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PRODUCTION TUNER TESTING FOR LCLS-II CRYOMODULE PRODUCTION

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Abstract

The 1.3 GHz elliptical cavity cryomodule production for the linac coherent light source (LCLS)-II is well underway at Fermilab. Several dozen cavity/tuner systems [1] have been tested such as tuning to 1.3 GHz from the cold landing frequency, range/sensitivity of the slow tuner, and range/sensitivity of the fast tuner. All this testing information as well as lessons learned from tuner installation will be presented in this paper.

TUNER TESTING DURING CRYOMODULE ASSEMBLY

The Phytron electromechanical actuators [2] pass a stringent set of tests at the vendor facility, including running the motors in liquid N_2 environment. In addition to these we conduct additional motor tests (winding resistance, winding shorts, rotational directions, etc) before installation on the tuner. Piezo-actuators [3] also were tested at Physik Instrumente (PI) per project specifications. Additional piezo testing before installation on the tuner include: measuring capacitance, heat dissipation factor, and stroke with 60V applied to piezo-stacks. Each tuner was tested after assembly on the cavity (see Figure 1). Operator runs stepper/piezo-actuators while monitoring the cavity frequency. Test procedure included the following steps: connect NWA, preload piezos to 200kN by tuning/compressing cavity by 45 kHz, run stepper motor 20 ksteps, apply 60V on each piezo individually and on both, discharge/apply 0V on both piezos, and finally run stepper back to initial position. At each step operator checks cavity detuning against expected value.

Each fast tuner is built from 2 piezo-capsules (top and bottom) [1]. Inside each capsule there are two electrically independent piezo-stacks. All together piezo-tuner has four electrically independent piezo-stacks, wired with 8 long wires and a couple additional intermediate connectors to the connector mounted to the cryomodule (CM) instrumentation flange. There is chance of cross-wiring of the 8 wires from 4 piezo-stacks which can be difficult to debug during cold tuner test. A simple procedure was developed to test polarity of the piezo-stacks. One piezo (piezo-A/top) is run with stimulus sine-wave pulse A=5V and F=20Hz (Figure 2. - CH1) to generate vibration on the cavity/tuner system. The three other piezo-stacks work as sensors. Amplitude and phase of the signals from the three other stacks (Figure 2 - CH2-4) will confirm correct wiring of the piezos.

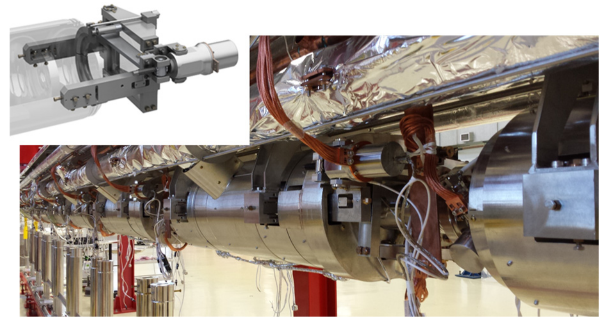

Figure 1: LCLS II cold-mass with tuners installed.

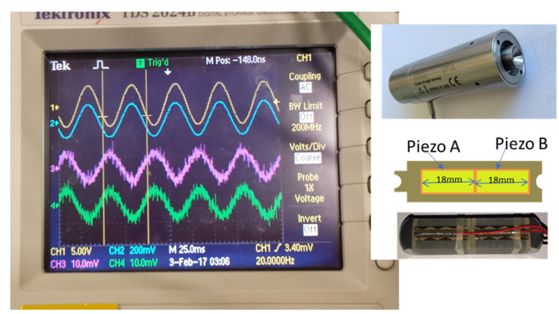

Figure 2: Procedure of the testing polarity of the piezo-actuators. Picture of the oscilloscope screen with signals from piezo-stacks. Photo and schematics of the piezo-capsule employed at LCLS II tuner.

