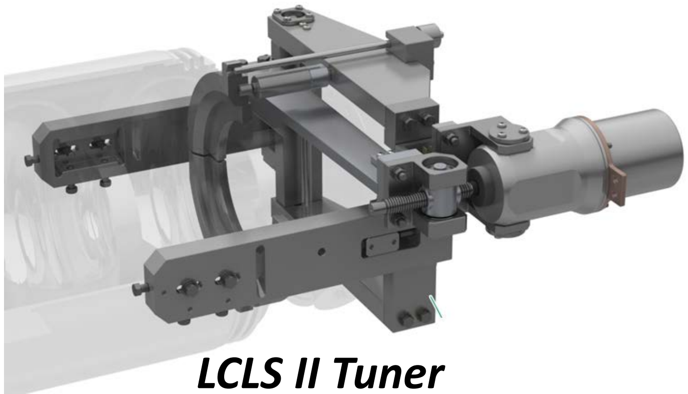
SRF Cavity Tuner. Tuner Reliability R&D program at FNAL

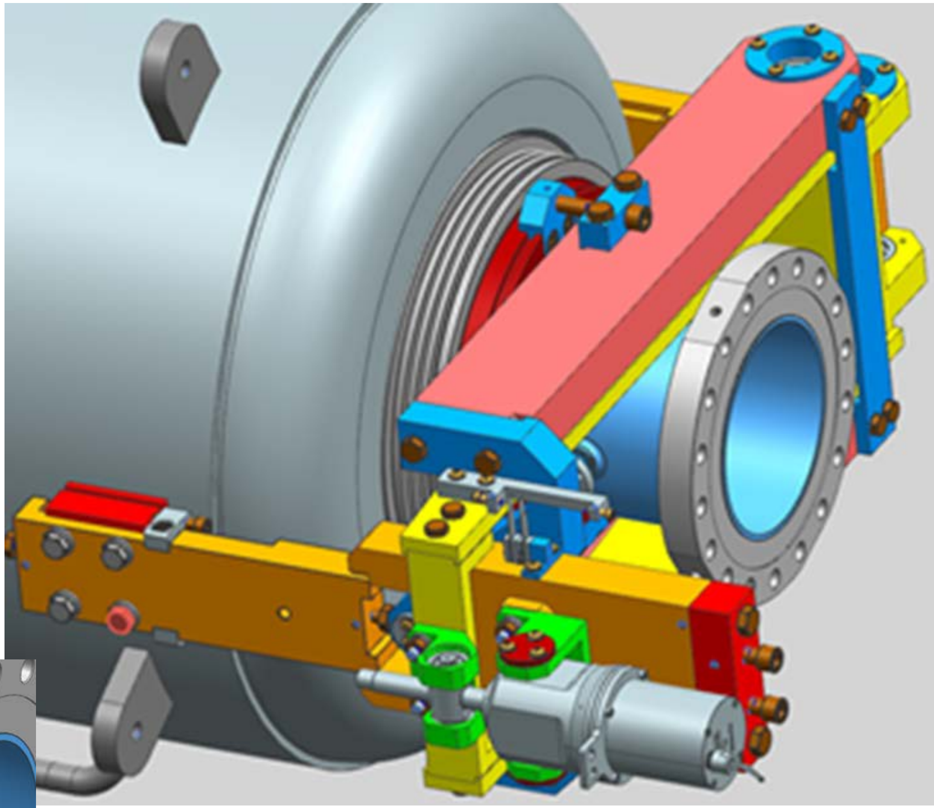
Yuriy Pischalnikov

PIP II meeting, November 1, 2016

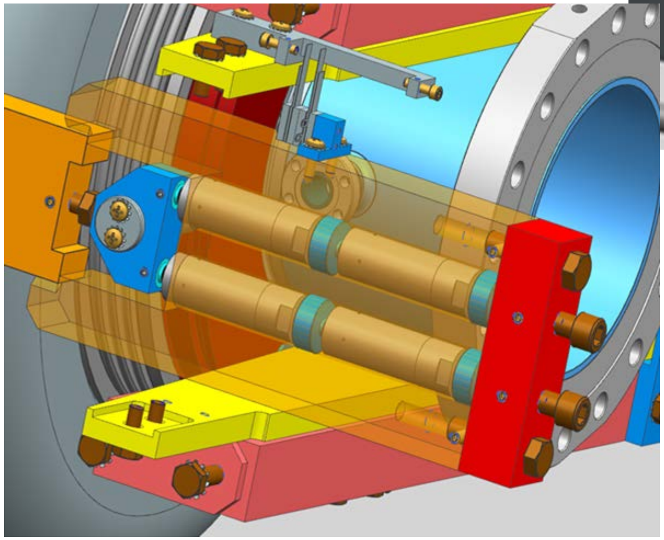
SRF Cavity Tuners for PIP II Project (650MHz)



