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DESIGN AND TEST OF COMPACT TUNER FOR NARROW BANDWIDTH SRF CAVITIES

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Abstract

The design of the compact tuner for 1.3 GHz 9-cell elliptical cavity will be presented. This compact tuner is designed for future accelerators that will operate in CW and pulsed RF-power modes. The major design features include highly reliable active components (electromechanical actuators and piezo-actuators) and the ability to replace tuner active components through designated ports in the cryomodule vacuum vessel. Results of tuner testing with cold cavity will also be presented.

TUNER DESIGN

Schematics of the tuner design are shown in Figure 1. The coarse tuner is a double lever tuner (with a 20:1 ratio) similar to the design of the SACLAY I tuner. The tuner works by compressing the cavity. The piezo-stack is installed close to the cavity end flange. This means that the piezo stroke is translated directly to the cavity, not through flex and/or bearing connections. This configuration will deliver better piezo-tuner resolution and decrease group delay of the fast tuner. Safety rods have been designed between the cavity end flange and main lever of the tuner. These safety rods protect the cavity from non-elastic deformation during cavity/helium vessel system leak check.

A split ring is attached to the conical flange welded to the cavity beam-pipe (Purple in Figures 2&3). All forces/stroke from the tuner to the cavity are translated through this split ring. The tuner is anchored to the helium vessel with two strong horizontal arms (Yellow in Figure 2). These arms have adjustment capabilities to accommodate differences (+3mm/-7mm) in the length of the 9-cell cavities after final tuning. The electromechanical actuator connects to the left arm and the lever system is attached through the bearings to the right arm. To decrease the cost of the tuner assembly, it was designed in several parts that are connected by welding or using screws. Set-screws and special washers were included to prevent loosening of the assembly screws during warmup and cool-down cycles.

A special adjustment screw (Figure 1) to hold the left side of the lever system to the left arm was introduced into the design. This addition allows the release of forces between the cavity and tuner system when either the electromechanical actuator or piezo-stack needs to be replaced through the designated port in the cryomodule.

Balls connections were chosen for the connections between the top & bottom encapsulated piezo-stack and the main lever. This prevents the build-up of shearing forces on the piezo-stack during tuner operation which are detrimental to piezo lifetime. Two adjustment screws (one in each main arm) help to uniformly preload piezo-stacks during assembly.

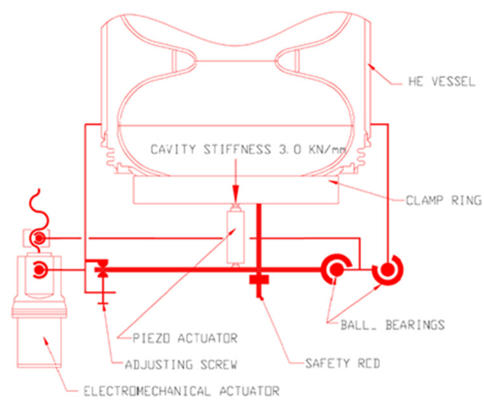

Figure 1: Schematic of the Tuner.

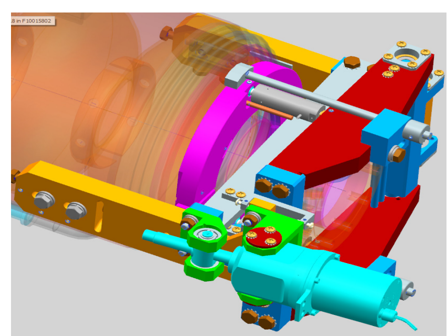

Figure 2: 3-D model of the Tuner, assembled on the cavity/helium vessel system.

ACTIVE COMPONENTS OF THE TUNER

The electromechanical actuator is the active element of the slow/coarse tuner. The electromechanical actuator translates rotation of the stepper motor to linear motion of the tuner arms. The tuner is equipped with a Phytron actuator (LVA 52-LCLS II-UHVC-X1) [1] designed for the FNAL linear SRF project. The Phytron actuator is built from:

- Stepper motor XXX
- Planetary gear (1:50 ratio)
- M12X1 spindle made from titanium
- Traveling nut made from stainless steel and radiation hard plastic material

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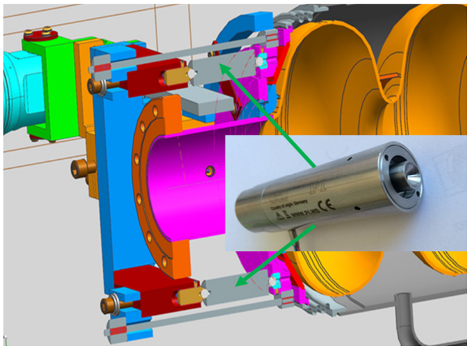

Figure 3: 3-D model (Cross-section) of the SRF cavity/helium vessel/tuner system. The figure shows details of how the force/stroke is translated from the main lever to the cavity flange through two encapsulated piezos (on the top and bottom). Inserted is photo of the encapsulated piezo unit.

