SRF Cavity Tuner for LCLS-II (*Preliminary)*

For FNAL team
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(Presented by N.Solyak)

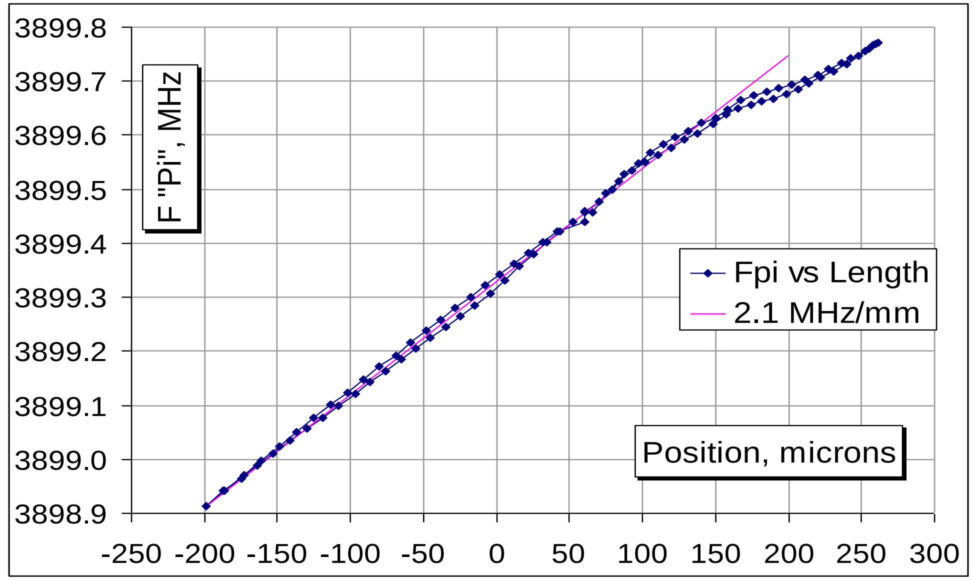
TTC meeting, DESY, March 23-27, 2014

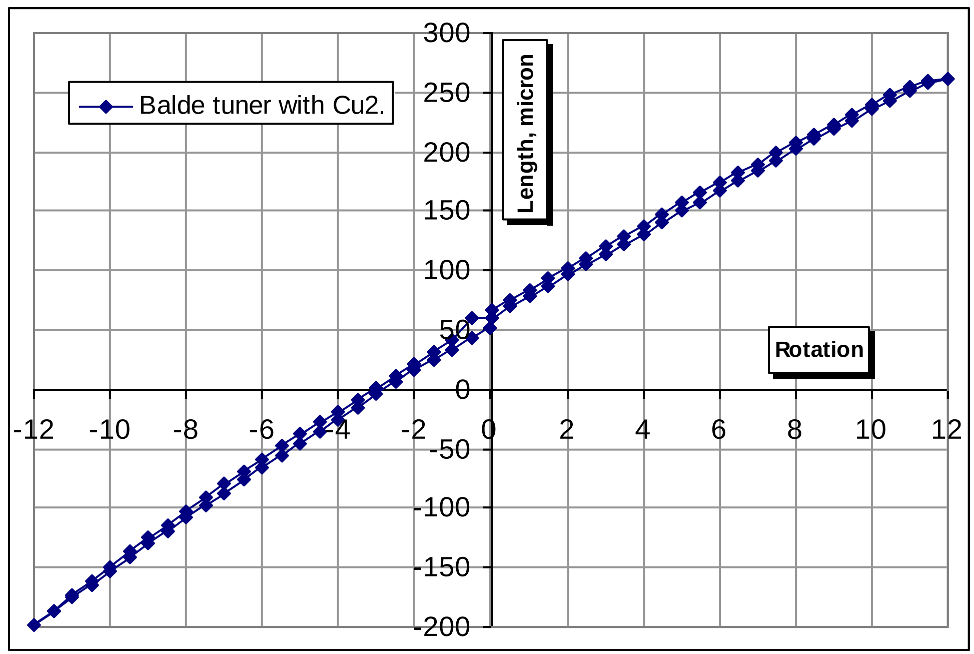
- **“Thermocycle related” tuning cycle:**
  - To bring cavity to/from resonance after/before cryomodule cool down;
  - To de-tune cavity from resonance (cavity failure; etc..);
  - To protect cavity from excessive detuning during cool-down (example of CM2/slim blade tuner);
- **“Operation cycle” – to keep cavity on resonance during operation:**
  - To compensate static LFD during powering up cavity;
  - To compensate dynamic Lorentz Force Detuning & cavity pre-detuning;
  - To compensate microphonics;