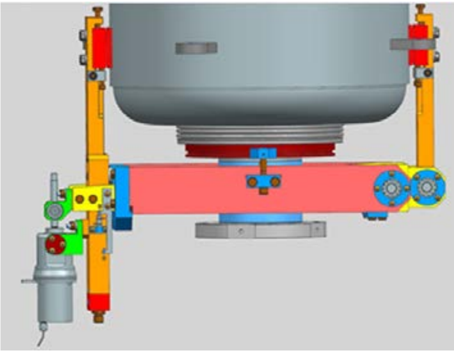
LCLS II Tuner



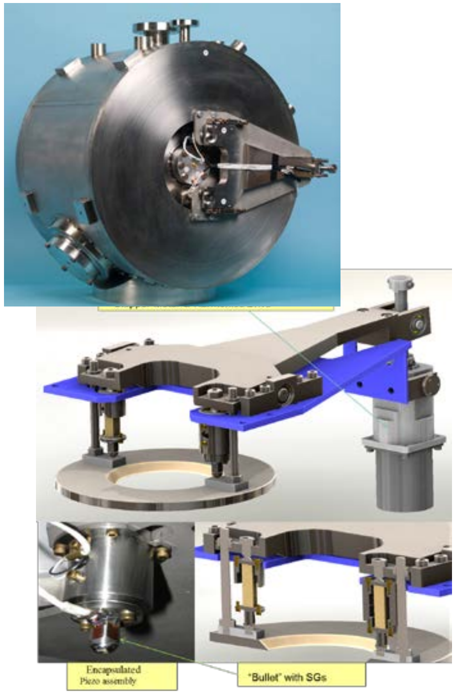
Electromechanical actuator



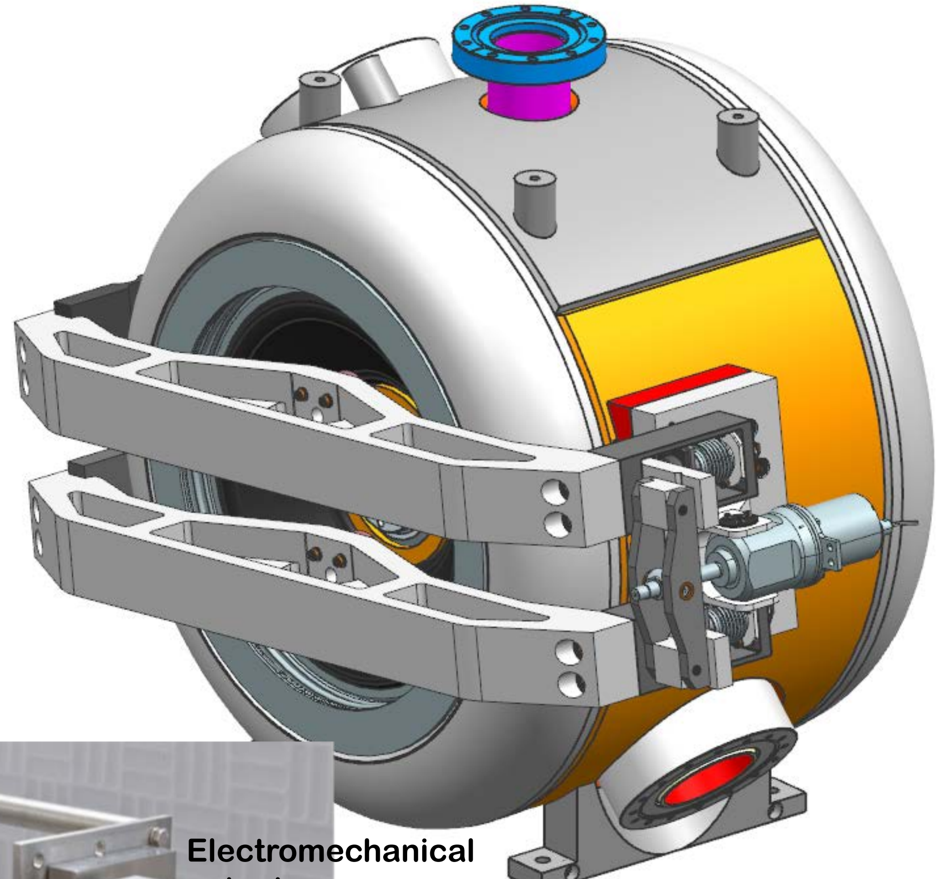
Piezo-ceramic actuators



SRF Cavity Tuners for PIP II Project (325MHz)



SSR1 Tuner prototype
For HINS



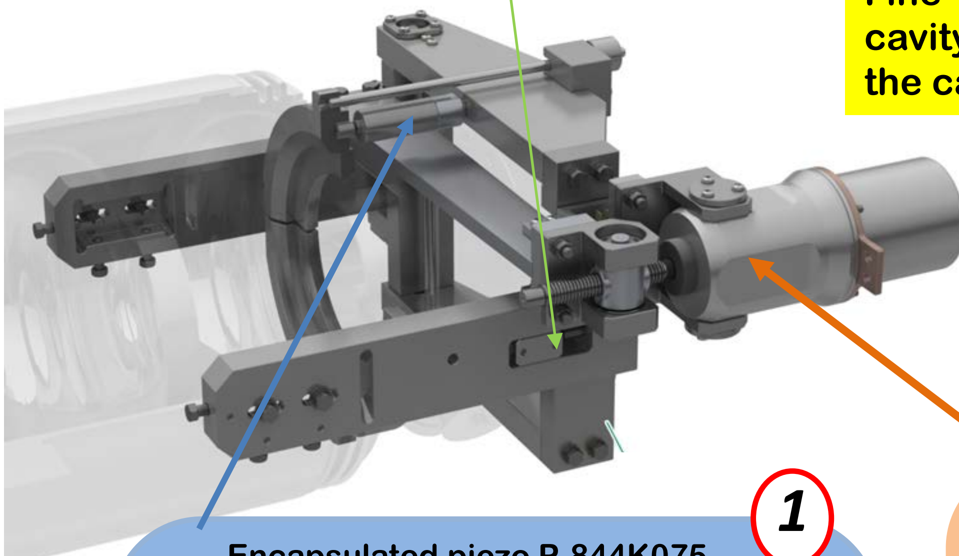
LCLS II SRF Cavity (1.3GHz) Tuner

“DESIGN AND TEST OF COMPACT TUNER FOR NARROW BANDWIDTH SRF CAVITIES “. IPAC2015

Coarse Tuner: double lever coarse (20:1 ration) similar to SACLAY-I tuner
Fine Tuner: two piezo-stacks installed close to cavity flange- direct translation of the stroke to the cavity

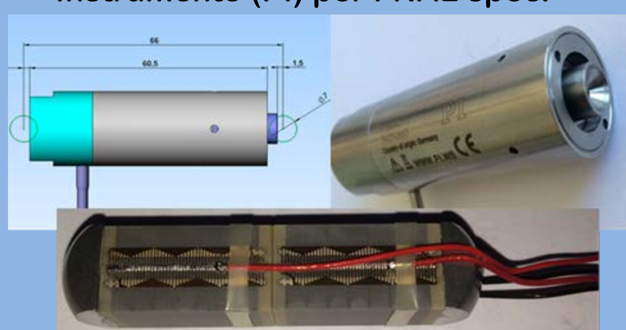
3

Tuner designed in the way that active components can be replaced through special port



1

Encapsulated piezo P-844K075 made from two 10*10*18mm PICMA butted piezo-stacks.- built by Physik Instrumente (PI) per FNAL spec.

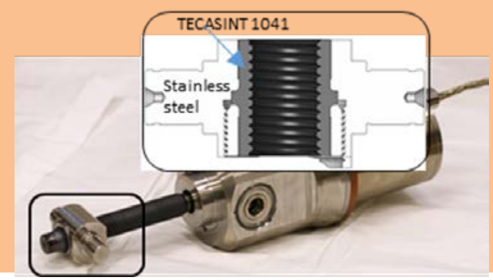


2

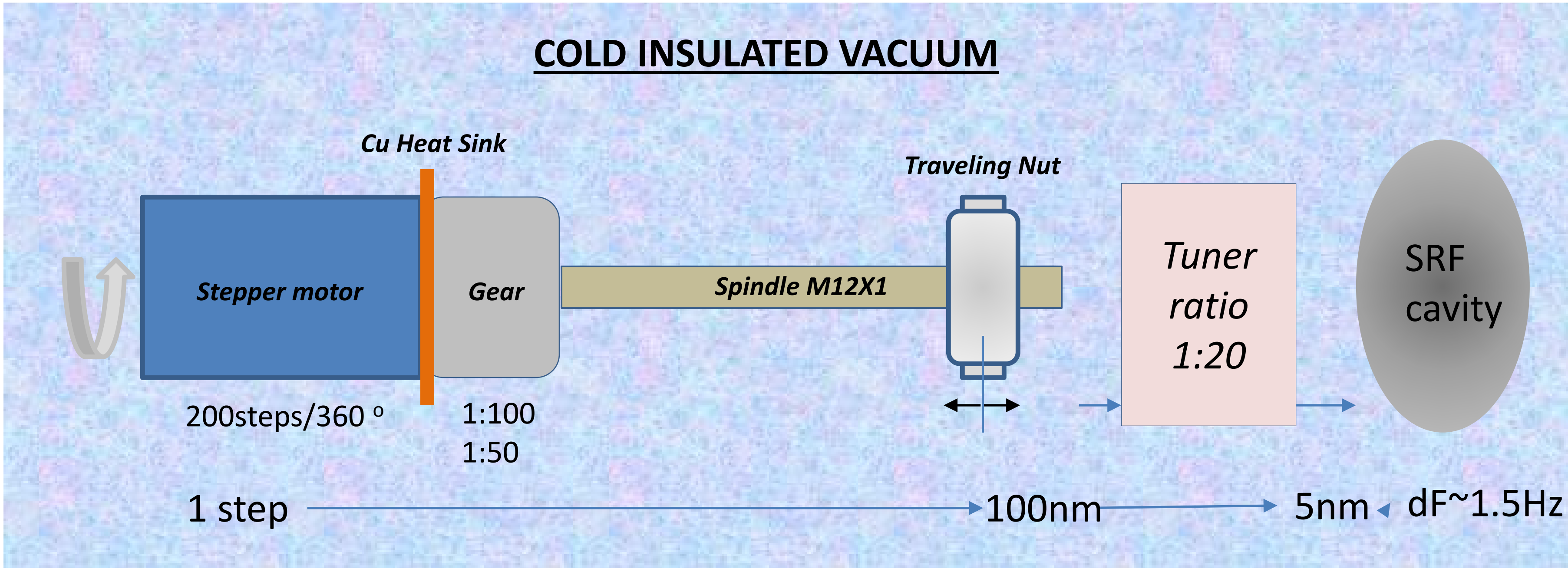
Designed by Phytron per FNAL specs

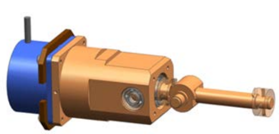
<u>Electromechanical Actuator</u> (LVA 52-LCLS II-UHVC-X1):

