TESLA TECHNOLOGY COLLABORATION TTC

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CERN

Fermilab

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Newest Piezo-Actuators for High Dynamic Rate Operation

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TTC2020, WG2

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Request for Piezo-actuators that will operate reliably for 25+ years at High Dynamic Rate at cryogenic temperature/insulated vacuum environment

- For the SRF LINACs operating at RF-pulse mode to compensate LFD piezo-actuators must run at high dynamic rate & high amplitude.
- It is well know fact that piezo-stack will be warm-up when operated at high dynamic rate & high amplitude.
- Piezo-ceramic material has low thermal-conductivity and heat dissipated inside ceramics need to remove to avoid overheating
- For “typical” industrial applications flow of the gas used to remove dissipated into piezo-ceramic heat
- When piezo-ceramic stack installed in to the SRF cryomodule (inside insulated vacuum & at T~20K) removing heat from the piezo-actuator became a problems that drastically limit reliability of the piezo & fast/fine SRF tuner

FNAL APS-TD Tuner team is working on this problem last years.

Preliminary results of these R&D efforts will presented in this talk

Overheating piezo-ceramic actuators when operated at cryogenic temperature & insulated vacuum

Power dissipated inside piezo-stack

$$P = \frac{\pi}{4} \cdot f \cdot C \cdot \tan(\delta) \cdot U_{p-p}^2$$

- Thermal conductivity of the piezo-ceramics is low.
- Removing heat from the actuator is necessary to avoid overheating at large amplitude and high operating frequency.

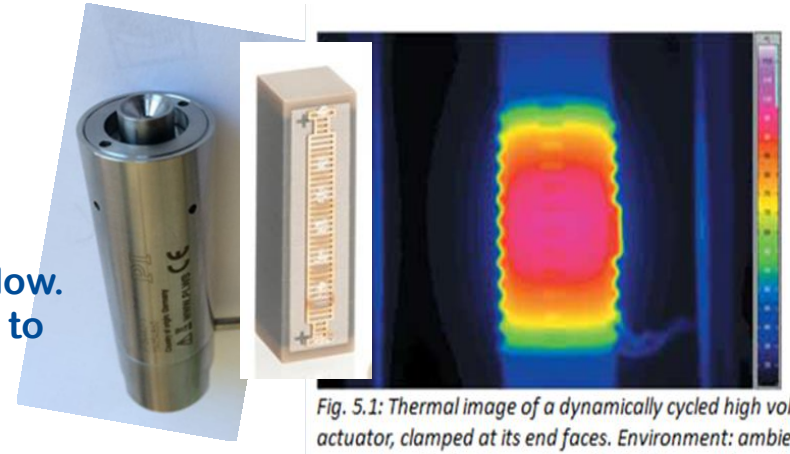


Fig. 5.1: Thermal image of a dynamically cycled high voltage actuator, clamped at its end faces. Environment: ambient air convection. Notice the cooling effect at the end-faces due to the clamping mechanics

Heating of the center of the piezo illustrated on the picture. Cooling effect at the end-faces due to clamping mechanics. At "standard" industrial applications operation (at room temperature) significant flow of the air/gas typically used to remove the heat…

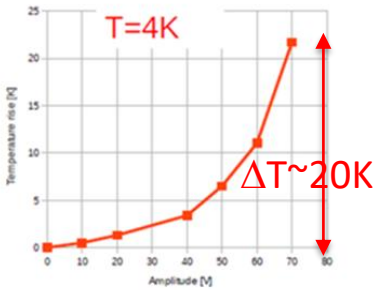
This approach definitely could not be applied for piezo-actuators installed inside SRF cryomodules (insulated vacuum and cryogenic temperature). In addition piezo-actuators installed (separated from tuner frame) with ceramic balls to avoid shearing forces on the stack… that also decrease heat transfer outside capsule.