Fermilab experience in Tuner design/operation

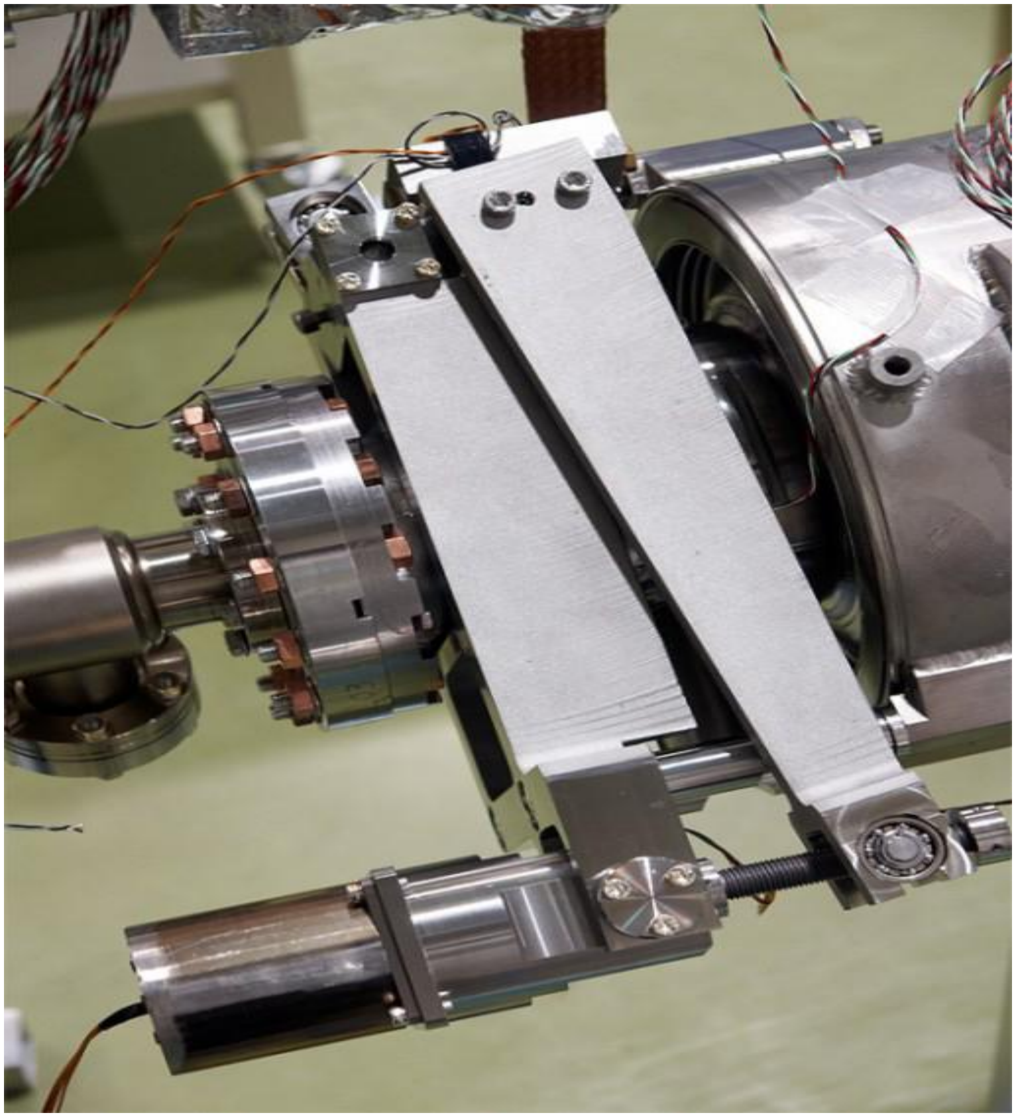
- 3.9 GHz Blade tuner (slow only, no piezo)
- Saclay tuner (CM#1)
- Blade-tuner (CM#2)
- New designs:
  - 325 MHz Single-Spoke cavity tuner
  - 650 MHz cavity Laver Tuner
  - 1.3 GHz LCLS-II cavity Laver tuner

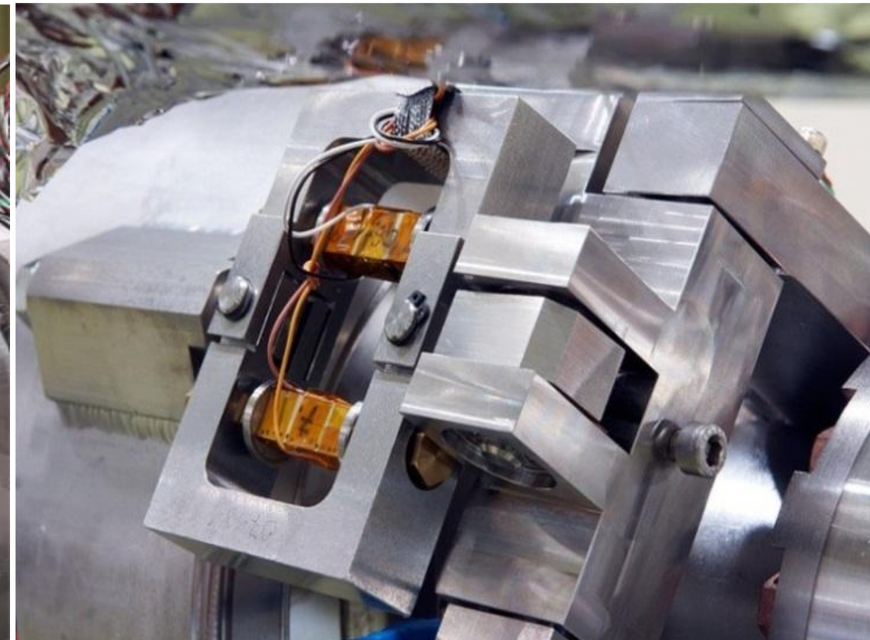
Blade tuner with 9 cell Cu2 cavity assembly.





