FNAL Tuners: LCLS-II to PIP-II

Yuriy Pischalnikov, FNAL

Second Topical Workshop on Microphonics,
LLRF Workshop Series.
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LCLS II 1.3GHz cavity Compact Tuner Design

- Slow/Coarse is double lever tuner (as at EuXFEL) with 1:20 ratio;
- Cavity tuned in “push” direction only /safety rod to protect cavity (vacuum test);
- Compact design (fit to the “short-short” cavity)... important for large Linac like ILC);
- Fast/fine tuner is 2 piezo-actuator installed between main lever and cavity flange, large stroke and small group delay
- Ceramic balls to interfaces between piezo and tuner/cavity (to minimize shearing forces;
- Strong arms (no flex like at on XFEL tuner ) connecting tuner to He Vessel→ increased stiffness; strong arms help to modify tuner on the cavity#1 (inside CM) to support GateValve– reduce microphonics
- Tuner design allow easy replacement (through designated CM port) of the electromechanical and piezo actuators

- Reliability of the tuner: design (set screws/lock-washers/lock-tight glue
- AND
- New reliable active components –
  - electromechanical actuator (Phytron LVA 52-LCLS II-UHVC-X1)
  - Piezo-electrical actuator (Physik Intrumente (PI) - PI-885.51)

Y. Pischalnikov, FNAL Tuner

Y. Pischalnikov et al., “Design and Test of Compact Tuner for Narrow Bandwidth SRF Cavities.” IPAC2015, Richmond, VA, USA.
Y. Pischalnikov et al., “LCLS II Tuner Assembly for the Prototype Cryomodule at FNAL.” NAPAC2016, Chicago, IL, USA.
LCLS II 1.3GHz cavity Compact Tuner Design

Y. Pischalnikov, FNAL Tuner
1.3GHz Slow/Coarse Tuner Parameters

- Slow tuner range >600kHz
- Small hysteresis (45Hz) and backlash 30(steps) for slow tuner
- Slow tuner sensitivity - 1.4Hz/step
- Tuner stiffness (est.) 25-30kN/mm

Slow tuner sensitivity for 96 tuner/cavity system installed on 12CM (tested cold)
### Fast Tuner Parameters

- Fast (piezo) tuner range is ~2.5kHz (at V=120V)
- Measured piezo resolution ~0.15Hz (limited by noise in HTS)
- Lowest mechanical resonances of the tuner/cavity system is 170Hz with major resonance at 235Hz
- Piezo tuner range will not changed with cavity tuned up to 600kHz

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

- Eight cavity transfer functions measured simultaneously at CMTS-1 on F1.3-09.

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**Detuning the cavities with fast/piezo tuner vs landing frequency off-set OR preload on the piezo-stack (~50% of blocking forces).**
Modification of the cavity #1 tuner to mitigate microphonics

Tuner Arms extension

Bellow

Y. Pischalnikov, FNAL Tuner
The LCLS II 3.9 GHz cavity is based on the design of the INFN slim blade tuner.

The tuner/He vessel was modified by FNAL to include two PI piezo-stacks for fast/fine tuning.

The Phytron electromechanical actuator was used.

The tuner operates by stretching the cavity only.

**Tuner Specs**

<table>
<thead>
<tr>
<th>Spec</th>
<th>Value 1</th>
<th>Unit 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse(slow) tuner range</td>
<td>750</td>
<td>kHz</td>
</tr>
<tr>
<td>Coarse(slow) tuner range</td>
<td>325</td>
<td>um</td>
</tr>
<tr>
<td>Fine(fast) tuner range</td>
<td>1</td>
<td>kHz</td>
</tr>
<tr>
<td>Fine(fast) tuner range</td>
<td>0.4</td>
<td>um</td>
</tr>
<tr>
<td>Halfbandwidth of the cavity</td>
<td>90</td>
<td>Hz</td>
</tr>
<tr>
<td>Peak detuning</td>
<td>30</td>
<td>Hz</td>
</tr>
<tr>
<td>Peak detuning</td>
<td>15</td>
<td>nm</td>
</tr>
</tbody>
</table>
### Slim Blade Tuner (with piezo) setting/operations specifics