- **Phytron stepper motor**
- **Planetary gear box (1:50)**
- **M12X1 spindle made form titanium**
- **Traveling nut made from SS with TECASINT-1041**



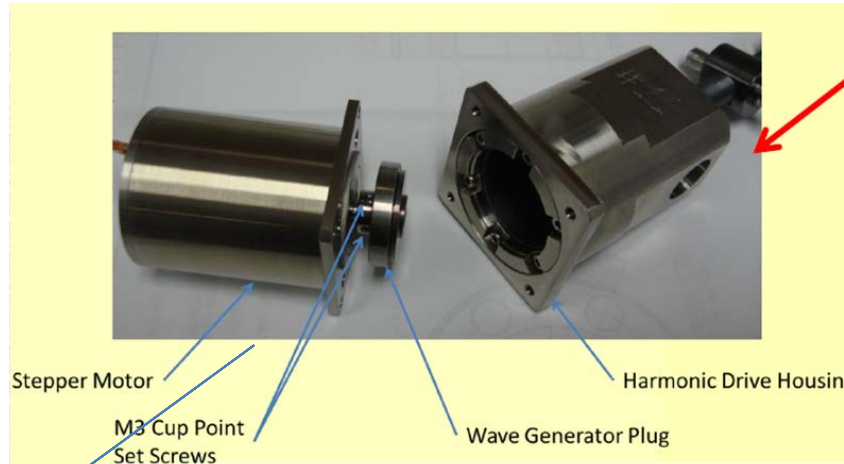
Electromechanical Actuator

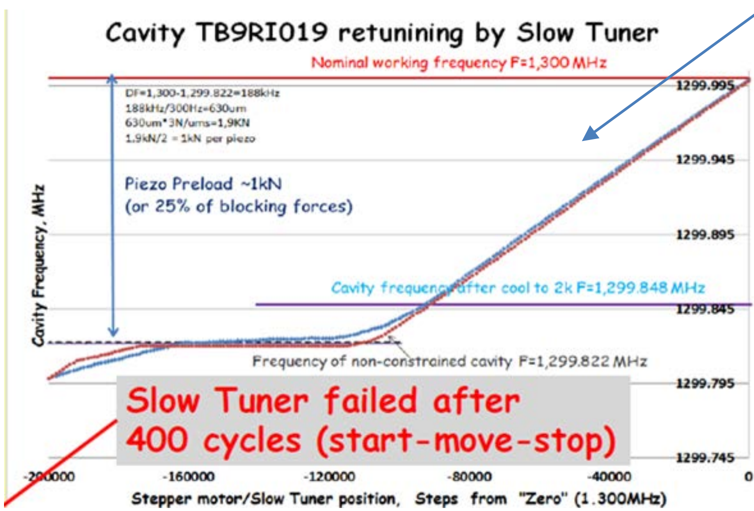


Picture	Name	Motor	Gear Box	Spindle/Nut	Forces	Longevity tested
	LCLS II	Phytron 1.2A	planetary gear (ration 1:50)	Titanium & SS M12*1	+/-1300N	tested in ins. vacuum at HTS for 5000 turns **(5 XFEL lifetimes).** In the force range +/-1500N. Motor run with current 0.7A
	XFEL	Sanyo	Harmonics Drive (ration 1:100)	CuBe (safety issues) M12*1	400N	tested in insulated vacuum at HTS for 3000 turns **(3 XFEL lifetimes)**.

What we got (heritage) from Europe (for CM2)

many failures in different places inside EM actuator
(procured/machined separate parts of EM actuator, send to local shop for dry lubrication coating; assembled in-house → guarantee for failure)

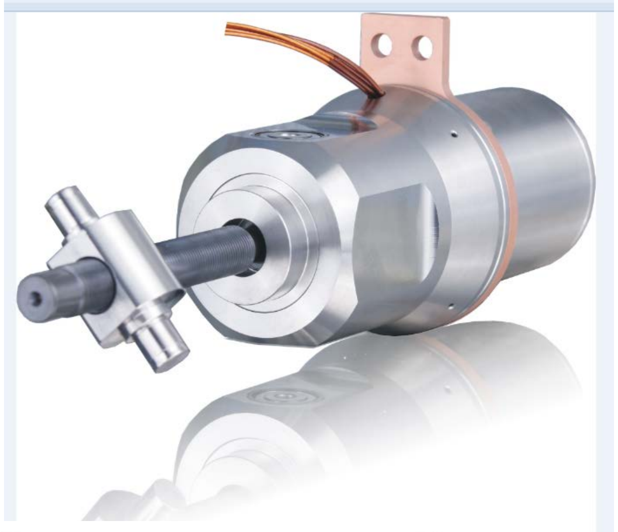


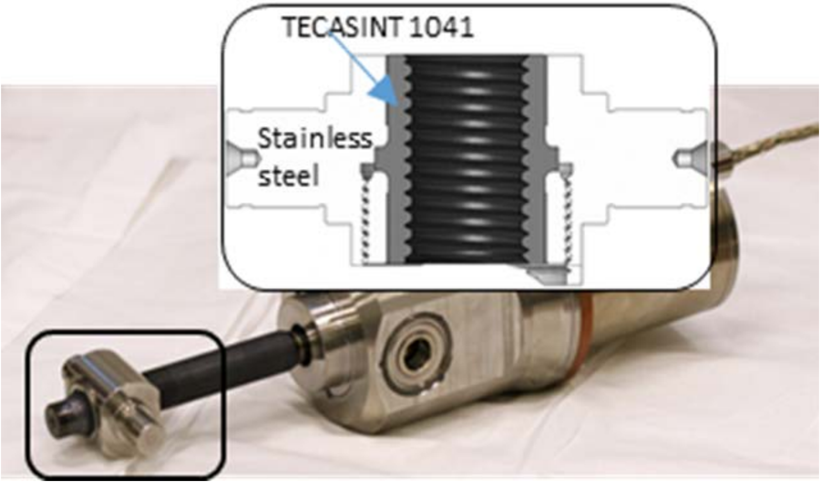


Picture of harmonic drive failure at SNS
14 failure (with 80 cavities) during life of the machine

Electromechanical Actuator for Project X. Collaboration with Phytron

In addition to many special requirements one the most demanding requirements to Phytron was to build EM actuator with **1300N forces (instead of 400N –old version)**





Accelerated Lifetime Test

Electromechanical Actuator

Picture	Name	Motor	Gear Box	Spindle/Nut	Forces	Longevity tested
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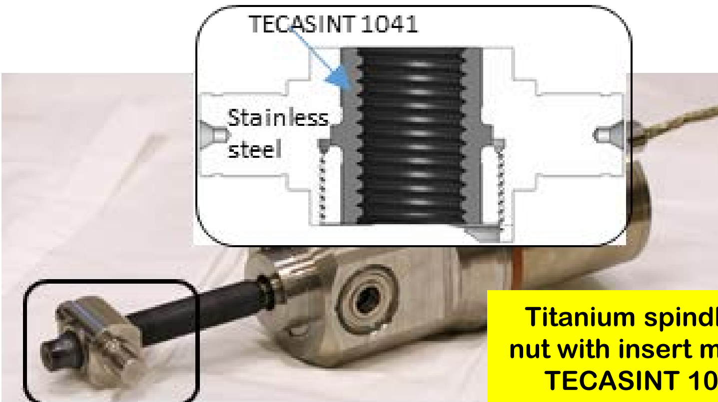
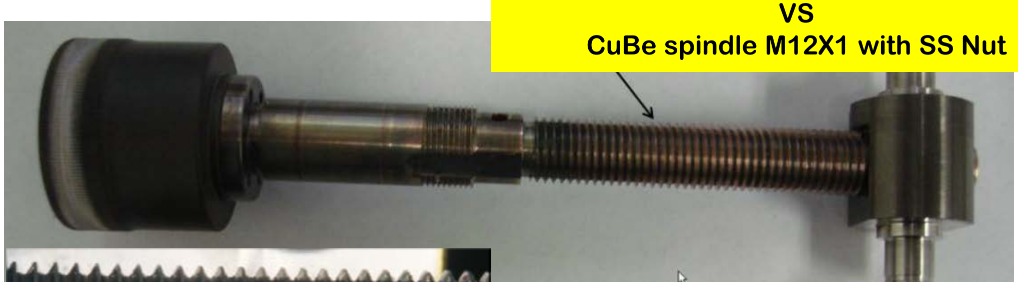
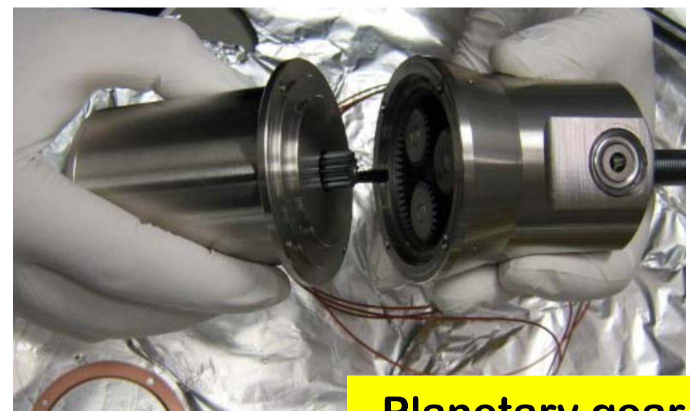
Latest test FNAL/JLAB team for LCLS II project – no any failure after **20 lifetime test**