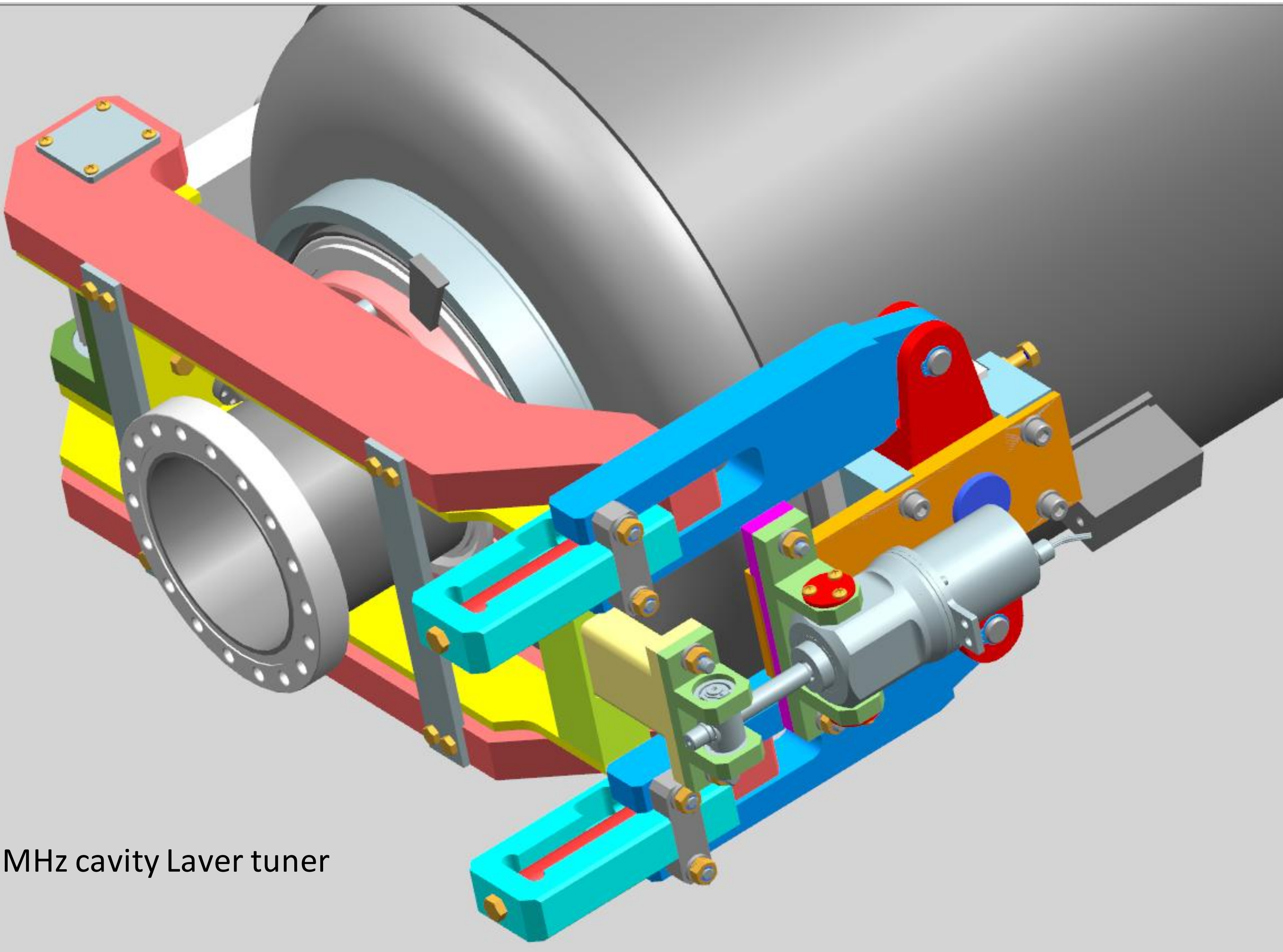
Saclay Lever Tuner





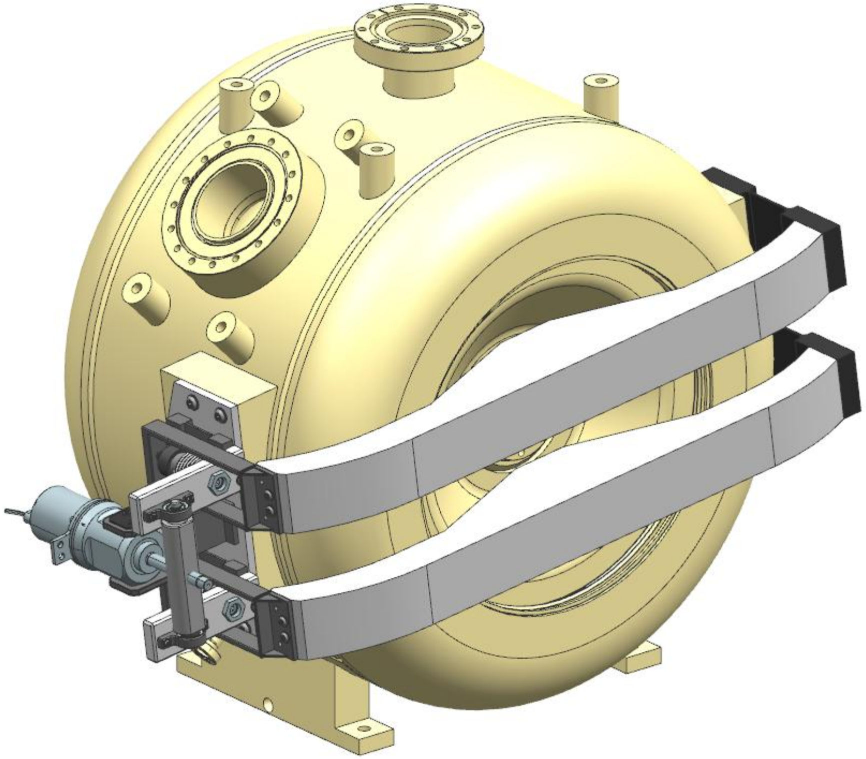
- Compound lever mechanism acting at one end of the cavity
- Saclay design
  - Further development at DESY
- In current use at TTF

Blade-Tuner



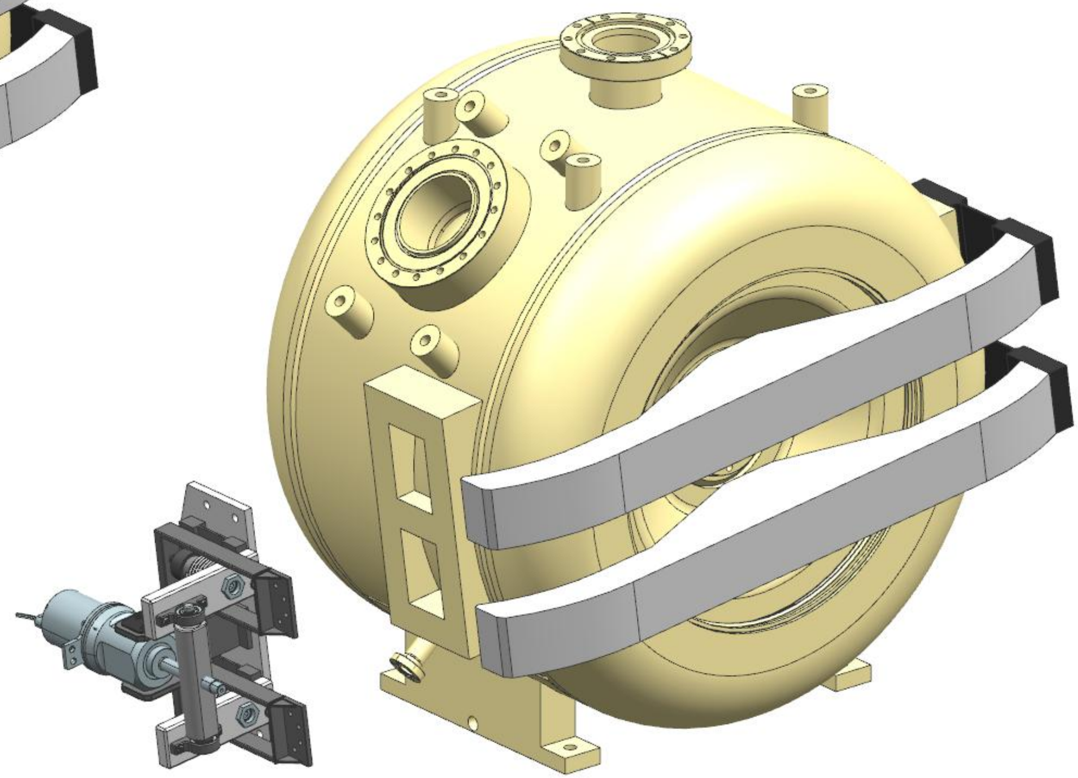
650 MHz cavity Laver tuner

Removable actuation system



SSR1, 325 MHz cavity

Removable from the port on the Cryomodule



LSLC II &ILCTA & Projet X Cavity Tuner Performance specifications.

