and external vibration generated by intentional hits on VTS Top Plate (Fig. 11). First observation that main resonances lines concentrated in the range of 20-50 Hz 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 confidents that 60 Hz line in cavity microphonics is come from 110 AC noise in our DAQ.

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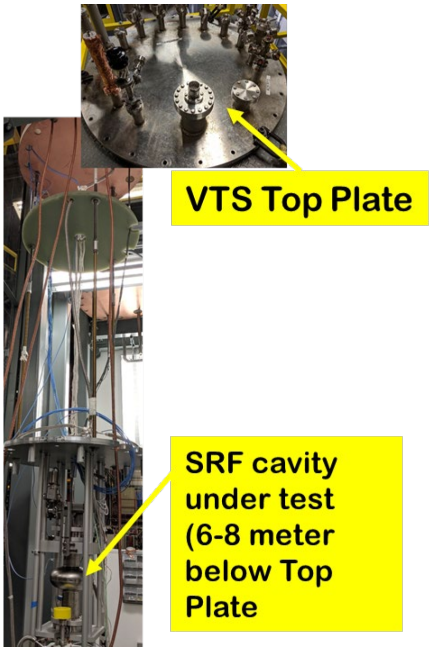

Figure 9: VTS Insert. Top Plate and long (8 m) insert with 1.3GHz single cell cavity (equipped with tuner).

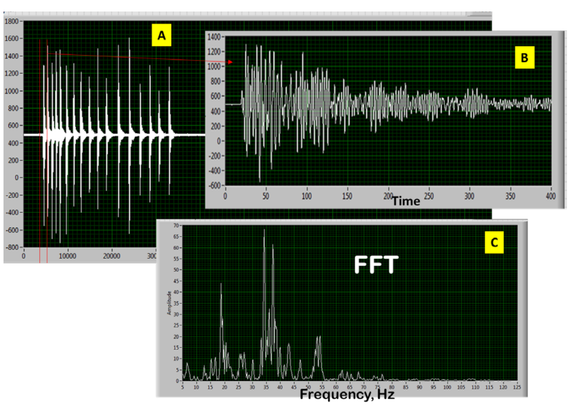

Figure 10: (A) Response of the cavity on the 18 hits on Top Plate with wooden block. Vertical axis is cavity detuning in Hz. (B) Zoomed in time: cavity vibrations from one hit. (C) -Spectrum of the vibrations: FFT of cavity response (B).

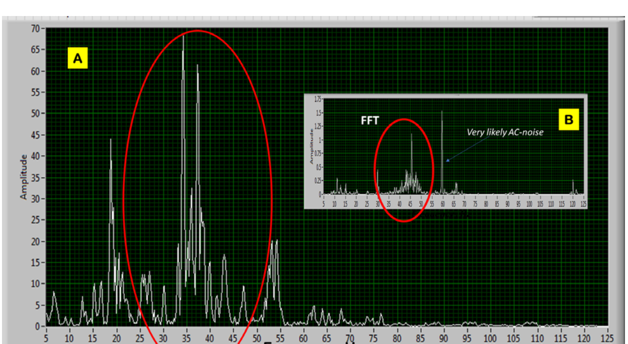

Figure 11: Two spectrums of the cavity vibrations. (A) Cavity response on the external (to Top Plate) hits. (B) Spectrum of the cavity microphonics.

CONCLUSION

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

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

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

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

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