Status of the SRF cavity tuner for the MEXT-ATD / ITN cryomodule being built at KEK

13th IHEP-KEK SRF collaboration meeting

2025/12/15

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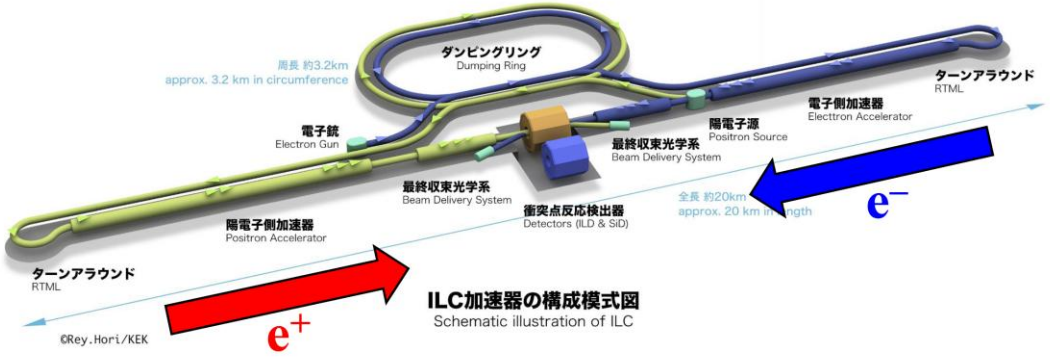
(on behalf of the KEK ITN tuner team)

Contents

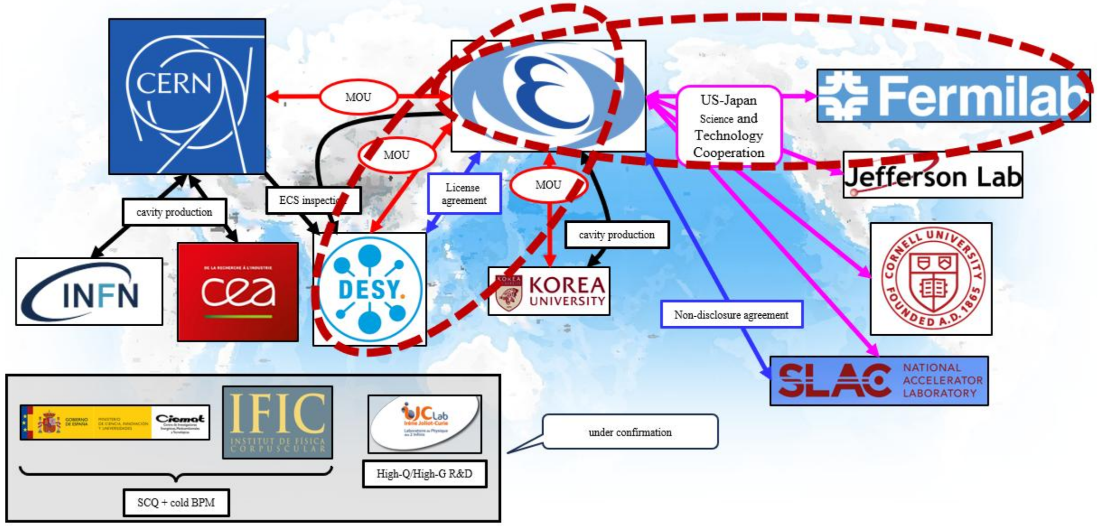
Introduction

- International Linear Collider (ILC)
  - Higgs factory machine (250 GeV center of mass energy)
  - ~ 8,000 superconducting radio frequency (SRF) 1.3 GHz 9-cell TESLA-type cavities
- ILC Technology Network (ITN)
  - The ITN is initiated, jointly by the High Energy Accelerator Research Organization (KEK) and ILC International Development Team (IDT) to execute high priority work packages for the ILC Pre-lab proposal.
  - ITN is an independent organization based on arrangements between KEK and participating laboratories.
- From 2023 to 2027 we will build and test an ILC prototype cryomodule at KEK, including all necessary infrastructure
  - Includes 8 cavities → requires **8 tuners**