Parameter	Value		
	ILCTA	LCLS II	650MHz
Cavity Frequency	**1.3GHz**	**1.3GHz**	**650MHz**
Cavity bandwidth	200Hz	30Hz	20Hz
Cavity elongation tuning	300Hz/µm	300Hz/µm	200Hz/µm
Cavity Spring constant	3N/µm	3N/µm	19N/µm
"Thermocycle related" cavity frequency range	500kHz	250kHz	200kHz
"Thermocycle related" tuner dimensional range	1650µm	825µm	1000µm
"Thermocycle related" tuning resolution	20Hz	20Hz	2Hz
"Thermocycle related" tuning speed	60Hz/sec	60Hz/sec	60Hz/sec
"Operational cycle" cavity frequency range	3kHz	**1kHz**	2kHz
"Operational cycle" tuning resolution	1Hz	1Hz	0.2Hz
"Operational cycle" response bandwidth	5kHz	5kHz	1kHz
Minimum tuner spring constant	30N/µm	30N/µm	200N/µm
Minimum tuner mechanical resonance	5kHz	5kHz	1kHz
Lifetime of machine	10(20?)years	10(20?)years	40years
expected number of thermocycle per year	2	2	
operational cycles per year	3*10e8	3*10e8	
mean time between failures	20(?)year	20(?)year	
mean time between repairs	3(?) year	3(?) year	
mean time for repairs	1month	1month	

LCLS II (1.3GHz) cavity Tuner Performance specifications.

Parameter	Value
Cavity Frequency	1.3GHz
Cavity bandwidth	30Hz
Cavity elongation tuning	300Hz/μm
Cavity Spring constant	3N/μm
Cavity Force Tuning	*100Hz/N*
Slow Tuner cavity frequency range	250kHz
Slow Tuner dimensional range	825μm
Slow/coarse tuning resolution	20Hz
Fast Tuner response bandwidth	5kHz
Fast Tuner cavity frequency range	**1kHz**
Fast Tuner dimensional range	3.5μm
Fast Tuner tuning resolution	1Hz
Min/Max piezo preload force /per mm^2 of piezo cross-section	5N / 25N
Maximum piezo voltage	120V
Minimum tuner spring constant	30N/μm
Minimum tuner mechanical resonance	5kHz
Tuner operating condition	insulated vacuum; T=20-60K
Slow/coarse Tuner lifetime range (20years)	**1000 spindle rotations**
Fast/fine Tuner lifetime range	5*10e9 pulses (with A=50% max V)

2 piezo in parallel:
1st - working - 2nd - spare

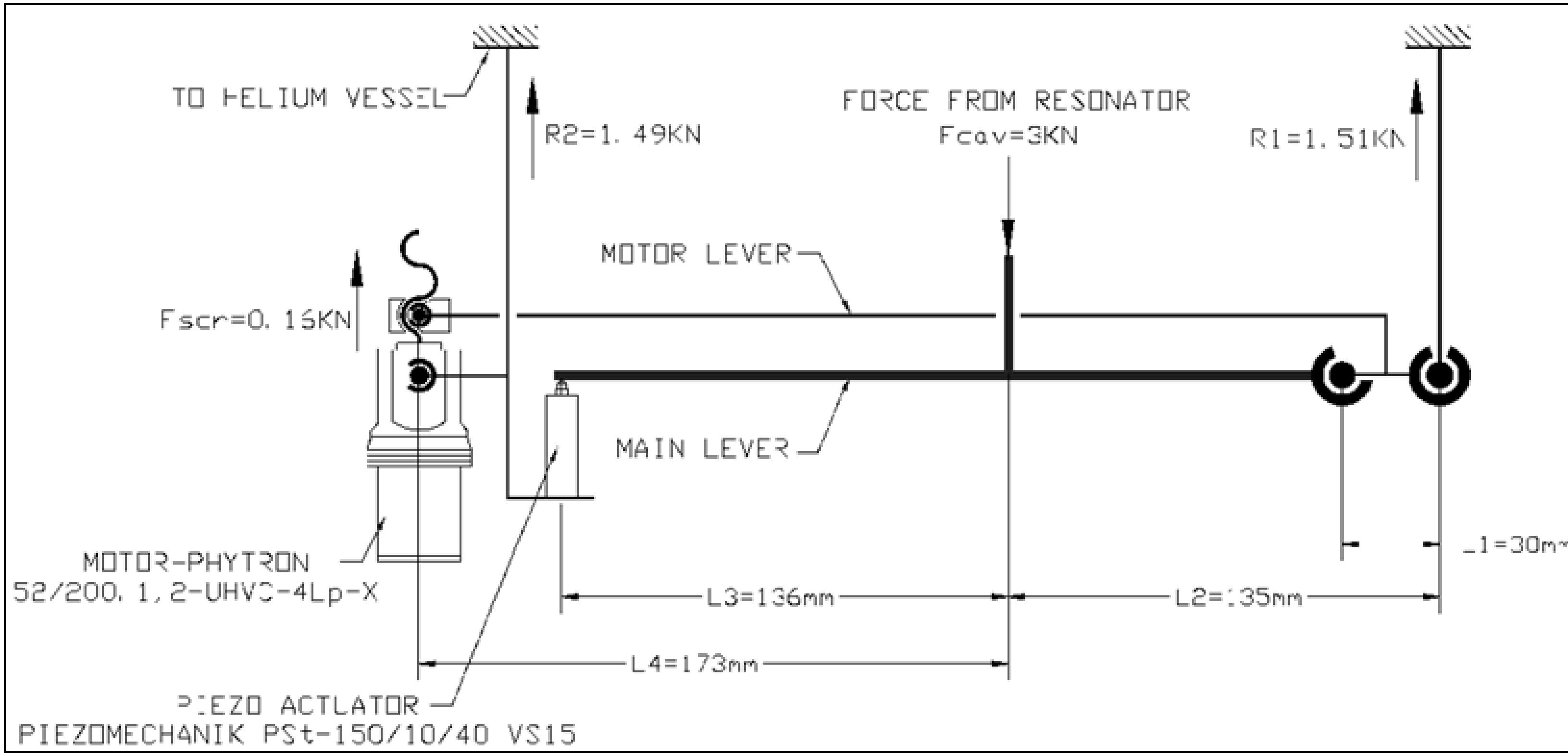
Size 10*10*36mm (P-888.91)
Stroke (38um/7-8um)