PI sealed/filled with inert gas piezo-actuator

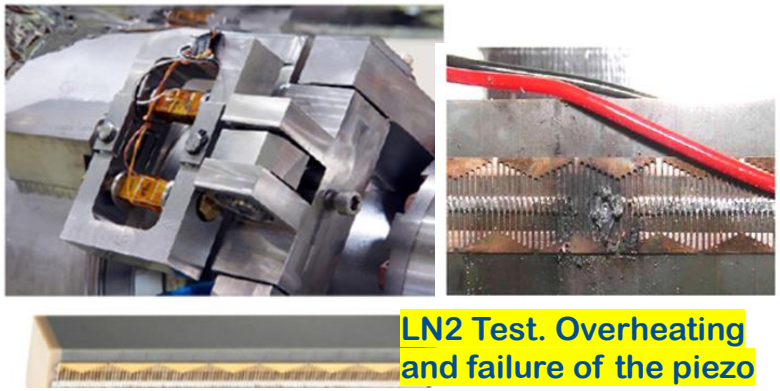
Results of the testing piezo-actuators at high dynamic rate at " SRF cryomodule like" environment

Studies of the INFN/DESY team in the frame of the ILC/XFEL projects.

M. Grecki, et al. LLRF13 Lake Tahoe.



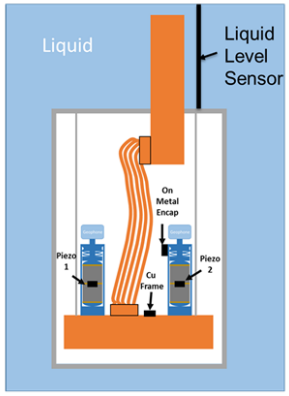
Temperature rise in function of pulse amplitude, single pulse, 10Hz repetition rate

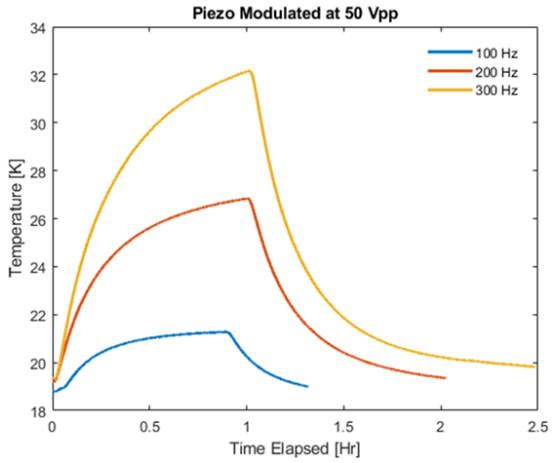


LN2 Test. Overheating and failure of the piezo

FNAL Studies in the frame of LCLS II/ PIP II & ILC (and the future RF-pulsed LINACs)

SRF2019, Y. Pischalnikov et al., TESTING OF THE PIEZO-ACTUATORS AT HIGH DYNAMIC RATE OPERATIONAL CONDITIONS





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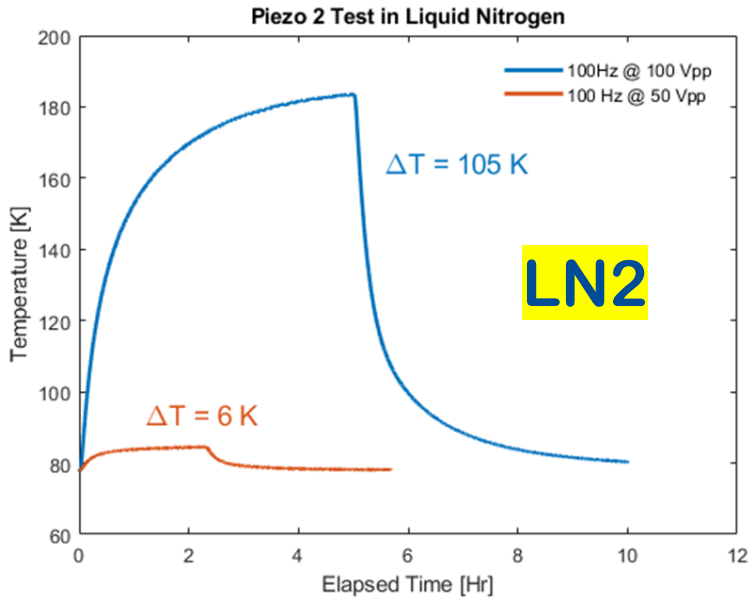
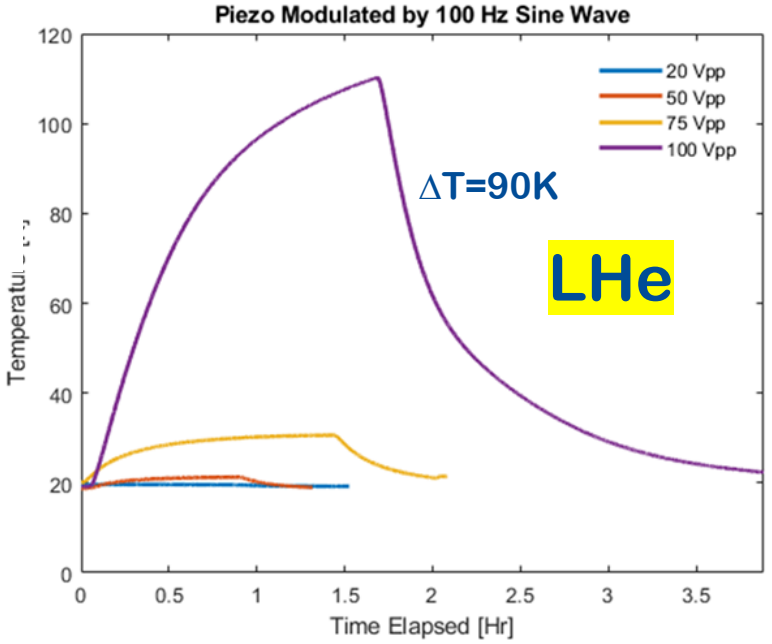
Heating of the PICMA PI 10*10*36mm^3 (LCLS II) capsulated piezo-actuator

