650MHz SRF Cavity TUNER

Yuriy Pischalnikov
PIP-II Fine Tuning Workshop, Saclay
26 June, 2018
Tuner Functional Specifications

• Tuner must tune cavity (slow and fast) and protect cavity/He Vessel system during CM production cycle and operation of the accelerator

• The same design of the Tuner (with minimum modifications) must serve HB650MHz and LB650MHz cavities.

• Active tuner components (electromechanical actuator & piezo-stack) need to be replaceable through special ports;

• High reliability of tuner → longevity of the active components (electromechanical actuator and piezo-actuator);

• Tuner need to be build from materials with relative low magnetic permeability non-magnetic material (316L stainless steel or titanium) to preserve SRF cavity high Q0

• Tight requirements for slow/coarse & fast/fine tuning resolution → cavity has narrow bandwidth (~29Hz) and resonance control requirements \( \Delta F_{\text{peak}} = 20\text{Hz} \) (or \( \sigma = 3.5\text{Hz} \) in RF-pulse* and CW modes of operation

• High stiffness of the TUNER to minimize level of the LFD on the cavities
# 650MHz cavities parameters and specs for tuner

<table>
<thead>
<tr>
<th></th>
<th>beta</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.92</td>
</tr>
<tr>
<td>Cavity stiffness, (N/um)</td>
<td>3-4</td>
</tr>
<tr>
<td>cavity tuning sensitivity, [Hz/um]</td>
<td>160</td>
</tr>
<tr>
<td>bandwidth (F₁/₂), [Hz]</td>
<td>29</td>
</tr>
<tr>
<td>Lorentz Force Detuning coefficient, [Hz/MV/m]^2</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Cavity sensitivity to pressure, dF/dp [Hz/mbar]</td>
<td>20</td>
</tr>
<tr>
<td>Tuner stiffness [N/um]</td>
<td>&gt;40</td>
</tr>
<tr>
<td>required coarse tuning range, [kHz]</td>
<td>200</td>
</tr>
<tr>
<td>coarse tuner resolution, [Hz/step]</td>
<td>1-2</td>
</tr>
<tr>
<td>fine tuner range, [Hz]</td>
<td>1200</td>
</tr>
<tr>
<td>fine tuner range, [um] at T=20K (20% from RT)</td>
<td>7.5</td>
</tr>
<tr>
<td>fine tuner range, [um] at T=300K</td>
<td>37.5</td>
</tr>
<tr>
<td>cavity resonance control reqs (peak), [Hz]</td>
<td>20</td>
</tr>
<tr>
<td>fine(piezo) tuner resolution, [Hz]</td>
<td>1</td>
</tr>
<tr>
<td>max. forces on the tuner system, kN</td>
<td>4</td>
</tr>
</tbody>
</table>

---

**Notes:**
- Cavity stiffness, cavity tuning sensitivity, and bandwidth are given in the table.
- Lorentz Force Detuning coefficient is given in both units.
- Cavity sensitivity to pressure is constant across both beta values.
- Tuner stiffness is also constant across both beta values.
- Required coarse tuning range and coarse tuner resolution are constant.
- Fine tuner range and fine tuner resolution are for different temperatures.
- Maximum forces on the system are given in kN for both beta values.
For 650MHz tuner design copy as much as possible from tuner design that FNAL team used for 1.3GHz elliptical cavity LCLS II (including active components: electromechanical actuator & piezo-actuator)

- Slow/coarse tuner – double lever (close to design of the SACLAY I);
- Solid connection to the He Vessel (no flexible joints);
- Push (cavity) compression tuning only;
- Safety rods (protect cavity);
- Piezo-actuator installed between tuner main lever and cavity flange;
- Compact tuner ...fit to the short/short cavity;
- Piezo-actuator and stepper motor cartridge replaceable through special port;

- Reliable electromechanical actuator from Phytron
- Reliable piezo-actuator from PI

Built ~ 300 units
Assembled into CM ~80%
Cold tested ~60%
FNAL 650MHz Tuner (Version II) (3D Model)
Major issues addressed during modification of the 650MHz Tuner Version I

- **Tuner stiffness**
- **Simplification of the design**

*Initial ANSYS simulations (before prototype built) stated that $K_{\text{tuner}} \approx 65-70 \text{ kN/mm}$. Later we found that model/simulation was not correct... but only after we built first prototype. Measured stiffness on the prototype was $\approx 30\text{kN/mm}$*