Blocking forces 3800N

C=13/3uF

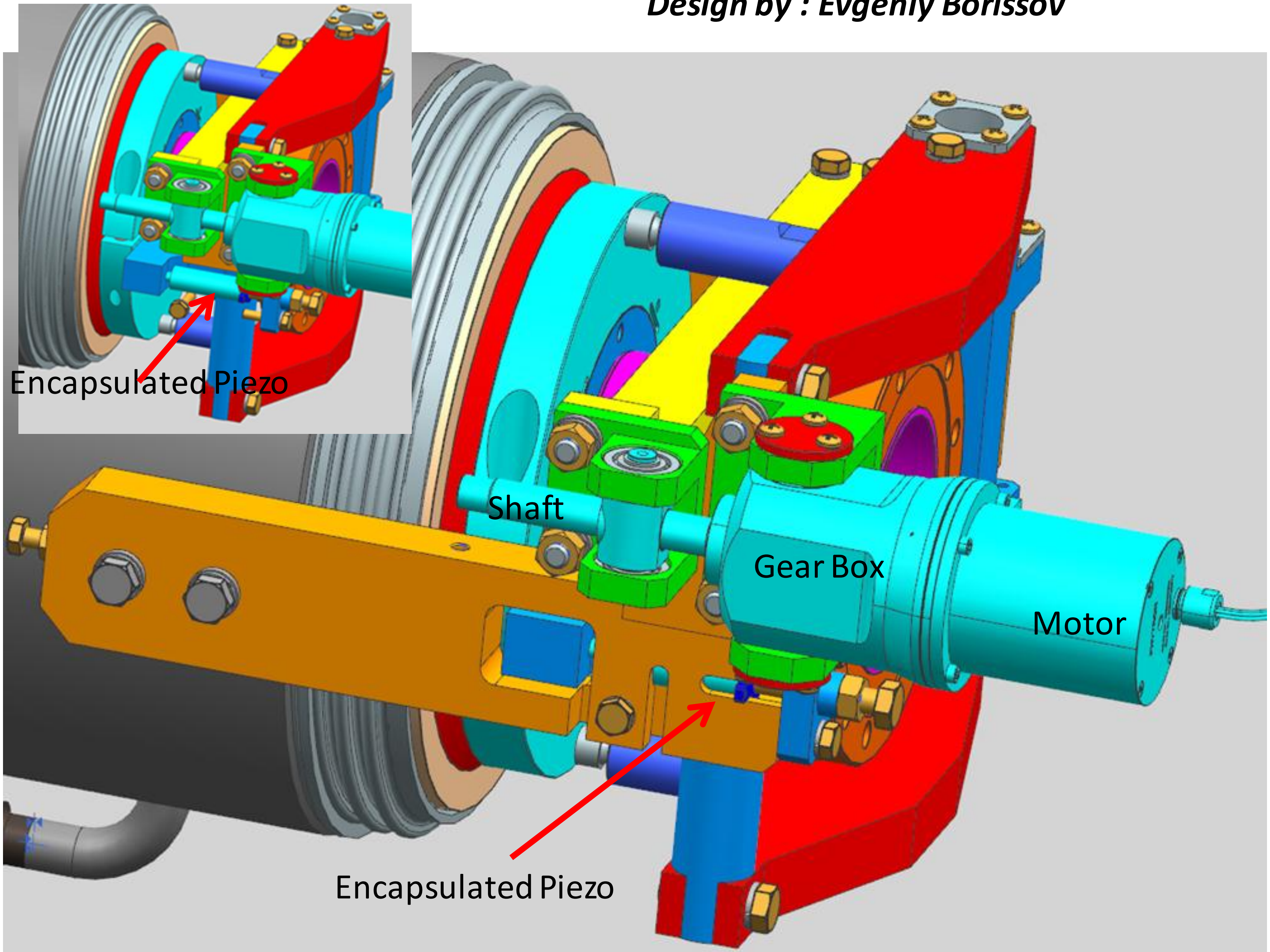
Tuner schematic

Basic schematic adopted from SACLAY-I(DESY) tuner
Electromechanical Actuator (motor) and Piezo from the one side
(to satisfy requirements : to replace motor/piezo throu acsess port)