Stimulus pulse on the piezo - sinewave f=100Hz and amplitude Vpp=20-100V



V_{pp}	ΔT
0	0
20	0.1
50	2
75	10
100	90



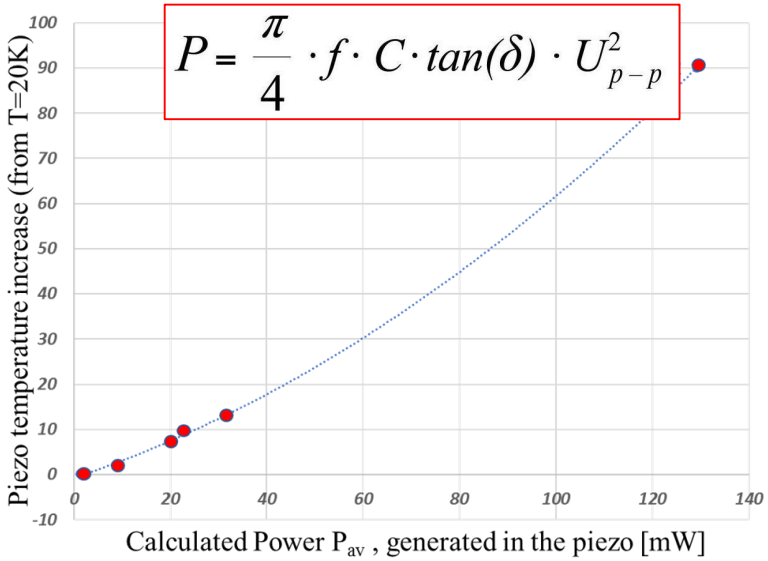
Temperature of the piezo – stack (at the center) raised very fast after V_{pp} larger than 75V (~ 55% of the $V_{nominal}$)

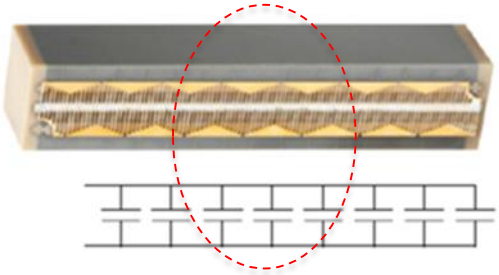
Heating of the PICMA PI 10*10*36mm^3 (LCLS II) capsulated piezo-actuator