The actuator is specified for a long time inside the insulating vacuum at cryogenic temperatures (1000 spindle rotations over a 20+ year lifetime). The actuator was designed for the maximum force between the motor body and traveling nut to be up to 1300N. We successfully tested the actuator up to 5000 spindle rotations without any performance degradation.

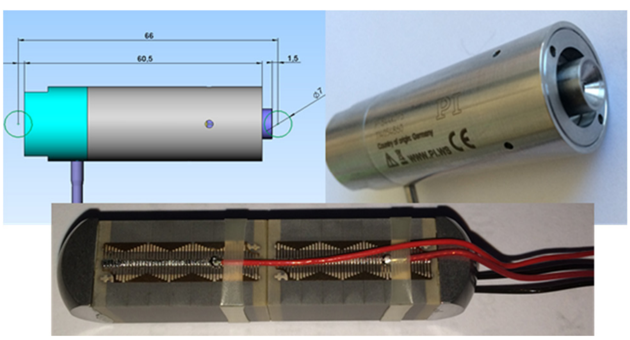

Figure 4: Encapsulated piezo P-844K075 made from two 10*10*18mm PICMA butted piezo-stacks.

The piezo actuator P-844K075 used in this tuner is an encapsulated piezo-capsule designed and built by Physik Instrumente (PI) [2] per FNAL specification (fig.4). The encapsulation is made from 316L stainless steel. Inside are two 10*10*18mm PICMA piezo-stacks butted together. During normal operation the tuner will use all 4 piezo-stacks (2 on the top and 2 on the bottom piezo capsule). The lower the piezo operation voltage the longer the lifetime of the tuner will be, this is why 4 stacks were used. Even if three piezo-stacks fail one piezo-stack is still able to deliver the specified cavity elongation although the lifetime may be reduced. The piezo is preloaded to 800N inside its encapsulation at cryogenic temperature. The technique (patented by PI) for piezo-stack encapsulation will minimize shearing forces and, as a result, increase lifetime of the piezo tuner. FNAL has constructed a designated facility to conduct piezo-lifetime testing at cryogenic temperatures and in an insulated vacuum environment. An accelerated piezo longevity test to achieve $2*10^{10}$ pulses is on-going and results will be reported in future papers.

TUNER PERFOMANCE

The cavity with assembled tuner was tested at FNAL HTS [3] for dedicated tuner performance tests. For these particular tests bandwidth of the cavity was near ~0.1Hz.

Slow Tuner Performance

Slow/coarse tuner performance (cavity frequency change vs motor steps) is presented in Figure 5. The measured maximum range of the tuner is ~450 kHz. This range is consistent with the expected maximum stroke of the tuner: 1.3 mm. Slow tuner sensitivity is 1.4 Hz/step.
An important parameter of the slow/coarse tuner (especially for narrow bandwidth cavities) is short tuning range hysteresis. Measurements of the tuning capability of the coarse tuner in short range (+/-150 Hz) is presented in figure 6. Backlash of the mechanical system (motor/ planetary gear/spindle/traveling nut) is ~30 steps and tuner hysteresis is ~45 Hz (or ~150 nm).

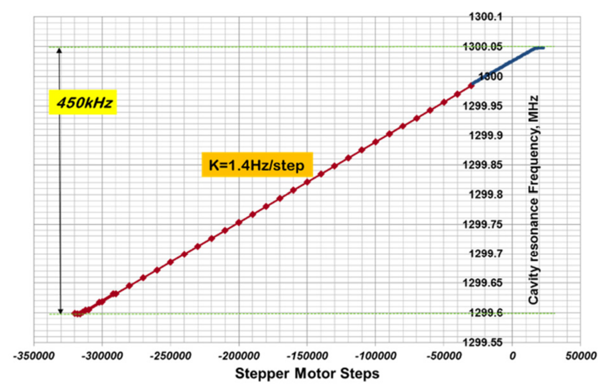

Figure 5: Cavity tuning with slow/coarse tuner. Range of the tuner is 450 kHz set by hard stops.

Fast/fine Tuner Performance Tests

The cavity static detuning when a DC Voltage (0-100 V) is applied to all 4 piezo is presented in Figure 7. There were no temperature sensors installed on the piezo-stack so the temperature of the piezo (T~20 K) was estimated from the piezo capacitance measurements. The same measurements were conducted with a DC voltage applied to just two 10*10*18mm piezo-stacks (one on the top and on the bottom) and then only one piezo on the top. When 100 V was applied, two piezo-stacks tuned the cavity by 1300 Hz and one stack by 600 Hz.