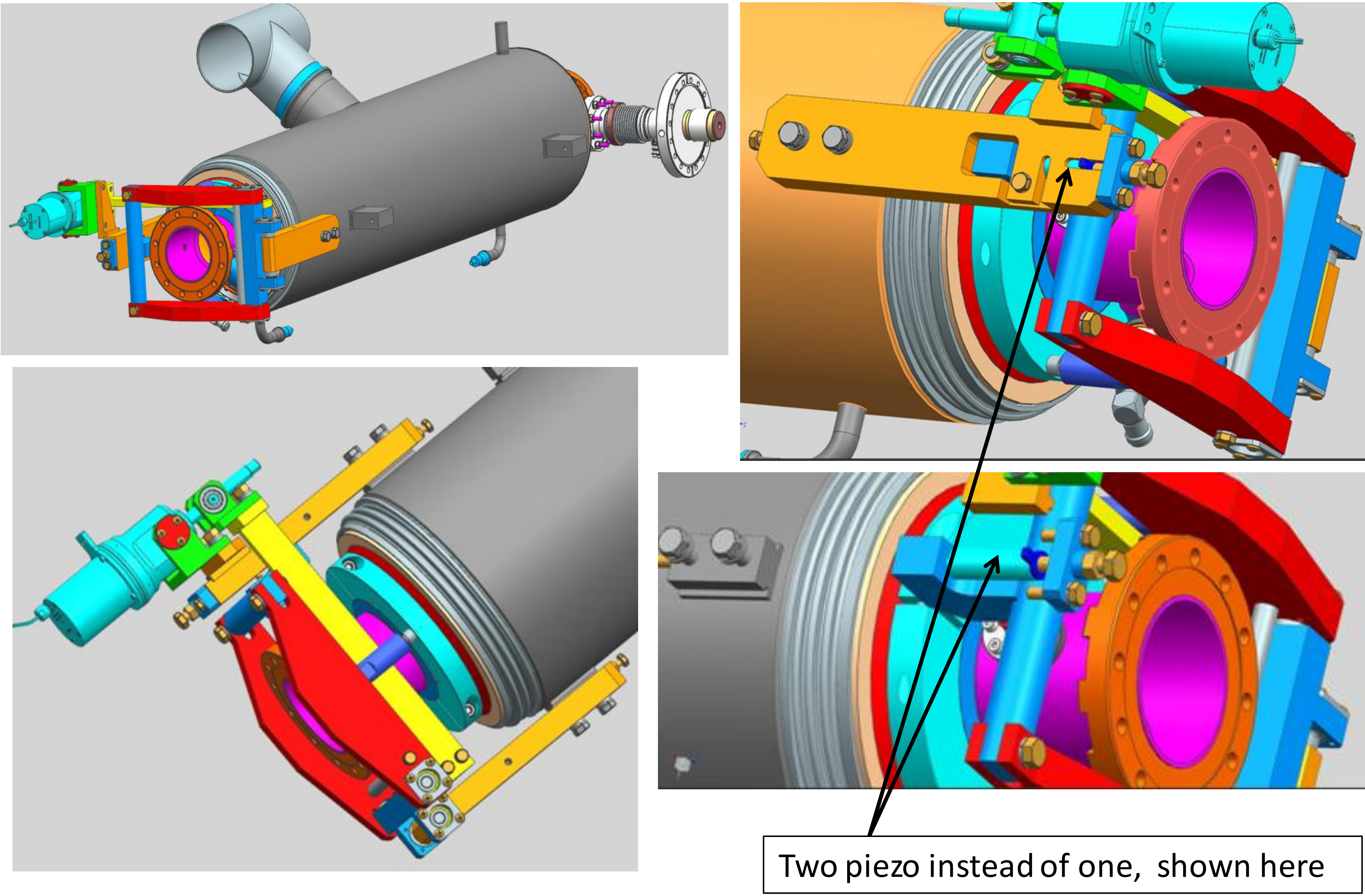


Tuner ratio: 1/20
For 1mm cavity tune (300KHz) forces on Moor shaft - 150N and load on piezo 1500N
Piezo stroke efficiency ~50%

Design by : Evgeniy Borissov



At this drawing is ONE piezo... To increase reliability TWO piezo: In parallel? In serious?

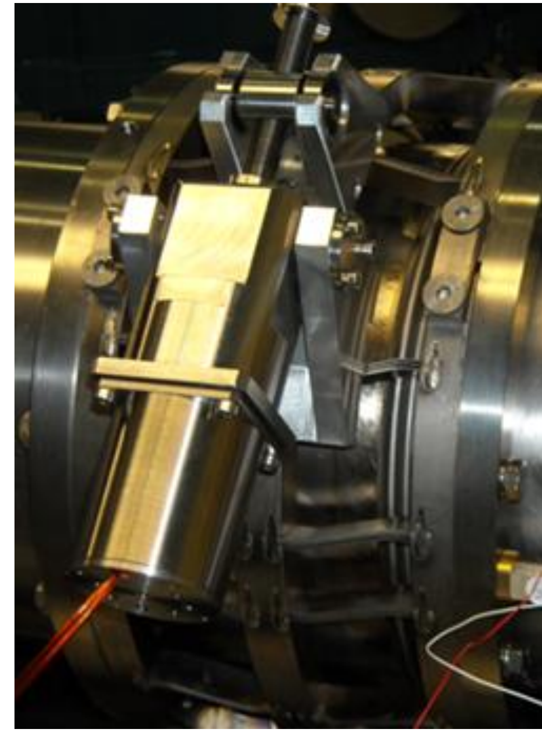

Two piezo instead of one, shown here

Tuner Reliability

Lessons Learned (CM2 at FNAL; S1Global; SNS; FLASH)

Electromechanical Actuator:

- Stepper Motor
- Reduction Gearbox
- Rotational-to-Linear Conversion (Shaft&Nut)

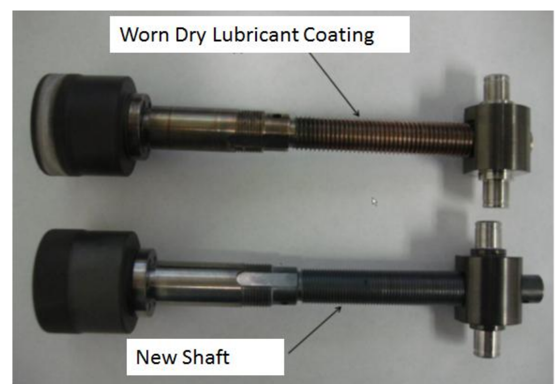


Cold vacuum is difficult environment for electromechanical systems. Every component is a potential point of failure, piezo, stepper, gearbox, linkage…

Multiple Failure of harmonics drive and Shaft at SNS, CM2, S1G

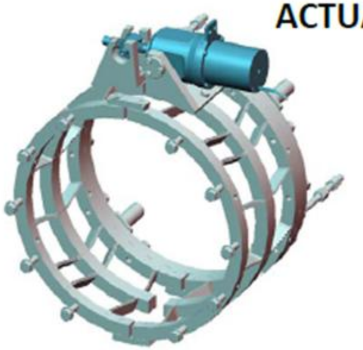
Failure after ~31Msteps (HTS)