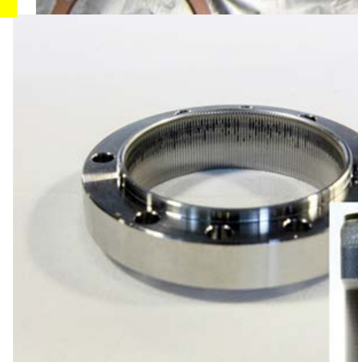
Titanium spindle M12X1 with SS traveling nut with insert made from rad. hard material TECASINT 1041 (polyimide; fillers 30% Molybdenum disulfide (MoS2)
VS
CuBe spindle M12X1 with SS Nut



Titanium (Phytron) shaft after 5lifetime test /no any damage or loss of lubrication



Planetary gear
vs
Harmonics drive



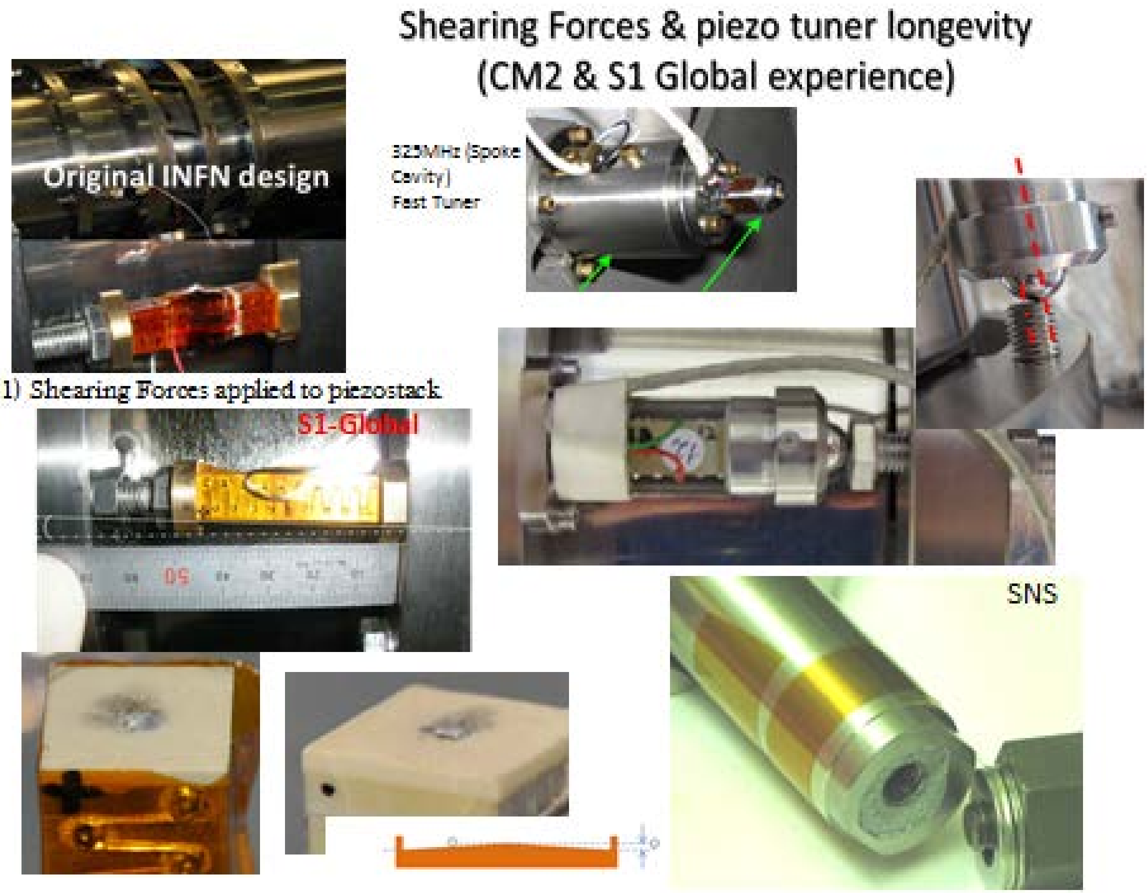
Piezo-tuner reliability/ lifetime R&D program

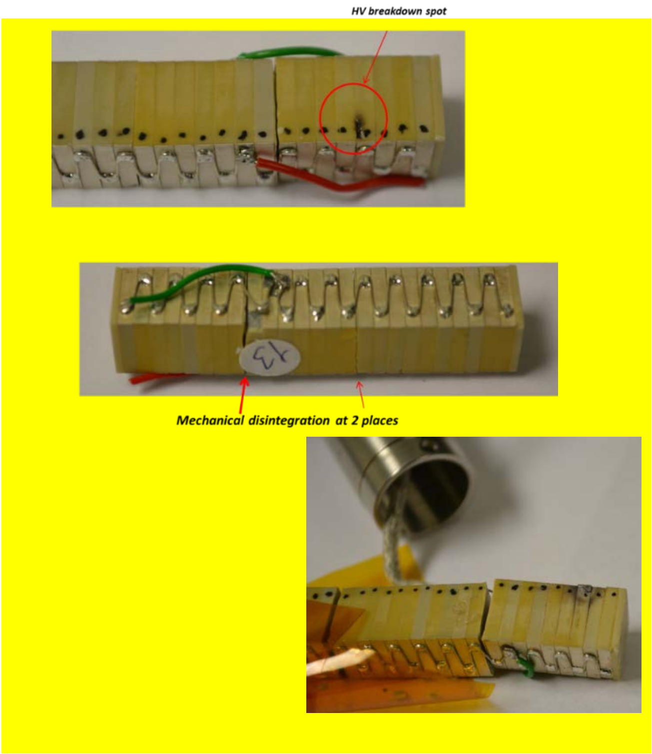
(at FNAL as a part of LCLS II tuner design efforts)

Factors that can affect piezo-tuner lifetime :