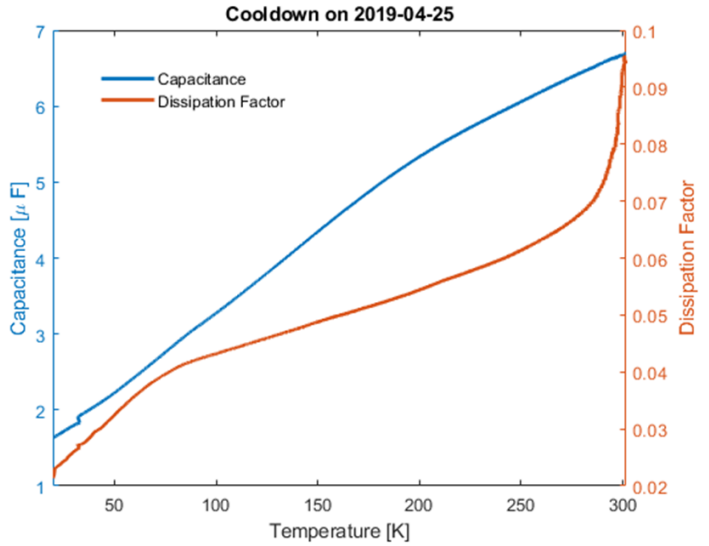
Increase of V_{pp} will lead to heat up center of the piezo. C & Dissipation Factor of the central layers will increase.

The nonuniform current distribution at piezo structure could lead to the positive thermal feedback…!!!

$$P = \frac{\pi}{4} \cdot f \cdot C \cdot tan(\delta) \cdot U_{p-p}^2$$







QUESTIONS THAT WE TRIED TO ADDRESS/SOLVE:

- How to remove heat from the whole stack of the piezo-actuator when it is inside insulated vacuum and at temperature T~20K
  - piezo continuously stretching/compressing
  - Surface of the piezo under HV

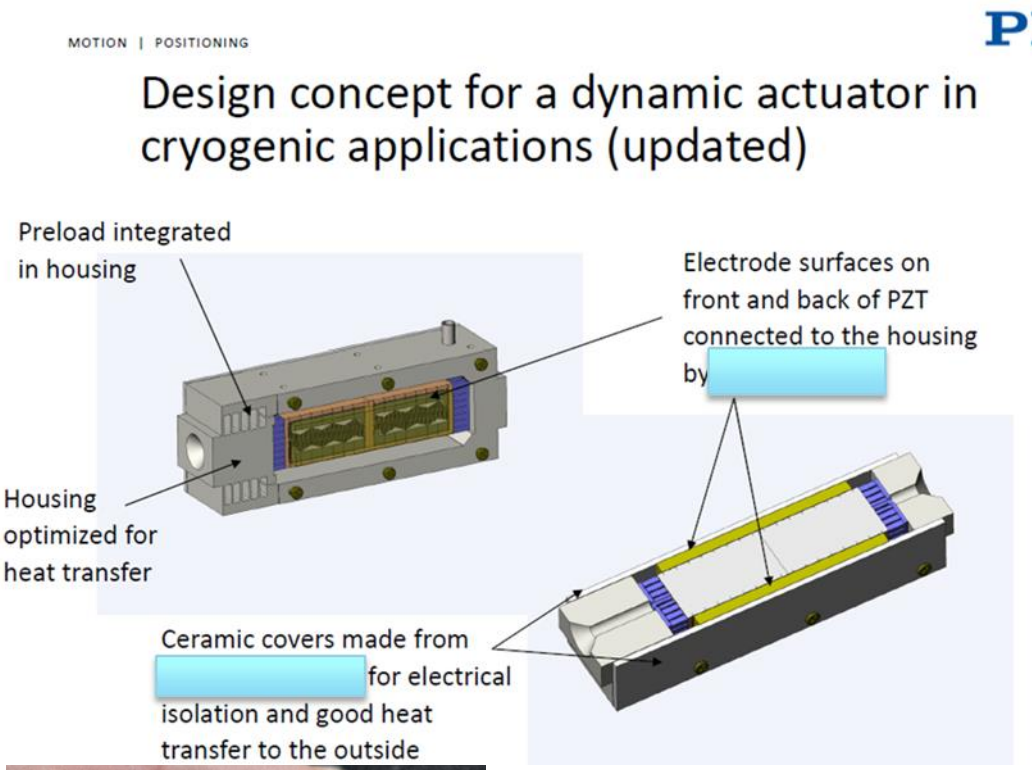
- How to make sure that piezo-stack stay at fixed temperature *(mounting RTD on the surface is not reliable & expensive)*

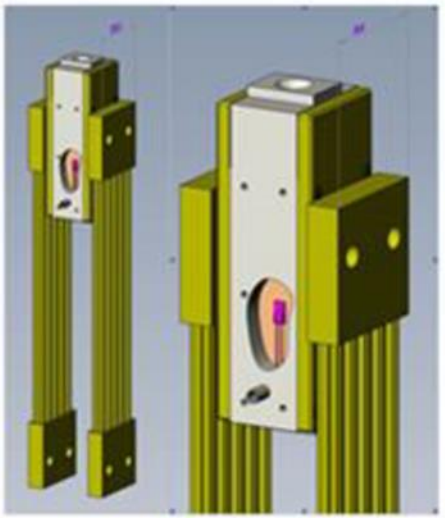
  T=4K ?