harmonic drive gear stripped and the wave generator got stuck in the spline gear



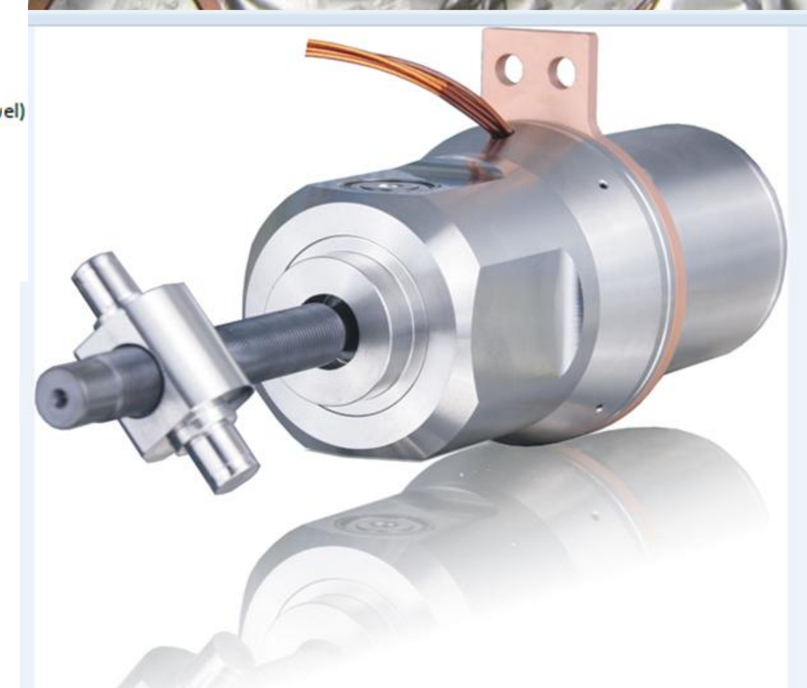
Joint efforts of FNAL and Phytron

FERMI CAVITY TUNER
ACTUATOR BY PHYTRON



- stepper motor with 200 steps/rev. (1.8°), with integrated gear (50:1) ==> 10,000 full steps/rev
- integrated planetary gear, ratio 50:1, dry lubricated, backlash (35 arc-min)
- spindle and nut system with M12x1mm
- 2 different spindle material combinations for the prototypes. non magnetic,
- efficiency will be verified during prototype lifetime test at FERMI
- material for housing, flanges and internal parts stainless steel
- Low flux leakage rotor
  - Actuator capacity: 1,300N axial push force and 200N pull force
  - Rated for vacuum and -270°C to +40°C
  - Phytron will perform a functional test at -196°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 400Hz full step. At motor shaft
  - max. winding temperature 130°C
  - Middle copper plate for cooling
    - 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. 600 Blair Park Rd., Ste. 220, Williston, VT 05495
Tel.: 802.872.1600 Fax: 802.872.0311 E-mail: info@phytron.com Web: www.phytron.com



Summary of the Life Time Test of Phytron actuator at HTS

5 Lifetimes of LCLS II

- Worked without any signs of degradations in the range of the forces **+/-1500N** for
- **<u>50Msteps</u>**
- **<u>(5000spindle rotations)</u>** I_{motor}= 0.7A
- (1.2A-nominal)

Lifetime requirements for motor/actuator FERMI-1.

Large scale SRF cavity tuning range – it will be done 4 times in year.

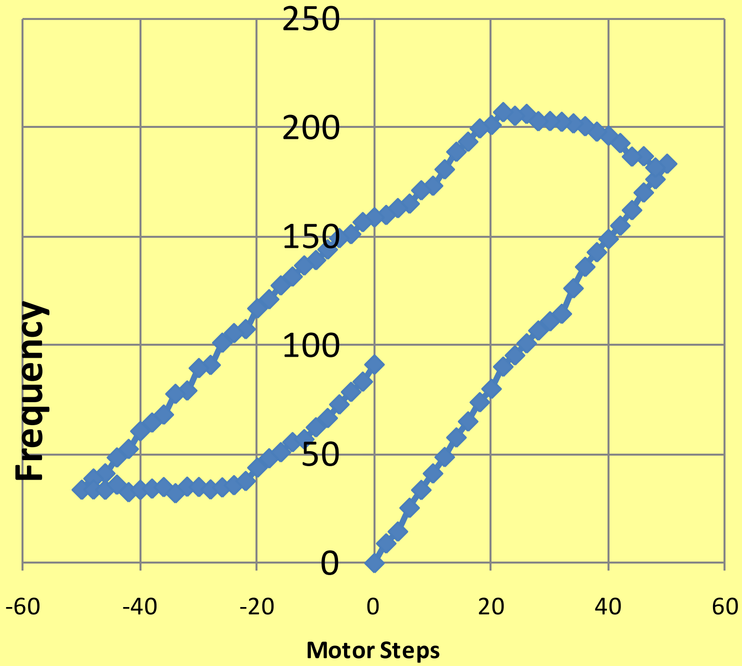
Max. Cavity Tuning range (kHz)	600kHz
Cavity sensitivity (Hz/um)	300Hz/um
Max. Cavity elongation/ stroke (mm) --(600kHz/300Hz/um)	2mm
Max. Linear stroke on shaft (mm) -- assume tuner advantage 1:10	20mm
Spindle/Shaft rotations per max. cavity tuning (M12*1)	20
Amount of max. tuning per year	4
Amount of shaft rotations per year	80
Lifetime of the system (years)	20
Spindle/Shaft rotations during lifetime of system	1600
Lifetime of system in Msteps of motor (200step/turn & 1:50 gear)	16Msteps

Small scale SRF cavity tuning range – it will be done 1 times/day

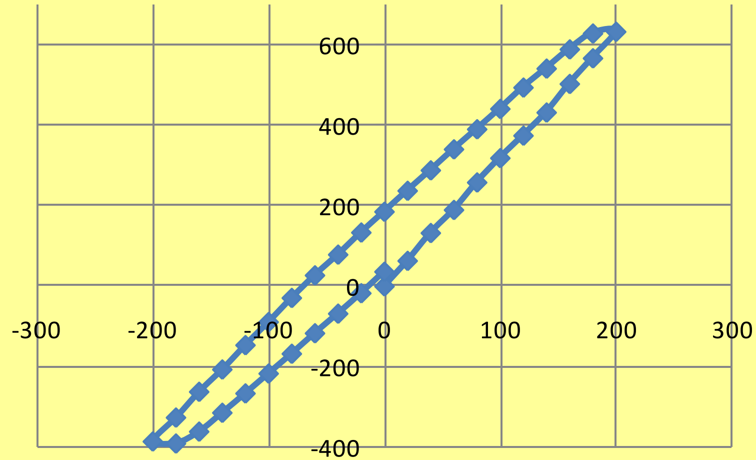
Small Cavity Tuning range (kHz)	1kHz
Cavity sensitivity (Hz/um)	300Hz/um
Small Cavity elongation/ stroke (um) --(1kHz/300Hz/um)	3um
Small Linear stroke on shaft (um) -- assume tuner advantage 1:10	30um
Spindle/Shaft rotations per small cavity tuning (M12*1)	0.03
Amount of small tuning per year	300
Amount of shaft rotations per year (to accomplish small tuning)	9
Lifetime of the system (years)	20
Spindle/Shaft rotations during lifetime of system	180
Lifetime of system in Msteps of motor (200step/turn & 1:50 gear)	1.8Msteps