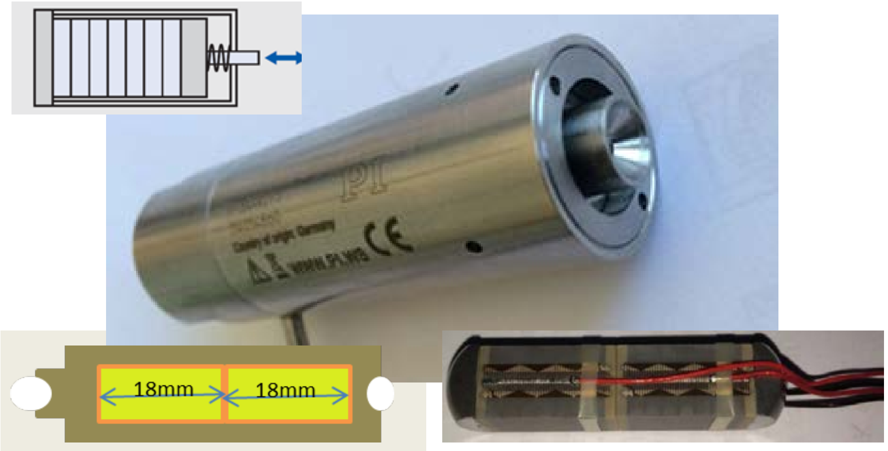
- **Environment (warm .vs. cold)**
  - *- (pros)* *-* temperature, humidity, and voltage
  - *- (cons)* - transfer of the heat dissipated into piezo stack --- overheating piezo-ceramics at insulated vacuum environment
- **Shear forces on the piezo-ceramic stack (design of the fixture → "in-house design" 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.**

Shearing Forces on the piezo ----Piezo-stack capsulation



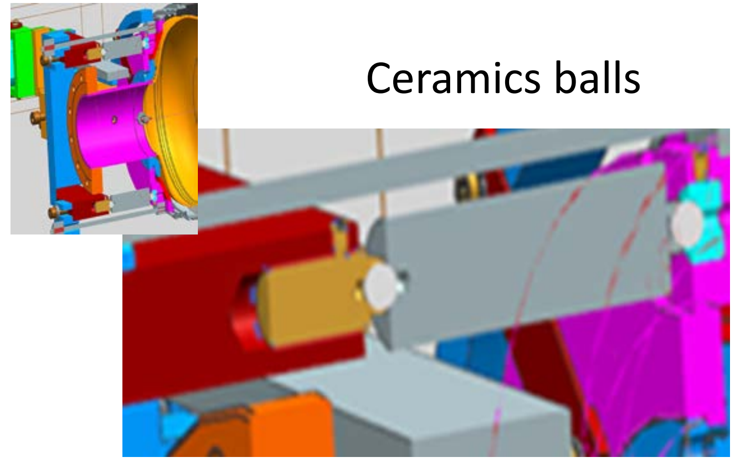


LCLS II piezo-stack (designed and built in collaboration with PI)



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)

Ceramics balls



- *Internal preload (800N at 2K)*
- *Minimization of the shearing forces*
- *through balls connections*
- *<u>Piezo-ceramic stack glued to substrates (as recommended by all piezo companies)</u>*
- *<u>PI using patented technology … taking into account different thermo-expansion coefficient for piezo-ceramics and stainless steel</u>*
- *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)

Requirements to the piezo for operation in XFEL/PIP II and LCLS II
Impact on the longevity of the piezo

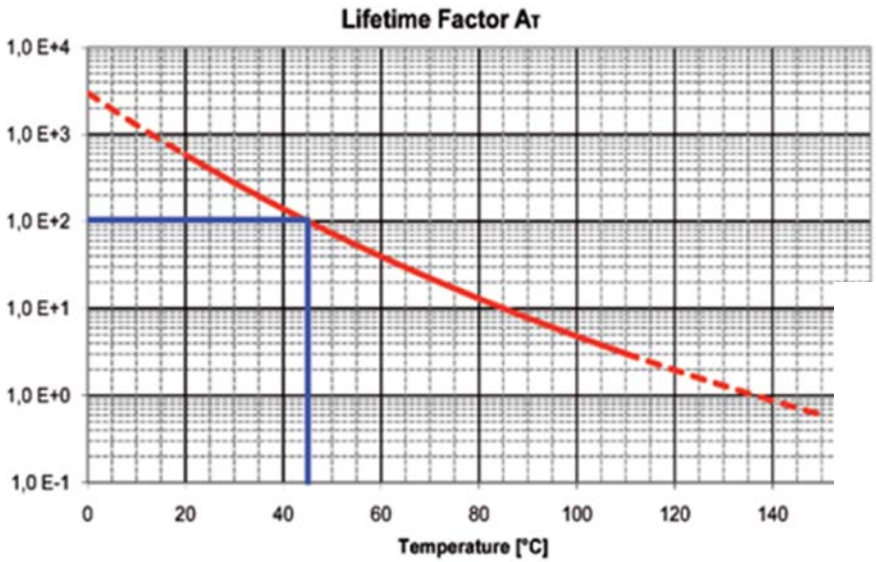
	XFEL(PIP II)	LCLS II	FNAL-test-stand *(2month)*	
Operation	10 pulses/sec (20)	CW	CW	
stimulus pulse, Hz	200 *(2 sinewave per pulse)*	40	5000	
Vpp, V	120	2	2	
piezo stroke,[um]	5	0.2	0.2	
number pulses for 20 years	1E+10	2E+10	2E+10	
total stroke of piezo for 20years, [km]	60 (120)	5	5	
Piezo-stack motion speed (rms) (mm/s)	4.5	0.02	2.2	
Piezo-stack motion acceleration (rms)(g)	0.6	0.0004	7	*$P_{av}=\pi CU^2 f * D$, where D is dissipation Factor (~5-20%)*
Heat dissipation, [mW]	90 (180)	0.05	6	estimated
Piezo ΔT raised	20K (40K)	0.1K	2K	measured

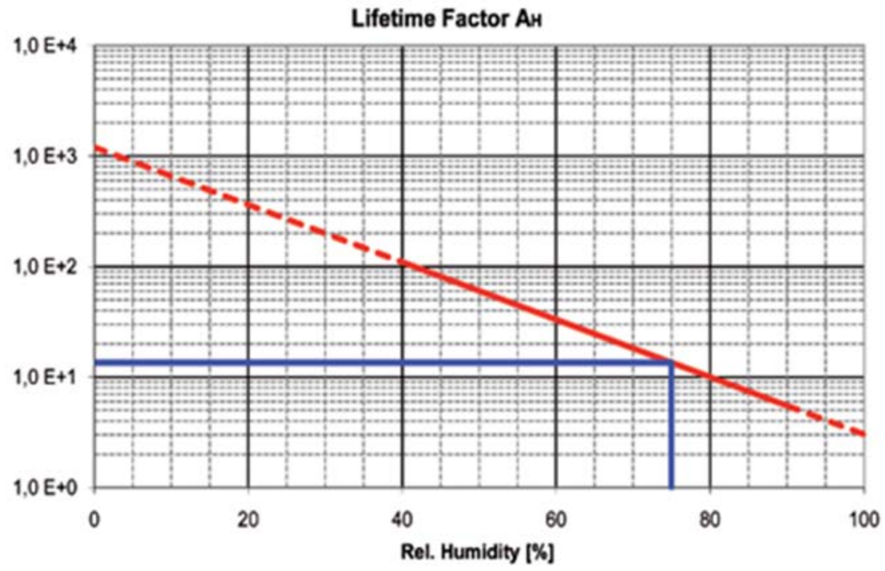
Piezo Tuner Lifetime (1)

In contrast with electromechanical devices ,

Environmental factors:

temperature, humidity, and voltage;

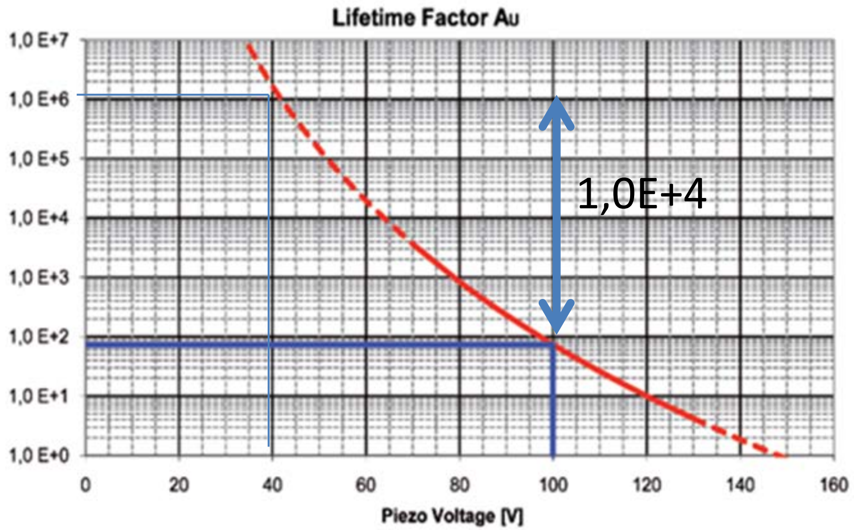




Piezo Tuner Lifetime (2)