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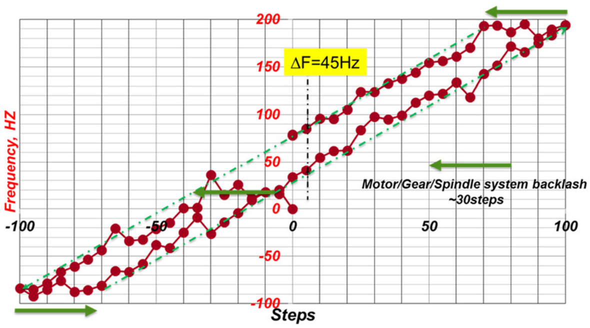

Figure 6: Coarse Tuner performance in the short (300Hz) cavity tuning range. Increment is 5 steps of the stepper motor.

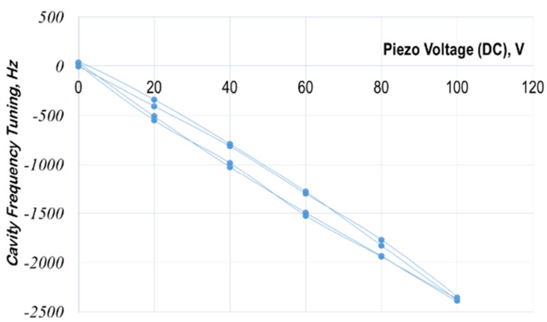

Figure 7: Cavity static detuning by piezo tuner when DC voltage applied to all 4 piezo simultaneously.

An important parameter of the piezo tuner for compensation of microphonics detuning is tuner resolution. To measure resolution a sinusoidal stimulus was applied to all four piezo-elements with frequency of 5 Hz. The amplitude was varied from 1 mV to 3 V with small increment (1 mV) in the range of the 1-20 mV and with larger steps after that (Figure 8). This driving term was present in the cavity detuning spectrum with an amplitude proportional to the driving voltage. 5 Hz was chosen because there was a very low spectral background at that frequency. These direct measurements give an upper bound on the piezo tuner resolution of 110 mHz.

The transfer function of the cavity/He vessel/tuner system is presented in Figure 9. The cavity was excited with the piezo driven by a sinusoidal stimulus (A = 6 V) with frequency changing from 1 Hz up to 500 Hz in 1 Hz steps. For each particular frequency, the cavity was excited for 10sec (after 3 sec relaxation time). The RF cavity response and stimulus pulses were recorded. This data was used to perform system identification (determine the cavity's mechanical resonances frequency and quality factor). The strongest mechanical resonances of the cavity tuner system are near 250Hz (Figure 9). During this test HTS had strong external vibration sources which are shown in figure 8 as parallel lines with frequencies near 56Hz; 30Hz; 80Hz. These sources were identified and suppressed during following tests.

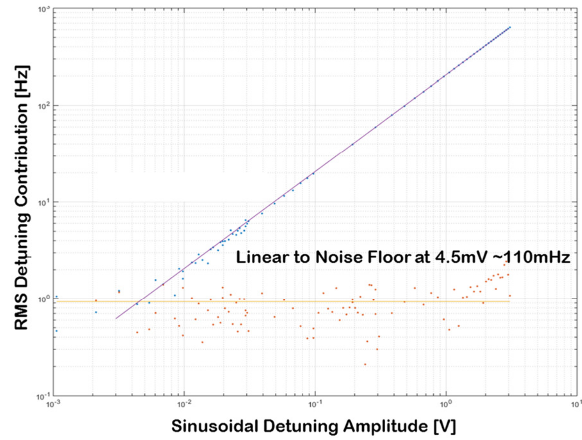

Figure 8: Fast tuner resolution measurements. Piezo driving amplitude vs Noise floor – 5 Hz

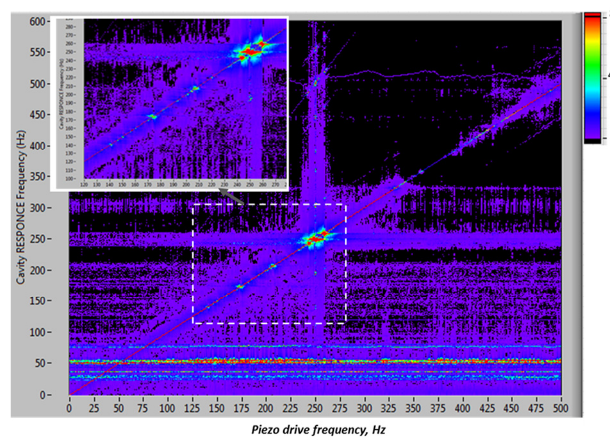

Figure 9: Piezo-to-RF transfer function of the cavity/vessel/tuner system.

CONCLUSION

A prototype compact tuner was designed, built, successfully installed and tested at the HTS at FNAL. The tuner exhibited the expected range and resolution for both slow and fast tuning mechanisms. The tuner was used to characterize the cavity/tuner mechanical system.

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[2] http://piceramic.com/product-detail-page/p-844-101210.html

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