First goal of the Tuner is to protect SRF cavity

9-cell 3.9GHz cavity (when its warm) has **150um** limit on compression/stretching... (non-elastic limit)

During several steps of assembly/operations non-constrained cavity could be stretched up 600um...(beyond limits) \(\rightarrow\) required restraints. (**SAFETY RODS**)

### Impact of various pressure conditions during anticipated steps of assembly and operation.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Insulated Vacuum, bar</th>
<th>He Vessel, bar</th>
<th>Cavity Beamline, bar</th>
<th>Forces, kN (constrained cavity)</th>
<th>Stroke, mm (non-constrained)</th>
<th>Safety rod gap, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity after dressing</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Cavity leak check at MP9 clean room</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>-0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>He Vessel leak check at MP9</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>-1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>He Vessel pressure test at MP9</td>
<td>1</td>
<td>3.3</td>
<td>1</td>
<td>3.45 (20um)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>He Vessel leak check in CM</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>-1.1 (50um)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>He Vessel pressure test in CM</td>
<td>1</td>
<td>3.3</td>
<td>0</td>
<td>0.6</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Start of cooling down CM or HTS</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>0.4</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Cold loss of vacuum accident</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

**Safety Rods**

Before tuner installation on the cavity protection done with 4 long safety rods during cavity testing/handling

• All leak check and pressure tests are safe with 4 rods installed
• Pressure test with tuner installed without safety rods is not recommended

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Y. Pischalnikov, FNAL Tuner
Slim Blade Tuner specifics

1. During HTS test of the dressed cavity Safety Gaps have been set to **300um**.
2. Before cool-down tuner has been compressed (by running stepper motor on 3 shaft turns) to keep safety gaps less than 150um during pressure test and cool-down.
3. After cool-down to 2K, tuner stretch cavity to bring to nominal frequency (3.9GHz)
4. Before warm-up tuner must be run to “zero position”... to avoid non-elastic detuning of the cavity when it warm...

These steps are necessary to 1) protect cavity & 2) avoid locking the piezos during cooldown ...

"tuner compressing the cavity through safety rod – piezos unloaded"

"normal operation of the tuner – tuner stretching the cavity through piezo "

Y.Pischalkov, FNAL Tuner
3.9GHz Blade Tuner performance (measured at HTS)

**Coarse/Slow Tuner**
- **Range**: 750kHz
- **Resolution**: 13Hz/step
- **Hysteresis**: ~500Hz
- **stepper back-lash**: 30 steps

**Fine/Fast Tuner**
- **Range (V=100V)**
  - both piezos: 13kHz
  - 1/2 piezo: 3kHz
  - specs: 1kHz

**Tuner Transfer Function**

(1) tuner/cavity system don’t have internal mechanical resonances below 150Hz
(2) major contributions to microphonics spectrum came from sources with frequencies below 150Hz.
(3) Additional internal magnetic shielding doesn’t cause strong mechanical resonances in the low (below 150Hz) frequency range.
PIP II Tuners
Spoke Cavities Tuner (SSR1&SSR2)


Lever Tuner
(1 : 6.5)
Flex joints (no bearings)
Two piezo-actuators on side
(1/2 forces & ½ stroke)

Cavity stiffness ~ 21kN/mm …
Cavity sensitivity ~500kHz/mm
Forces on the motor-actuator ~ 1200N

Main Specifications:
- Coarse Tuner Range > 135kHz
- Fine Tuning >1kHz
- Stiffness > 30kN/mm

In-house made encapsulation

Y.Pischalnikov, FNAL Tuner
Spoke Cavities Tuner / Tested with SSR1 cavities at STC (cold test results) 
(active resonance control results in Warren Schappert presentation)

“Performance of the Tuner mechanism for SSR1 Resonators During Fully Integrated Tests at Fermilab”. D. Passarelli et al., SRF2015, Canada

Slow Tuner range >140kHz  
Slow Tuner sensitivity ~4 Hz/step  
Tuner stiffness (estimated) ~20kN/mm  
Slow Tuner hysteresis 500-1000Hz