  T=35-45K(CM thermo-shield)?

  T=77K (LN2 shield)?

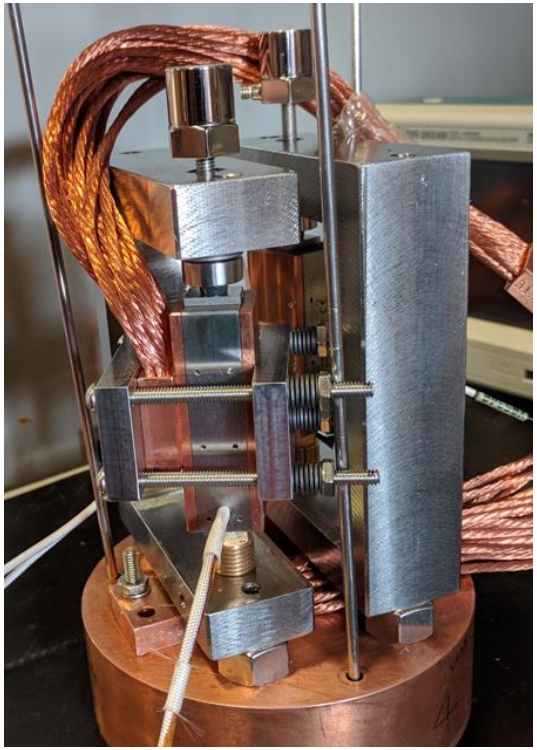
Design of the PI High Dynamic Rate encapsulate piezo actuator (patent pending)

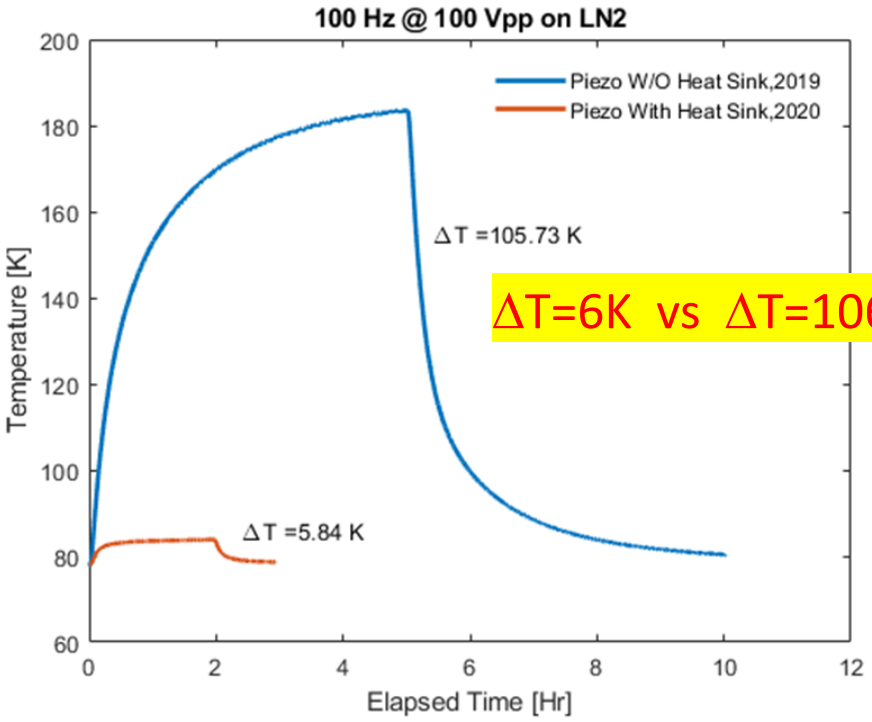




Physik Instrumente (PI) GmbH & Co. KG
Auf der Roemerstrasse 1
76228 Karlsruhe
Germany

New Piezo results at (LN2)