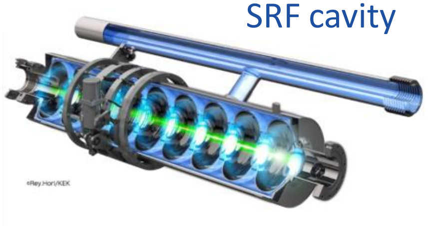
ILC



Global collaboration on SRF for MEXT-ATD/ITN



SRF cavity



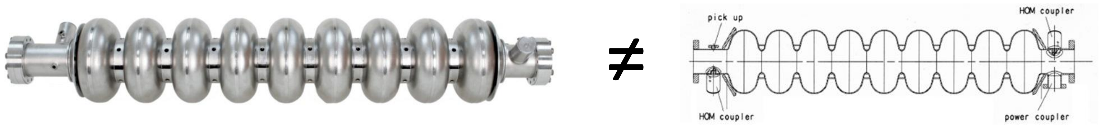
8 x

ILC prototype cryomodule

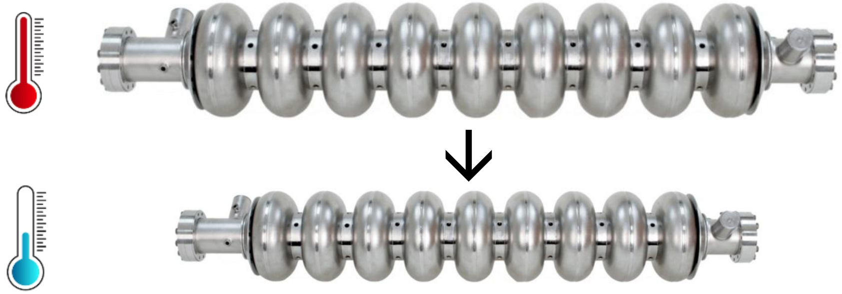
Why do we need a cavity tuner?

- The eigenfrequency of the cavity is determined by its shape

- Cavity cannot be built perfectly
→ we have to tune it to the target frequency inside the CM



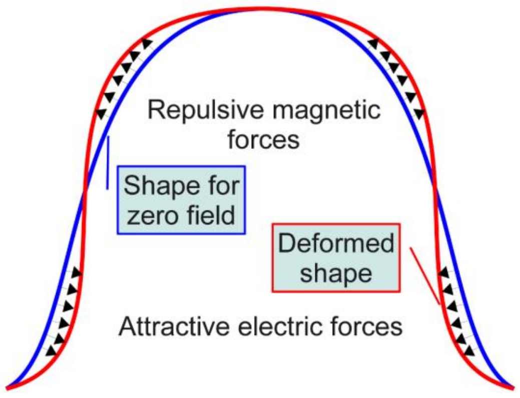
- When we cooldown the cavity, it shrinks
→ we have to compensate for this change in frequency