Fine tuner range ~1.2kHz (120V)
### 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 (316LN 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 $\Delta F_{peak} = 20Hz$ (or $\sigma = 3.5Hz$) 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>beta</th>
<th>0.92</th>
<th>0.61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity stiffness, (N/um)</td>
<td>3-4</td>
<td>3-4</td>
</tr>
<tr>
<td>cavity tuning sensitivity, [Hz/um]</td>
<td>160</td>
<td>240</td>
</tr>
<tr>
<td>bandwidth ($F_{1/2}$), [Hz]</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Lorentz Force Detuning coefficient, [Hz/MV/m]$^2$</td>
<td>0.8-1.0</td>
<td>1.4-1.8</td>
</tr>
<tr>
<td>Cavity sensitivity to pressure, dF/dp [Hz/mbar]</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Tuner stiffness [N/um]</td>
<td>&gt;40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>required coarse tuning range, [kHz]</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>coarse tuner resolution, [Hz/step]</td>
<td>1-2</td>
<td>1-2</td>
</tr>
<tr>
<td>fine tuner range, [Hz]</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>fine tuner range, [um] at T=20K (20% from RT)</td>
<td>7.5</td>
<td>5</td>
</tr>
<tr>
<td>fine tuner range, [um] at T=300K</td>
<td>37.5</td>
<td>25</td>
</tr>
<tr>
<td>cavity resonance control reqs (peak), [Hz]</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>fine(piezo) tuner resolution, [Hz]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>max. forces on the tuner system, kN</td>
<td>4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**compact; cost effective; reliable; high stiffness (minimize LFD)**
For 650MHz tuner we copied 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)

Reqs for high tuner stiffness led to large size/cross-section arms. Piezo-actuator installed inside main tuner arms (top & bottom). Piezo-actuator is replaceable through port.
Tuner stiffens optimization (minimization of LFD)

ANSYS Simulation of the stiffens for Tuner-Dressed Cavity system

Stiffness of the Tuner frame $K_{\text{tuner frame}} \approx 140\text{kN/mm}$

Stiffness of the overall system $K \approx 45\text{kN/mm}$ *(limited by “piezo” & cavity/tuner interface)*

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

Lorentz Force Detuning (static)

values of expected (with 40kN/m)

<table>
<thead>
<tr>
<th>Pulsed SRF accelerators, existing and projects</th>
<th>Cavities Half-bandwidth, Hz</th>
<th>LFD, Hz</th>
<th>LFD/HBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNS (LB/HB)</td>
<td>550/500</td>
<td>300/100</td>
<td>0.55/02</td>
</tr>
<tr>
<td>ESS (HB)</td>
<td>500</td>
<td>400</td>
<td>0.8</td>
</tr>
<tr>
<td>FLASH/XFEL</td>
<td>185/141</td>
<td>550</td>
<td>3/4</td>
</tr>
<tr>
<td>PIP II (LB/HB)</td>
<td>29/29</td>
<td>300/500</td>
<td>10/17</td>
</tr>
</tbody>
</table>

Y. Pischalnikov, FNAL Tuner
The 650MHz tuner characteristics measured when assembled on the test-stand (cavity mock-up)

Stiffness ~ 45kN/mm
Range > 1mm (200kHz)
Resolution 5nm/step (1Hz/step)

Piezo stroke
(T=300K & 120V) - 32um
(T=20K & 120V) - 6.5um (1,3kHz)

Tuner worked against Spring with $K_s=5kN/mm$ (mock-up of 650 cavity)
Tuners reliability & maintainability (for LCLS II and PIP II Projects)

• 1. Design elements to prevent any loosening of the tuner’s screws/nuts during transportation and 20+ years of the SRF Linac operation

• 2. Tuner access port & tuner design characteristics that allowed to replace active components without tuner dis-assembly

• 3. Employ highly reliable active components/actuators that developed by specialized companies to operate into insulate vacuum environment at cryogenic temperature.
Tuner Reliability
Lifetime and rad. hardness
of the active components
(electromechanical actuators & piezo-actuators)
Joint efforts of FNAL and Phytron (during ILC R&D program) → used by LCLS II now by PIP II

FERMI CAVITY TUNER
ACTUATOR BY PHYTRON

- Stepper motor with 200 steps/rev (1.8°), with integrated gear (30:1) => 10,000 full steps/rev
- Integrated planetary gear, ratio 50:1, dry lubricated, backlash (5% arc-min)
- Spindle and nut system with M12x1.25
- 2 different spindle material combinations for the prototypes: non-magnetic, stainless steel
- Efficiency will be verified during prototype lifetime test at FERMI
- Material for housing, flanges and internal parts: stainless steel
- Low friction leakage rotor