- Piezo Operational Voltage.-

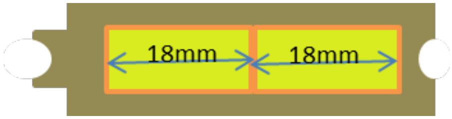
→ Increase length of piezo& operate at lowest Voltage

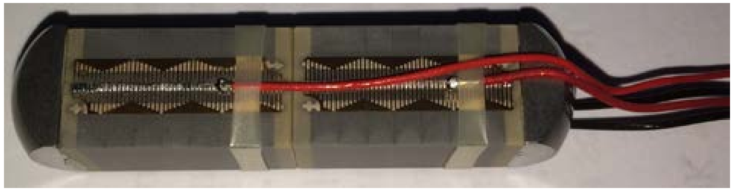


With decrease voltage lifetime increase exponentially

Decreasing operational voltage from 100V to 40V will increase lifetime in ***10,000 time.***
Do not design piezo-tuner with assumption to run NEAR Vmax.
Selected longer piezo/ to operate at lower possible Voltage

LCLS II configuration allowed for max. length 36mm piezo
Piezo capsule build with piezo stack made from 2*18mm piezo





Piezo Tuner Lifetime (3)

…..cold vacuum is an almost ideal environment for piezo actuators… **<u>except the problems to heat transfer from piezo inside insulated vacuum…</u>**

Piezomechaniks ΔT~70Degree

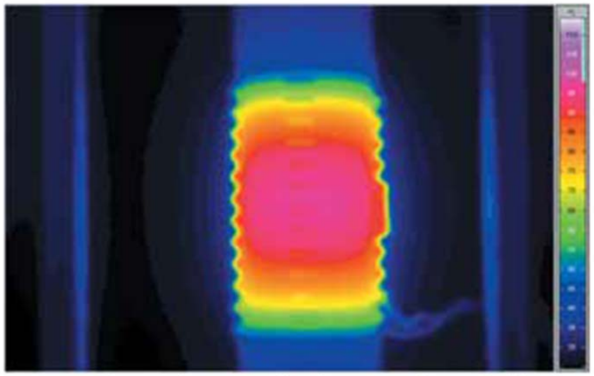
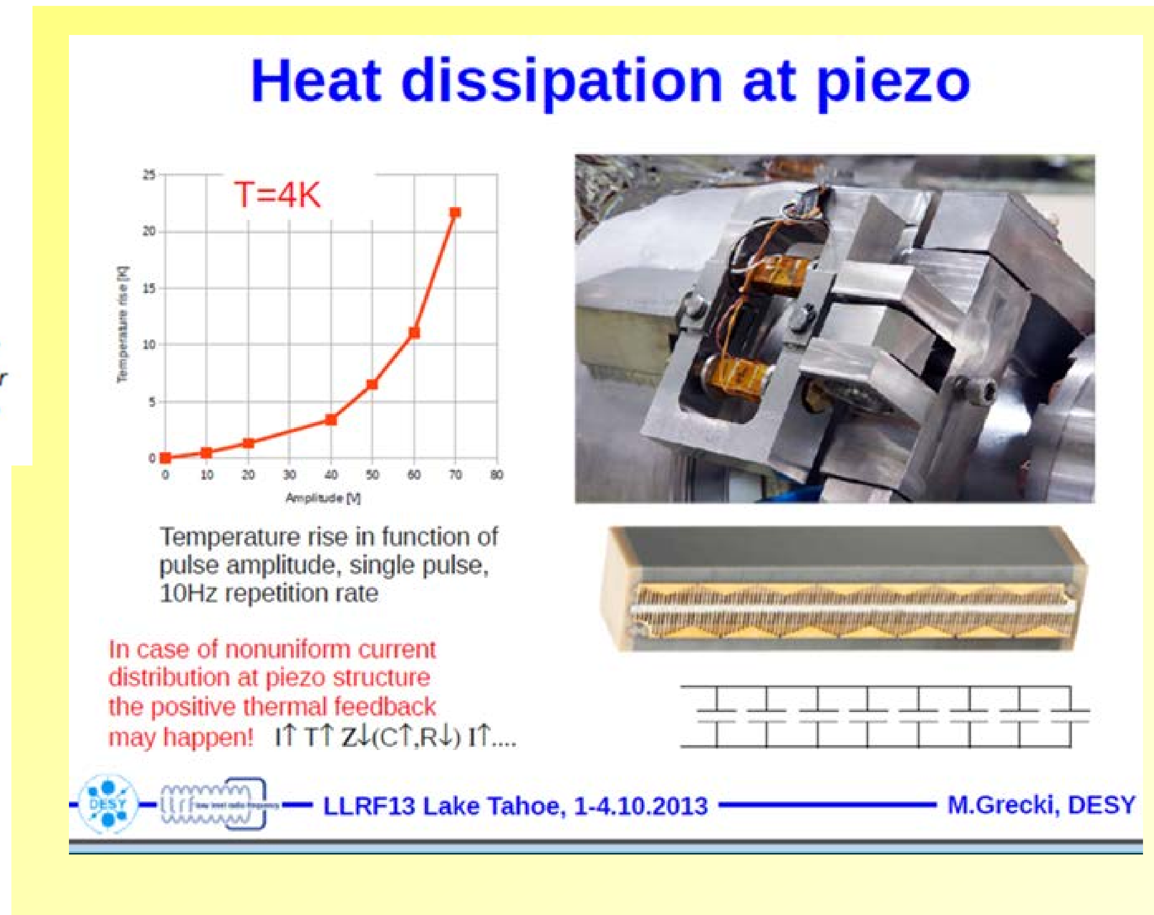


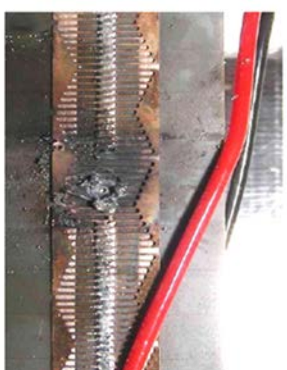
Fig. 5.1: Thermal image of a dynamically cycled high voltage actuator, clamped at its end faces. Environment: ambient air convection. Notice the cooling effect at the end-faces due to the clamping mechanics



DESY/XFEL Piezo Test

THIS TEST DONE AT LN2. Heat from piezo boil LN2 around piezo → changed heat transfer and overheat one piezo-gap→ HV breakdown

Major concerns are cooling of the piezo-stack inside insulate vacuum environment



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stimulus pulse, Hz	200 *(2 sinewave per pulse)*	40	5000	
Vpp, V	120	2	2	
piezo stroke,[um]	5	0.2	0.2	
number pulses for 20 years	1E+10	2E+10	2E+10	
total stroke of piezo for 20years, [km]	60 (120)	5	5	
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Piezo-stack motion acceleration (rms)(g)	0.6	0.0004	7	*$P_{av}=\pi C U^2 f * D$, where D is dissipation Factor (~5-20%)*
Heat dissipation, [mW]	90 (180)	0.05	6	estimated
Piezo ΔT raised	20K (40K)	0.1K	2K	measured

Designated facility at FNAL to test piezo at the CM environment (insulated vacuum and LHe) at IB1/TD