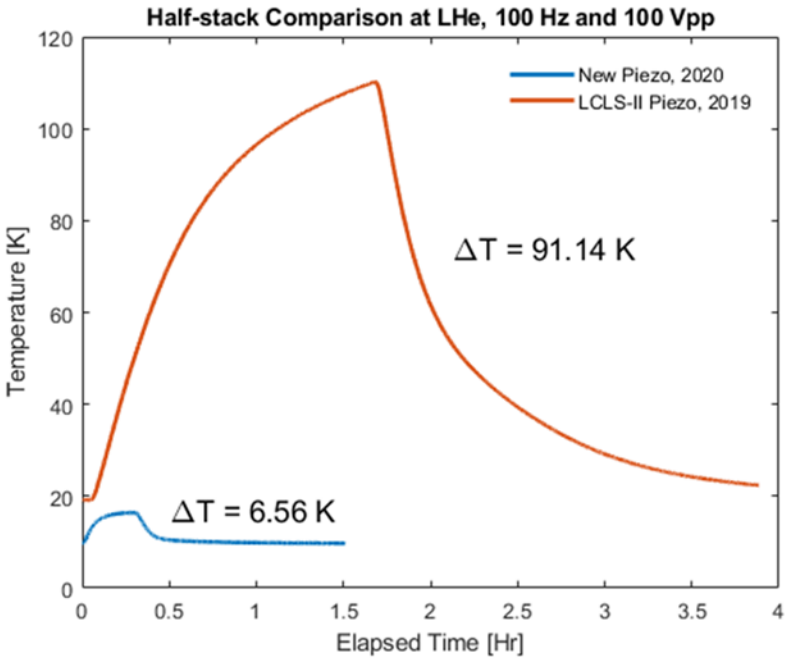




ΔT=6K vs ΔT=106K

The same sinewave signal 100Vpp@100Hz warmed up the
new (HDR) piezo on just ΔT=6K
when “standard” piezo-actuators on ΔT=106K

New Piezo results at LHe



The same sinewave signal 100Vpp@100Hz warmed up the new (HDR) piezo on just ΔT=7K
when “standard” piezo-actuators on
ΔT=91K

ΔT=7K vs ΔT=91K

Summary (I)

- New High Dynamic Rate capsulated piezo-actuator has been developed as results of the collaboration between FNAL and Physik Instrumente (PI).
- Innovative design allowed to remove heat from piezo-ceramic through heat sink strap .. **As results piezo actuator could be operated at higher amplitude and high dynamic rate without overheating and failures**
- First prototypes built at PI and tested at FNAL (at specialized piezo test stand) when cool-down with LN2 and LHe
- Piezo-actuator, when operated with sinewave 100Hz@100Vpp, warmed up just on $\Delta T=6K$. In similar test LCLS II piezo-actuator ceramic temperature raised on $\Delta T\sim100K$

Summary (II)

- Keeping piezo-ceramic at fixed temperature (40K or 77K) could increase stroke of the piezo (at fixed V_{pp})
- Also keeping temperature of the piezo-ceramic below 77K could allowed to safely operate piezo at $-V_{nom}$ to $+V_{nom}$. Operation at 2Vpp could allowed to deliver the same stroke(same level of the cavity tuning) with shorter piezo-stack.

Remarks: To have reliable SRF Cavity tuner required investment into R&D/ joint programs with industry experts

- During several last years FERMILAB Tuner Team conducting R&D efforts/ working with industry experts to develop newest reliable components for SRF Cavity Tuning system.
- As usual R&D started for some particular Project :
  - Phytron electromechanically actuator ( ) was developed for FNAL ILC project (and later was adapted for LCLS II, LCLS II HE, PIP II) and as I know many small projects procured this actuator …
  - PI piezo-actuator (P-844K075) developed for LCLS II (and later adapted for PIP II and LCLS II HE). Again several small SRF projects considering or already used P-844K075.
- Development of the New High Dynamic Rate piezo-actuator has been started for PIP II several years ago, when PIP II has been considered as RF-pulse LINAC with very demanding specs for piezo-actuators. Now PIP II is CW LINAC and do not need this type of piezo.
- But I am confident that in the near future new SRF project with demanding RF-pulse operations specs will adopt this new piezo-actuator.

Acknowledgements

- Thanks to FERMILAB APS-TD /SRF Sector management (Sergey B., Anna G., Alex R. Slava Y.) for their continuous support of Reliable SRF Tuners R&D program.
- This new piezo development could not be done without funding that they provided.