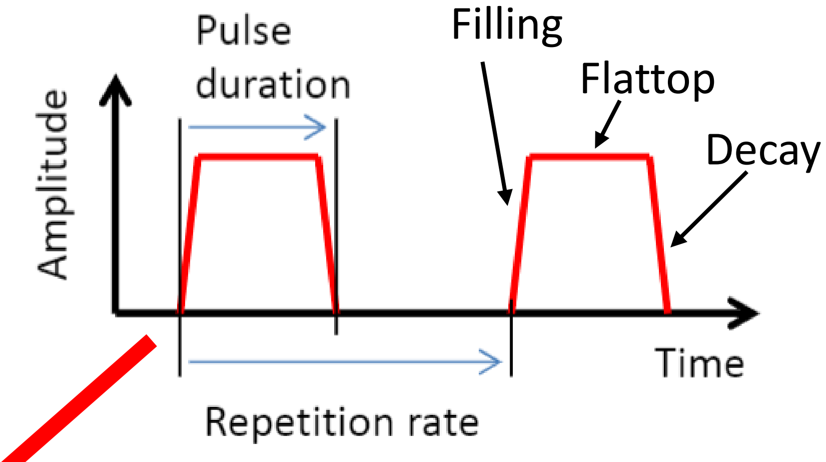


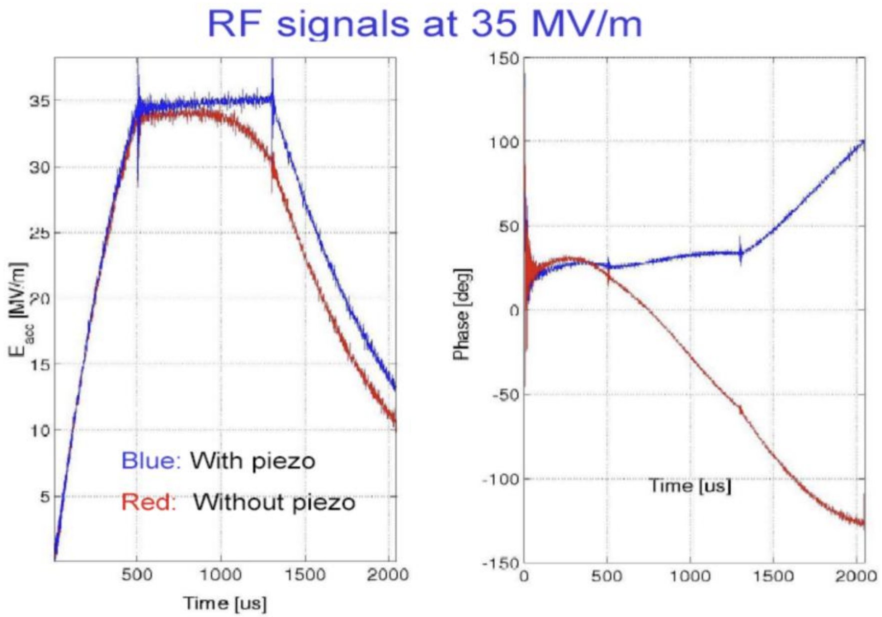
Why do we need a cavity tuner?

- Pulsed mode
  - Short Pulse mode (SP)
    - Duty factor of e.g. 1%
  - Long Pulse mode (LP)
    - Duty factor of 10% to 50%
  - Only a certain portion of time (flattop) is useable for beam acceleration
- When we apply pulsed RF, **Lorentz force detuning** occurs, which deforms the cavity
  → has to be compensated for

Change of cavity shape







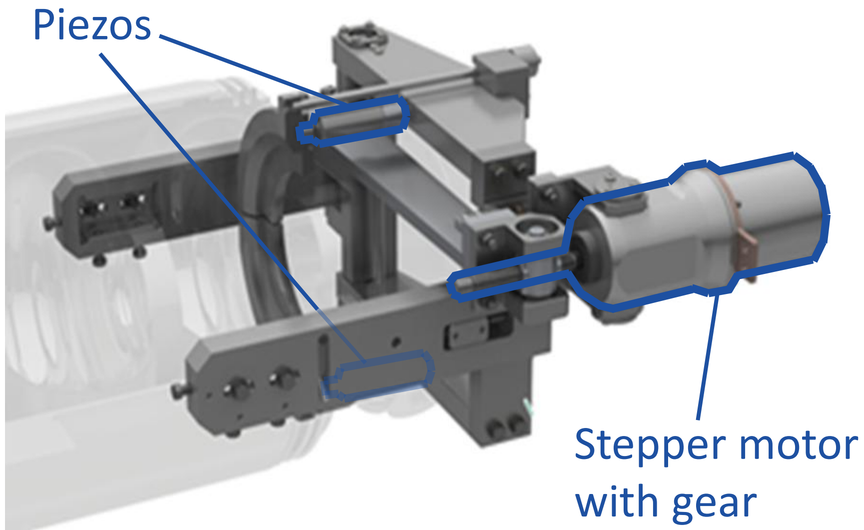
Timeline for ITN tuner

Activities	FY2023	FY2024	FY2025	FY2026	FY2027
Selection of tuner, preparational work					
Production and test of prototype tuner					
Series production					
Component testing, pre-assembly					
CM assembly, CM test					