Version I. Cartridge with 4 piezos located on the same side as motor (to satisfy cavities with high stiffness $K_{\text{cavity}} = 20\text{kN/mm}$)

650MHz Tuner (Version I) assembled on the test stand
Details of the 650MHz Tuner (V2) Fast/Fine Tuner design

- Capsulated piezo-actuator
- Safety rod
- Ceramic balls
- Piezo adjustment/loading screw
Details of the Tuner-to-cavity Interface

No “split-ring” parts that mounted on the alignment ring ...unlike 1.3GHz cavity interface

Interface ring (Nb-Ti) welded to beampipe & cavity 1st cell

Nb-Ti ring (serve as interface to the tuner)
Details of the Tuner design (from the motor side)

Part that lock together top & bottom main levers & transfer forces from the cavity on the right tuner arms
ANSYS Simulation of the stiffness for Tuner-Dressed Cavity system

Stiffness of the Tuner frame $K_{\text{tuner frame}} \approx 140\text{kN/mm}$
(without “piezo” & transition ring)

Stiffness of the overall system $K \approx 42\text{kN/mm}$

At this stage we are consider this design as optimal from the point of view tuner stiffness. Increasing stiffness MORE will require significant modification of the cavity-tuner interface & new (large cross-section) piezo-actuator development

ANSYS simulations

$K_{\text{frame}} \approx 600\text{kN/mm}$
But $K_{\text{tuner/dressed cavity system}} \approx 55\text{kN/mm}$
Status of the 650MHz Tuner (Version 2) & near term plans

- Tuner manufactured. Will be arrive from vendor in 1 week.
- Small design modification of the test stand (cavity mock-up) finished.
- Parts in FNAL machine shop. Will be ready next week.
- Assembly of the tuner on the stand
- Testing main tuner parameter (July, 2018)
  - slow tuner characteristics (calipers)
  - piezo-tuner characteristics (laser displacement system)
  - tuner stiffness evaluation (load cells)
- Testing tuner on the first dressed 650MHz cavity (warm) (as soon as cavity available)
  - transfer function measurements
  - etc...

<table>
<thead>
<tr>
<th>#</th>
<th>f(Hz)</th>
<th>tau(ms)</th>
<th>kappa(Hz/V)</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>235</td>
<td>49</td>
<td>14.5</td>
<td>0.65</td>
</tr>
<tr>
<td>2</td>
<td>168.1</td>
<td>41</td>
<td>6.86</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>471.2</td>
<td>46</td>
<td>5.79</td>
<td>0.09</td>
</tr>
<tr>
<td>4</td>
<td>402.2</td>
<td>17</td>
<td>1.29</td>
<td>0.04</td>
</tr>
<tr>
<td>5</td>
<td>232.6</td>
<td>126.4</td>
<td>1.29</td>
<td>0.03</td>
</tr>
</tbody>
</table>

LCLS II Tuner
On the dressed warm cavity
Maintainability →

**Tuner access port** + design of the tuner allowed to release/replace active components without tuner dis-assembly.

*Lessons learned: SNS ...24 tuner failures (for 80 cavities)... large size high power coupler port allowed to reach/maintain tuner*

**LCLS II CM vacuum vessel** have tuner access ports

*We don’t have any tuner failure so far after cold testing of 60% of tuners installed on inside CMs.... but tuner access ports used by team for many other sub-system fix/maintenance issues: HOM, etc.*
Reliability

Tuner mechanical frame long-run reliability: LCSL II approach → all screws have lock-washers + set screw + lock-tight glues

Vibration of the tuner during transportation and during the 20-30 years of operation.
Reliability

Active Components:

1. Electromechanical Actuator
Phytron electro-mechanical actuator
(stepper motor; gear-box; shaft-traveling nut).

2. Piezo Actuators
PI capsulated preloaded piezo-actuator.

650MHz tuner will use active components that were developed for Project X and LCLS II Projects.
Titanium spindle M12X1 with SS traveling nut with insert made from rad. hard material TECASINT 1041 (polyimide; fillers 30% Molybdenum disulfide (MoS2) VS CuBe spindle M12X1 with SS Nut