TUNER TESTING DURING CRYOMODULE QUALIFICATION TEST

Once the cryomodule is cold, one of the first testing steps is verification of slow tuner performance. The tuners are set such that they are loaded already in the cold-landing position. The cavities are first locked with the LLRF system, measuring the cold-landing frequency. Assuming this frequency is between 1300.300 and 1300.020 MHz, the slow tuner is moved 1000 steps to test polarity and sensitivity. If the sensitivity is within 20% of -1.4 Hz/step, then the tuner is tuned in large steps (30000 steps) to 1300 MHz. During this movement, the frequency is monitored by the LLRF system and the motor temperature is monitored and interlocked to below 70 K. Generally, the motor temperature starts around 30 K and doesn't see more than 4 K rise during long motion. The piezo tuner checkout process is more straight-forward. First, each of the cavity's piezos (all four) are energized to +20 V. If there are no polarity errors in the piezo wiring and the piezo stacks are behaving properly, then this results in a cavity detuning of

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~400 Hz. This being true triggers energizing the piezos to 100 V. These voltages are held for several minutes and the frequency shift from 100 V to 0 V is recorded.

Figures 3-7 show the results of tests for 56 tuners in the cryomodules from 1 up to 7. Figure 3 presents frequency required for cavities to be tuned by slow tuner to bring each cavity to operating frequency of 1.3GHz. Average tuner range was ~200kHz with maximum range for couple of the cavities just slightly more than 300kHz. Figure 4 shows the distribution of the tuner sensitivity. Tuner sensitivity is the slope of the linear fit for slow tuner curve: cavity frequency change vs steps of the electromechanical actuator [1]. It is determined by tuner's kinematics model and by stiffness of the cavity/ tuner system. The slope for CM1 is 5% lower than for CM 2-6. This can be explained by the cavity interface (split ring mounted on the cavity's beam-pipe) on the CM1 tuner is slightly different from the other cavities starting from CM2. Lower sensitivity for tuners mounted on the cavity #1 at CM4&5 have been contributed to the modification of the tuner mounting technique [4].

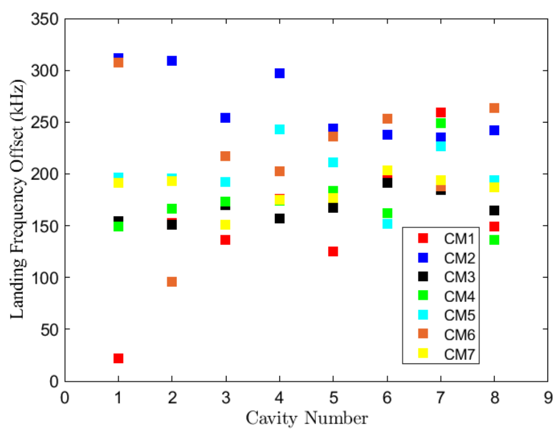

Figure 3: Cavities frequency offset from 1.3GHz after CM cool-down to T=2K. Measurements for 7 CM tested at the cryomodule testing facility (CMTF).

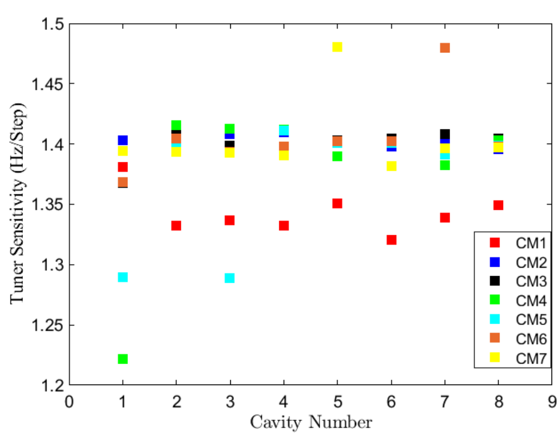

Figure 4: Slow tuner sensitivity for 56 tuner/cavity system installed on 7 CMs.