Insert into LHe dewar with cryo/vacuum and electrical connections

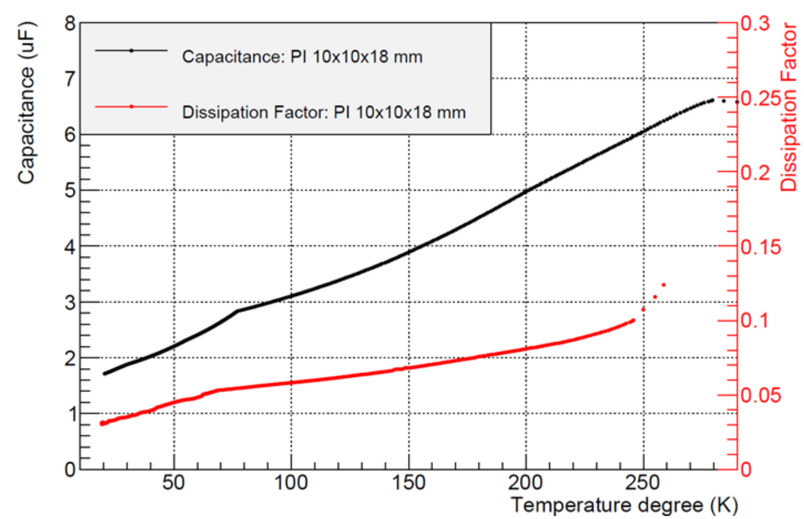
Helium Dewar

Vacuum Enclosure

Capsules (up to 5)with Piezo-stacks Mounted on the copper block

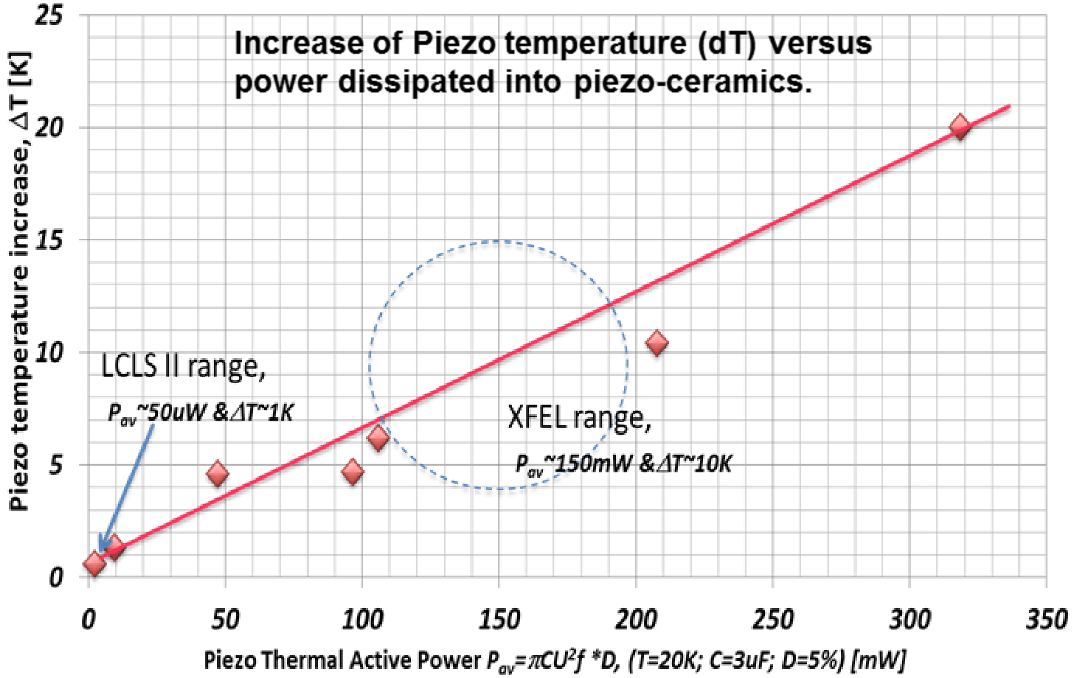
- RTD (Cernox) – to mount on Piezos

- Geophones (to monitor piezo stroke)



Summary:
Piezo Overheating at Cold/Ins. vacuum environment

PIP II requirements for piezo operation (for LDF compensation) is much more demanding as for LCLS II.
Designated R&D program for tuner reliability study required.

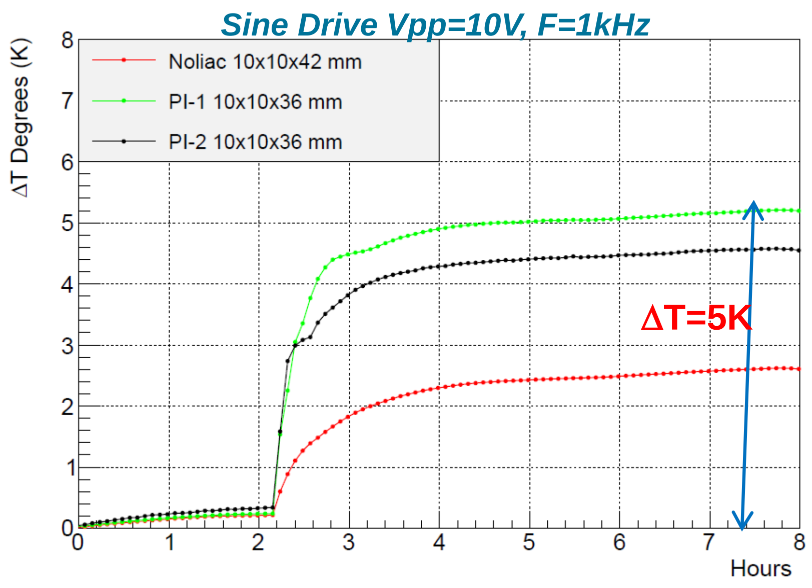


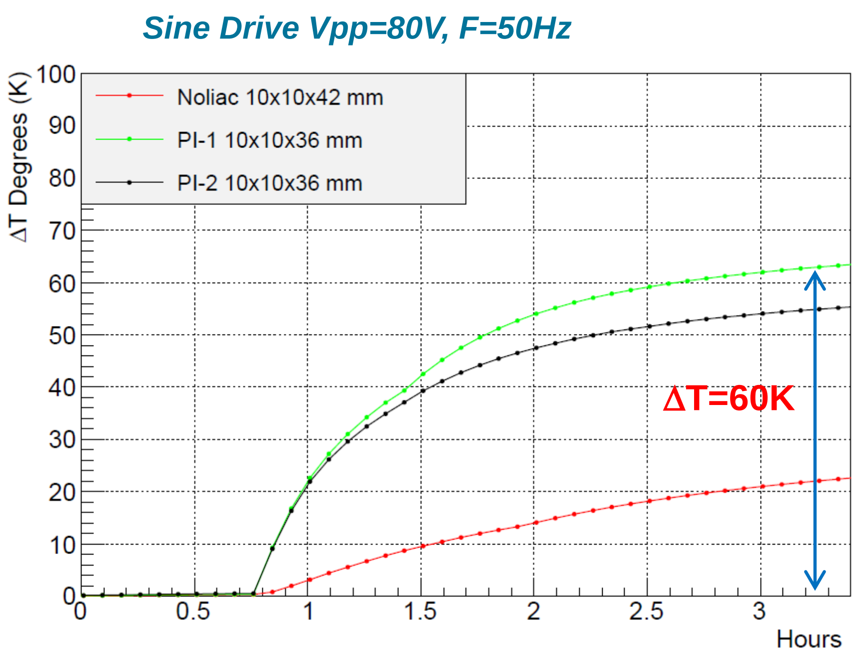
Accelerated piezo-stack lifetime test
$2*10^{10}$ pulses (V_{pp} = 2V & F = 40Hz)
20years → 2 month (40Hz→5kHz)

LCLS II --- P_{av}~ 50μW (40Hz, 2V)
During ALT at 5kHz P_{av}~ 6mW (ΔT~2K)

LCLS II Tuner piezo-stacks run for $2.5*10^{10}$ pulses (or 125% of LCLS II expected lifetime) without any degradation or overheating