Phytron electromechanical actuator

<table>
<thead>
<tr>
<th>Picture</th>
<th>Name</th>
<th>Motor</th>
<th>Gear Box</th>
<th>Spindle/Nut</th>
<th>Forces</th>
<th>Longevity tested</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td>LCLS II</td>
<td>Phytron 1.2A</td>
<td>planetary gear (ratio: 1:50)</td>
<td>Titanium &amp; SS M12&quot;1</td>
<td>+/-1300N</td>
<td>tested in ins. vacuum at HTS for 5000 turns (5 XFEL lifetimes). In the force range +/-1500N. Motor run with current 0.7A</td>
</tr>
</tbody>
</table>

Planetary gear vs Harmonics drive

+/-1300N
Phytron Actuator Accelerated Lifetime and Radiation Hardness tests

Material found between spindle thread (Molybdenum disulfide (MoS2)

**TECASINT Insert**

before

after

Successful run for 10 lifetime of the regular operation.

Long run at cryogenics/insulated vacuum environment

After irradiation to the dose $5 \times 10^8$ Rad there was no any degradation in the electromechanical actuator components:

- Windings of the stepper motor
- Limit switches
- Traveling nut

**Ti shaft has no any degradations**

Ti shaft

Material found between spindle thread (Molybdenum disulfide (MoS2))

there are signs of wear on the nut, but there is no significant damage seen on the threads

Fermilab

Y. Pischalnikov | 650MHz Tuner

16

7/2/2018
LCLS II piezo-stack (designed and built in collaboration with PI)

LCLS II configuration allowed for max. length 36mm piezo
Piezo capsule build with piezo stack made from 2*18mm piezo
LCLS II fast tuner can deliver 3kHz (V=120V) (all 4 piezo)

- Internal preload (800N at 2K)
- Minimization of the shearing forces
- through balls connections
- Piezo-ceramic stack glued to substrates (as recommended by all piezo companies)
- PI using patented technology ... taking into account different thermo-expansion coefficient for piezo-ceramics and stainless steel
- 316L stainless steel construction (High Q0 reqs)
- Wiring with kapton insulation wires

Ceramics balls

Fixture with piezo-capsule was cool-down inside LN2, installed into INSTRON and measured S vs Forces

Piezo Survived 25kN test
2Piezo-stacks ==50kN
(10kN requirements)

Crash
Fz 2800kg
High reliability of tuner components (piezo-actuator)

Accelerated Piezo Lifetime test at FNAL

Y. Pischalnikov, et al
“RELIABILITY OF THE LCLS II SRF CAVITY TUNER”, SRF2015

Designated facility at FNAL to test piezo at the CM environment (insulated vacuum and LHe)

Accelerated piezo-stack lifetime test
2x10^10 pulses  \( V_{pp} = 2V & F = 40Hz \)
20 years → 2 month (40Hz→5kHz)

LCLS II --- \( P_{av} \approx 50\mu W \) (40Hz, 2V)
During ALT at 5kHz \( P_{av} \approx 6mW \) (\( \Delta T\approx 2K \))

Increase of Piezo temperature (dT) versus power dissipated into piezo-ceramics.

LCLS II Tuner piezo-stacks run for 2.5x10^10 pulses (or 125% of LCLS II expected lifetime) without any degradation or overheating
Irradiation of the Piezo-stacks up to $10^9$ Rad (gamma)

Stroke of the piezo-stack decreased only on 10% after irradiation up to $10^9$ Rad
Summary

- 650MHz cavity tuner developed at FNAL based on proven LCLS II tuner design.  
  Version 2 tuner optimized to simplify design and increase tuner stiffness

- Tuner reliability and maintainability addressed the same way as it was done for LCLS II project:
  - designated ports
  - locking all fasteners
  - reliable active components (Phytron- electromechanical and PI piezo actuators)

- Tuner (V2) prototype built and will be tested (on cavity mock-up) in a month.

- FNAL’s Resonance Control is working on the all aspects of the SRF (650MHz) cavities frequency controls:
  - Developments and testing tuners
  - Passive resonance control aspects of CM design
  - Active resonance control (development of algorithms for RF-pulse and CW modes of operations)
  - Development (in collaboration with PI) new type of piezo-actuators for high dynamic rate operation.
LFD_{static} vs. Tuner Stiffness

Estimated cavity detuning by LF (static)

18.8 MV/m

16.9 MV/m