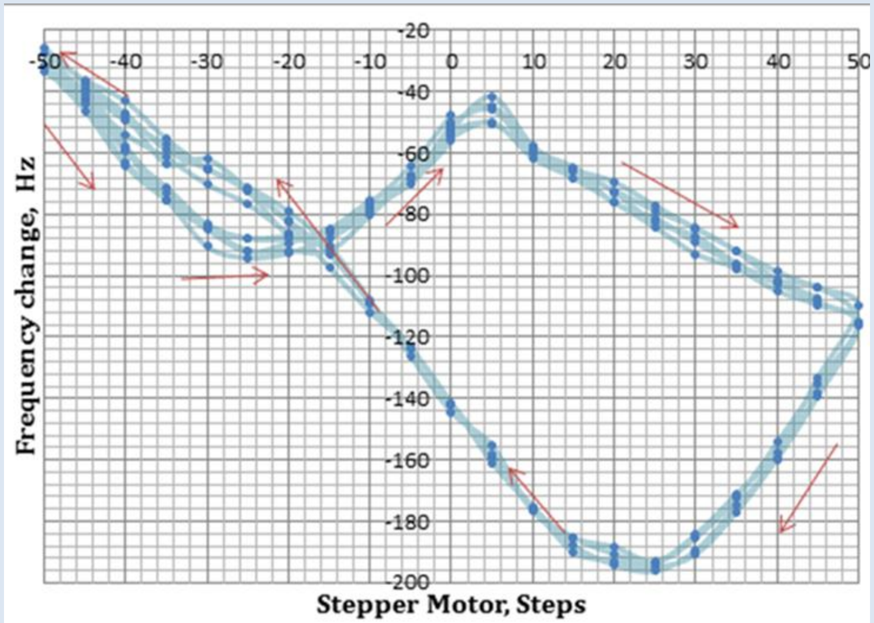
Slow (coarse) Tuner Hysteresis

FNAL's CM2 Blade Tuner (tested at HTS)



Planetary Gear Box 1:50





Harmonics Drive Gear Box with 1:100

Fast (piezo) Tuner Reliability

- NOLIAC
- PiezoMechaniks
- **PI Ceramics --- Best choice**

DC- and AC-signal Reliability

Humidity&Temperature are strong factor limiting lifetime under **DC-operation** (PI-ceramic patented ceramic coating)

Humidity 80% → 0%
Lifetime increase 100 times
Temperature 100C → 0C
Lifetime increase 1000t imes

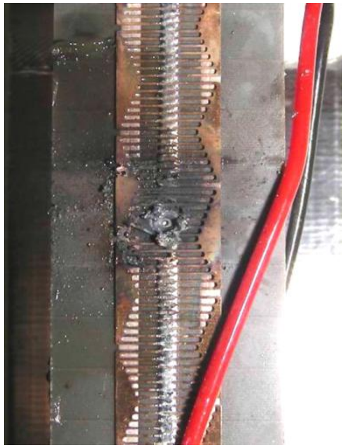
AC-tests

At Room temperature:

a) 0-120V unipolar sinewave (1kHz) – 10^{10}cycles
b) 0-150V unipolar rect.(80us slew rate) &150^{o}C to $5*10^9$ cycles
c) 20Vpp bipolar sine wave, 100kHz, to $1*10^{12}$cycles
d) A.Bossotti at el. (XFEL-program) cryo-condition T= 79K bipolar signal 500Hz Vpp=140V --$3.3*10^9$cycles

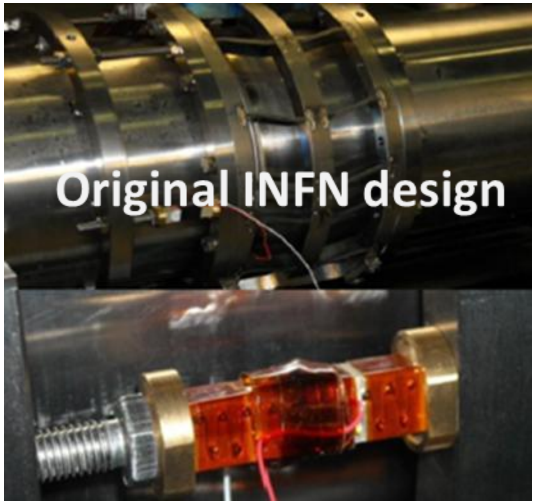
Destructive test (400Hz, rectangular Waveform+/-70 V)

Overheating (120K) and as result failure after 2 second

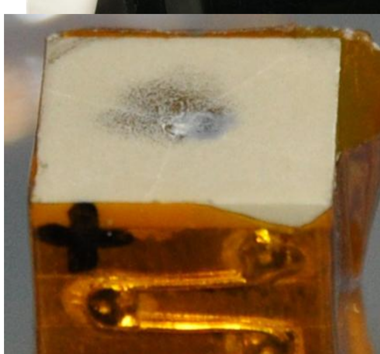


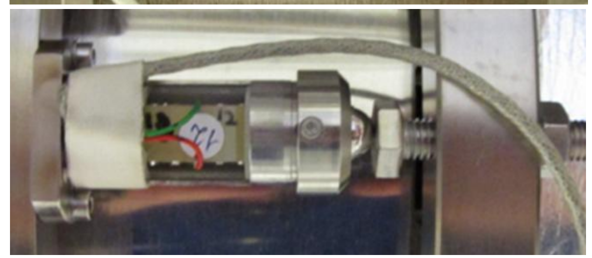
Piezo Tuner Reliability

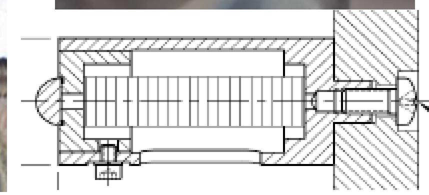
Encapsulation to protect from shearing forces



1) Shearing Forces applied to piezostack







Summary

- FNAL is working to finalize design of Tuner for LCLS II (as a basis used SACLAY I design)
  - *Special attention paid to reliability of electromechanical actuator and piezo tuner*
  - *Cost effective design/selection of the components*
    - *Negotiation with PI Ceramic; Noliac; PiezoMechanics*
    - *Negotiation with Phytron*
    - *Communication with DESY – exploring XFEL solutions*

- Components reliability testing program start at FNAL
  - Piezo Reliability at cold environment
  - Stepper motor/gear/spindle tests at cold-insulated vacuum environment

- Tuner prototype testing program
- Tuner QA program