- Actuator capacity: 1,200N axial push force and 200N pull force
- Rated for vacuum and -270°C to +460°C
- Phytron will perform a functional test at -270°C in liquid nitrogen only
- Designed for 16 Million full steps during lifetime. Lifetime test will be performed at FERMI at system level
- Designed for only a few steps per day, rest of time current off. 80 spindle rotations per year.
- Max. speed: 400rpm full step at motor shaft
- Max. winding temperature: 150°C
- Middle copper plate for cooling
- Laser marking with manufacturer, article and serial number at rear flange
- Assembling in clean production area (CPA)
- BOL (begin of life) inspection before delivery
- EOL (end of life) inspection with returned motors from FERMI after lifetime test

- 42V, nominal current 1.2A
- 4 leads parallel connection, Kapton, length 500mm, AWG 22
- 2 leads thermocouple in the motor windings, leads 500mm long
- EMC cable shielding, 450mm long
- Special EMC cable gland, lead exit axial, see ICD

Phytron, Inc. 800 East Park Rd., Ste. 120, Williston, VT 05495
Tel. 802.872.1600 Fax 802.872.0811 E-mail: info@phytron.com Visit www.phytron.com

Y. Pischalnikov, FNAL Tuner
### Electromechanical Actuator

#### Accelerated Lifetime Test – 5 Lifetime of the LINAC !!!!!

<table>
<thead>
<tr>
<th>Picture</th>
<th>Name</th>
<th>Meter</th>
<th>Gear Box</th>
<th>Spindle/Nut</th>
<th>Forces</th>
<th>Longevity tested</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="LCLS II" /></td>
<td>LCLS II</td>
<td>Phytron 1.2A</td>
<td>planetary gear (ratio: 1.50)</td>
<td>Titanium &amp; SS M12x1</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>

- **N. Huque, E. Daly, Y. Pischalnikov**
- *Results of ALT of LCLS II tuner motor, SRF2017*

### Planetary gear vs Harmonics drive

- **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**

- **Operation for 9 lifetimes**

- **Threads of the TECASINT inserts Before & after**

- **Molibden disulfate MoS2 - lubricant**

### Picture of the damaged Harmonic Drive gear from SNS

- During life of the linac 24 failure on 80 tuner

### Actuator operate inside cryogenic/insulated vacuum

- **Lubrication !!!!**

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Piezo-tuner reliability/lifetime R&D program
(at FNAL as a part of LCLS II tuner design efforts)

Factors that can affect piezo-tuner lifetime:

• Environment (warm vs. cold)
  - *(pros)* - temperature, humidity, and voltage
  - *(cons)* - transfer of the heat dissipated inside piezo stack --- overheating piezo-ceramics at insulated vacuum environment

• Shear forces on the piezo-ceramic stack (design of the encapsulation/fixture → “in-house design” vs “industrial/experts design”);

• Current Transients/ slew rate of the stimulus pulse (large acceleration applied to piezo-stack → cracks → HV breakdown)
  *design of the piezo-amplifiers with limited slew rate;*

• *Radiation Damage.*
Physik Instrumente P-844K075 encapsulated piezo-actuator

Example of the installation of the piezo-ceramic stack into fast tuner (Blade Tuner at S1Global) that failed after operation just for couple hours.

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
... 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

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 2800 kg

Y.Pischalnikov, FNAL Tuner
Operation of the piezo-actuator at cryogenic temperature and in vacuum.