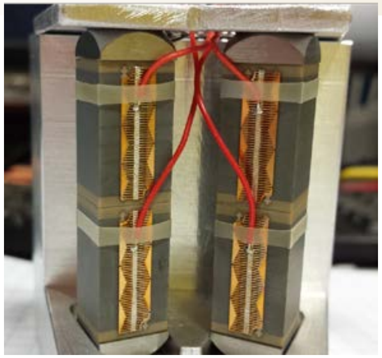
Status of the Piezo lifetime R&D program

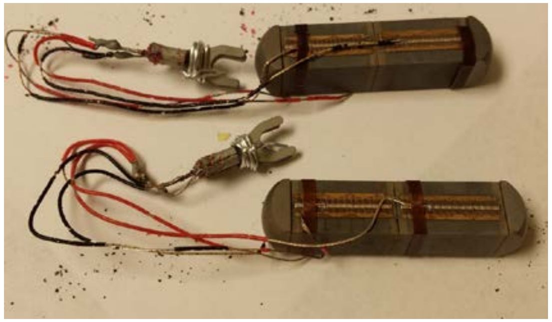


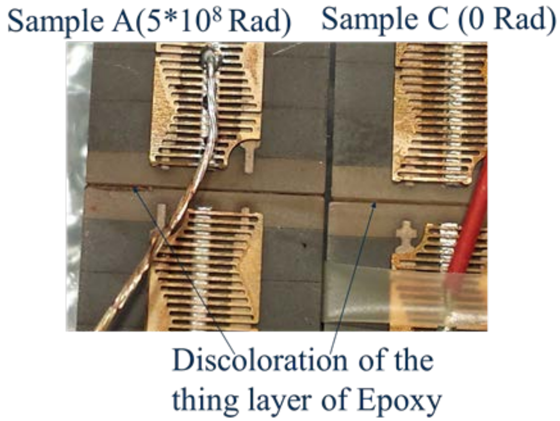


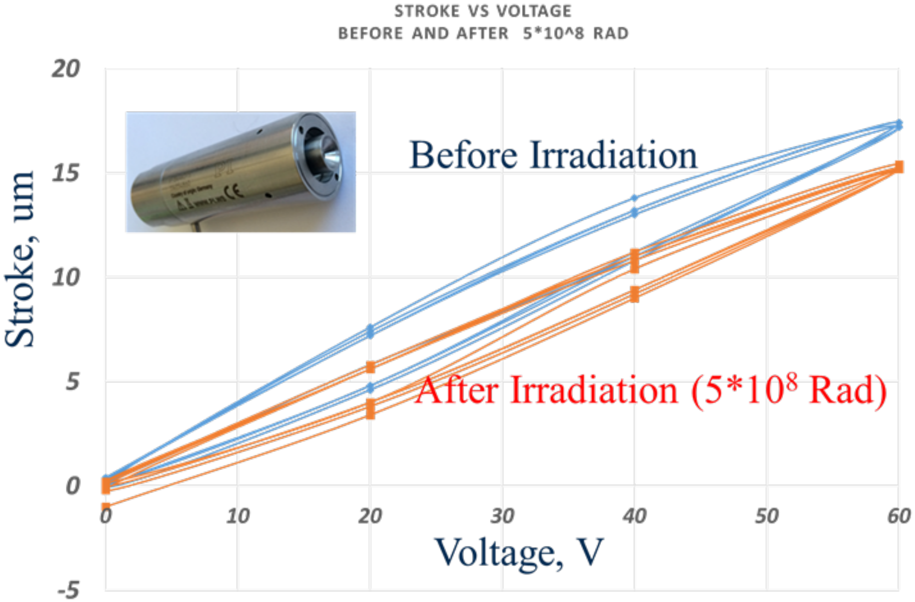
Radiation Hardness of the SRF Cavity Tuner Components

Irradiation of the Piezo-stacks up to 10^9Rad (gamma) (done at Sandia)





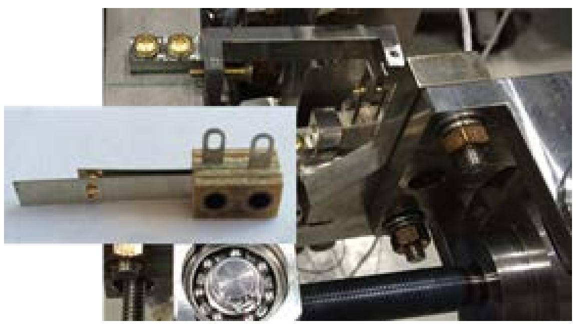




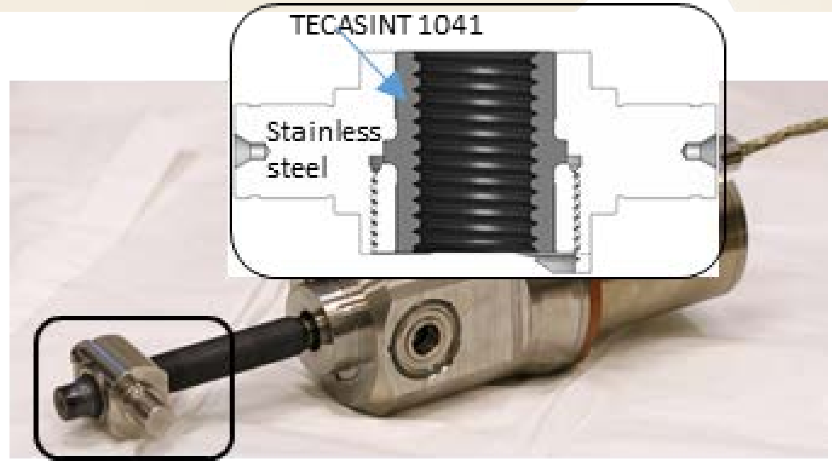
Stroke of the piezo-stack decreased only on 10% after irradiation up to 10^9 Rad

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

Phytron stepper motor internal windings after irradiation with dose 5*10^8 Rad



Limit switches mounted on the tuner.



Traveling nut on the Ti spindle. Schematic design of the nut made from the stainless steel with TECASIN-1041 insert. TECASINT 1041 is a high temperature polyimide with 30% MoS_2. This material has excellent radiation resistance properties (1-10*10^8 Rad).). Large radiation dose will cause material to “swell” [13]. This can lead to increased friction for Ti-spindle/traveling nut system. We conducted after-irradiation visual inspection and measurements of mechanical dimensions of the insert. No damages or size changes have been found.

There was no any degradation in the electromechanical actuator components:

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

Summary

To insure reliability of the SRF cavity tuners

Work with industry experts and Order active components of the tuner at specialized company…

avoid as much as possible "in-house made" assembly of the electromechanical actuators and piezo-fixtures …

- lessons learned at FNAL (in course of CM2& S1G) –

*how to build **"non-reliable"** tuner:*

(1) buy separately stepper, harmonic drive in plastic bag, machine spindle and traveling nut, sent to specialized company for dry lubrication coating, assembly all components "in-house" into "working" actuator;

(2) buy piezo-ceramic stacks and installed (without internal preload & glue) into "in-house made" fixture

Summary of ALT and RadHard Tests during LCLS II tuner design/ design verification efforts

If it is possible design piezo-tuner to operate at voltage much less than Vmax. *(decreasing voltage values are associated with exponential increases of lifetime)*

Piezo overheating is not an issue (at least for LCLS II)

BUT IT IS NOT A CASE FOR PIP II

Electromechanical actuator has no any degradation of the performance after irradiation up to 10^9Rad

PI piezo-stack (designed for LCLS II) lost ~10% of the stroke after irradiation up to 10^9Rad

PIP II requirements for piezo-stacks is extremely demanding.

Biggest concern is overheating piezo-stack … it will drastically decrease lifetime of piezo-tuner.

Possible Collaboration with industry experts (PI) to build piezo-capsule that can have higher blocking forces and better way to transfer heat outside piezo-ceramic stack