As part of fast tuner qualification measurements we measured each cavity detuning when a DC voltage of 100V was applied simultaneously to both (top and bottom) piezo-actuators. The piezo-tuner sensitivity for all 56 pairs of the piezo-actuators is presented in Fig. 5. Piezo-capsules mounted on CM2 show ~2 times higher sensitivity. Before the voltage is applied to each pair of the piezo-capsules the capacitances of the piezo-stacks were measured (Figure 6). Piezo tuner qualifications tests were done without waiting long enough for piezo-stacks to be cool-down for CM2. As a results capacitance and stroke/tuning sensitivity of piezos in CM2 were larger. Lesson learned from CM2 tests:
wait several days after start of CM cool-down before to start piezo-tuner qualification.

On Fig. 6 the piezo-tuner sensitivity versus frequency required to tune cavities to nominal 1.3GHz frequency is shown. Taking into account stiffness of the 1.3GHz dressed cavity (k~3kN/mm) and internal preload of the piezo-stack inside capsule (0.8kN) then the "landing frequency off-set" is converted to piezo loading. Average load on the piezo-capsule in normal operation position will be ~2kN (or ~50% of blocking forces) and the range from 1.2kN up to 2.8kN. Important to note that there are no dependency of the piezo-tuner response (sensitivity) versus piezo load in measured range.

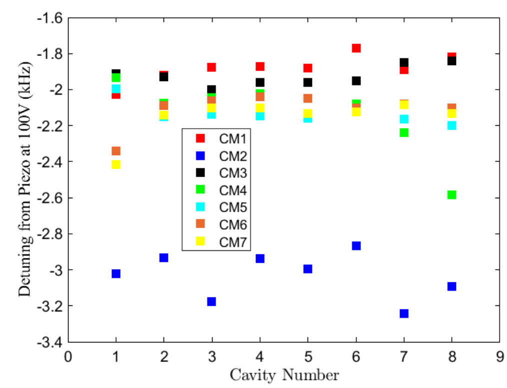

Figure 5: Piezo tuner sensitivity. Cavity detuning when DC voltage 100V applied to both piezo-actuators.

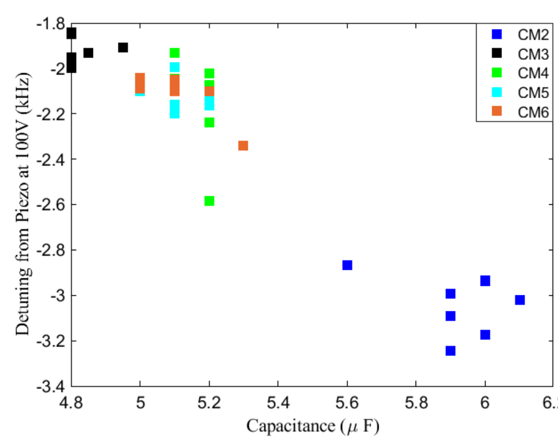

Figure 6: Piezo tuner sensitivity vs. capacitance of the piezo-actuators.

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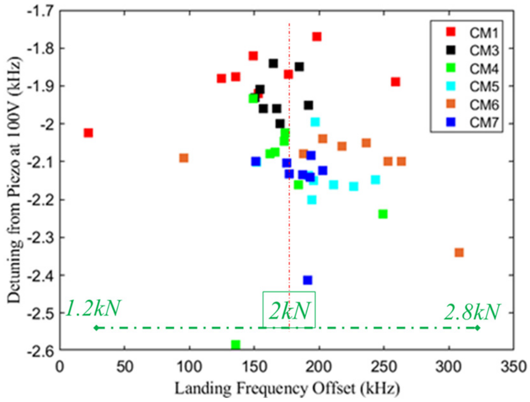

Figure 7: Detuning the cavity with fast/piezo tuner.

CONCLUSION

Developed and implemented procedure of the tuner testing as a part of assembly tuners on the CMs. Also procedure of the testing tuners as a part of the CM cold test at CMTF developed and implemented.

All 64 tuners (installed inside 8 CMs) tested cold. Parameters of all 64 tuners met requirements specifications.

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[4] Y. Pischalnikov *et al.*, "Modified Slow Tuner Design for Cavity 1 Inside LCLS II Cryomodules", presented at the 9th Int. Particle Accelerator Conf. (IPAC'18), Vancouver, Canada, Apr.-May 2018, paper WEPML006, this conference.