…..cold vacuum is an almost ideal environment for piezo actuators…

except the problems to heat transfer from piezo inside insulated vacuum

Piezomechaniks $\Delta T\sim 70$Degree

Fermilab Cold/Insulated vacuum Piezo Test stand
Requirements to the piezo for operation in XFEL/ PIP II and LCLS II

Impact on the longevity of the piezo

<table>
<thead>
<tr>
<th>Requirements to the piezo for operation in XFEL/ PIP II and LCLS II</th>
<th>XFEL/PIP II</th>
<th>LCLS II</th>
<th>FNAL-test-stand (2month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>10/20 pulses/sec</td>
<td>CW</td>
<td>CW</td>
</tr>
<tr>
<td>stimulus pulse, Hz</td>
<td>200 (2 sinewave per pulse)</td>
<td>40</td>
<td>5000</td>
</tr>
<tr>
<td>Vpp, V</td>
<td>120</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>piezo stroke,[um]</td>
<td>5</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>number pulses for 20 years</td>
<td>1E+10</td>
<td>2E+10</td>
<td>2E+10</td>
</tr>
<tr>
<td>total stroke of piezo for 20years, [km]</td>
<td>60/120</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Piezo-stack motion speed (rms) (mm/s)</td>
<td>4.5</td>
<td>0.02</td>
<td>2.2</td>
</tr>
<tr>
<td>Piezo-stack motion acceleration (rms)(g)</td>
<td>0.6</td>
<td>0.0004</td>
<td>7</td>
</tr>
<tr>
<td>Heat dissipation, [mW]</td>
<td>90/200</td>
<td>0.05</td>
<td>6</td>
</tr>
<tr>
<td>Piezo ΔT raised</td>
<td>20K/ ~40K</td>
<td>0.1K</td>
<td>2K</td>
</tr>
</tbody>
</table>

Operational voltage for PIP II piezo *(when operated at RF-pulse mode)* will be 60 times higher that for LCLS II. Power dissipation inside piezo-ceramic actuator for PIP II is 4000 large than for LCLS II. Overheating of PIEZO could be a serious problem.
Reliability of Piezo actuators

Summary of ALT (accelerated lifetime tests) and Rad-hardness study.

Accelerated piezo-stack lifetime test
\(2\times10^{10} \text{ pulses} \quad (V_{pp}=2V \& F=40Hz)\)

20 years → 2 month (40Hz→5kHz)

- LCLS II/PIP II - \(P_{av}\sim50\mu W (40Hz, 2V)\)
- ALT - \(P_{av}\sim6mW (5kHz, 2V)\)

PIP II
(RF-pulse mode)- Pav~200-500mV

Several Piezo successfully tested (ALT) for 20 years of LCLS II operation. Warming up piezo for LCLS II (PIP II-CW) operation less than \(\Delta T=1K\).

At the same time for pulse operation like XFEL (or PIP II) piezo will warm up to \(\Delta T=20K-60K\) that can decrease life time of piezo drastically.

Y. Pischalnikov, FNAL Tuner
Physik Instrumente/FNAL development of the newest “high dynamic rate” (HDR) piezo-actuators

Collaboration already have a proven actuator concept which is now being improved by better heat conductive materials between "hot" PZT-ceramic surface und casing. In addition there will be an optional mechanical interface to fix external Copper thermal straps. Copper thermal straps could be anchor to 5K or 40K or 77K. That will control temperature of the PZT (instead of floating temperature).

We are expecting that new HDR piezo-actuator will be good match to the serve new LINACs (like PIP II, ILC, MARIA, etc)
Irradiation of the Phytron actuator and PI Piezo-stacks up to $10^9$ Rad (gamma)

Radiation Hardness tests of the Electromechanical Actuator (up to $5 \times 10^8$ Rad)

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

Stroke vs Voltage
Before and After $5 \times 10^8$ Rad

Sample A ($5 \times 10^8$ Rad) Sample C (0 Rad)

Discoloration of the thing layer of Epoxy

There was no any degradation in the electromechanical actuator components:
Windings of the stepper motor
Limit switches
Traveling nut

Y. Pischalnikov, FNAL Tuner
Summary

• FNAL is working on development SRF tuners for LCLS II and PIP II.
• Our objectives were to develop low cost, easy to assemble, easy to maintain, reliable tuners.
• In addition to robust mechanical design we concentrated on the selection of the reliable active components: electromechanical and piezo actuators.
• Instead of “in-house” assembly of the actuators from components we collaborate with industrial partners: Phytron and Physik Instrumente.
• Our vision was& is to formulate industrial partners technical specs/ work together with expert to develop prototypes and use unique FNAL’s facility to test prototypes.. make necessary changes and develop products that will be provide benefit for whole community that are working in accelerator technology field