Tuner selection

- Requirements
  - Maximal force on the cavity 8.4 kN
  - 2 mm displacement (operational)
  - Lorentz Force Detuning compensation for gradients up to 40 MV/m (~2 kHz)
  - Reliable
  - Low cost
  - Compact (short beam pipe)
  - Derive from proven design

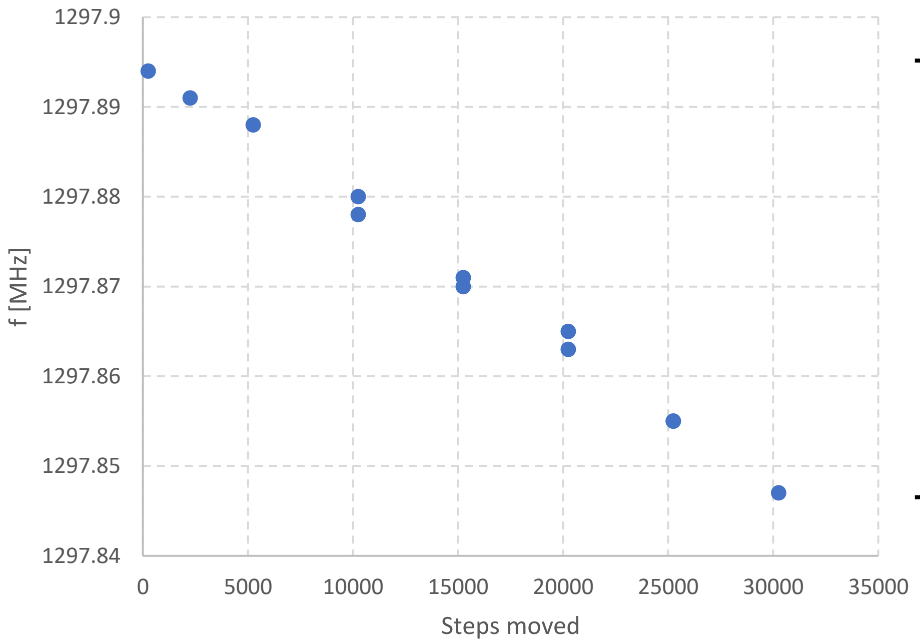
	Parameter	Specification
		ITN
General	Minimal operational temperature	4 K
	Maximal operational temperature	20 K
	Maximal non-operational temperature	40 degree C
	Operational pressure	10E-6 Pa
	Limited outgassing	10E-7 Pa m3/s
	Maximal force on the cavity	8.4 kN
	Displacement range (operational)	2 mm
	Displacement range (maximum)	3 mm
	Minimal stiffness	30 kN/mm
Slow actuator	Minimal tuning range	600 kHz
	Maximal hysteresis	10 um
	Motor characteristics	Stepping motor, power-off holding, magnetically shielded
	Motor location	Inside 5 K shield, accessible from outside
	Magnetic shield	< 20 mG
	Motor lifetime	32E6 steps
	Maximal heat load by motor	50 mW at 2 K
	Gear transmission ration	50:1
	Lifetime in gear output revolutions	3200 revolutions
Fast actuator	Lorentz Force Detuning compensation of gradients up to	40 MV/m
	Maximal LFD residuals	50 Hz at 31.5 MV/m flat-top
	Minimal tuning range	1.6 kHz at 2 K
	Actuator	Piezo actuator, located inside 5 K shield, two actuators for redundancy
	Maximal heat load by actuator	50 mW at 2 K
	Maximal drive voltage	150 V
	Magnetic shield	< 20 mG
	Minimal actuator lifetime	5E9 pulses



→The ITN tuner will be based on LCLS-II tuner
- Only solution for short beam pipe

Collaboration with Fermilab under the US-Japan Collaboration Program in HEP

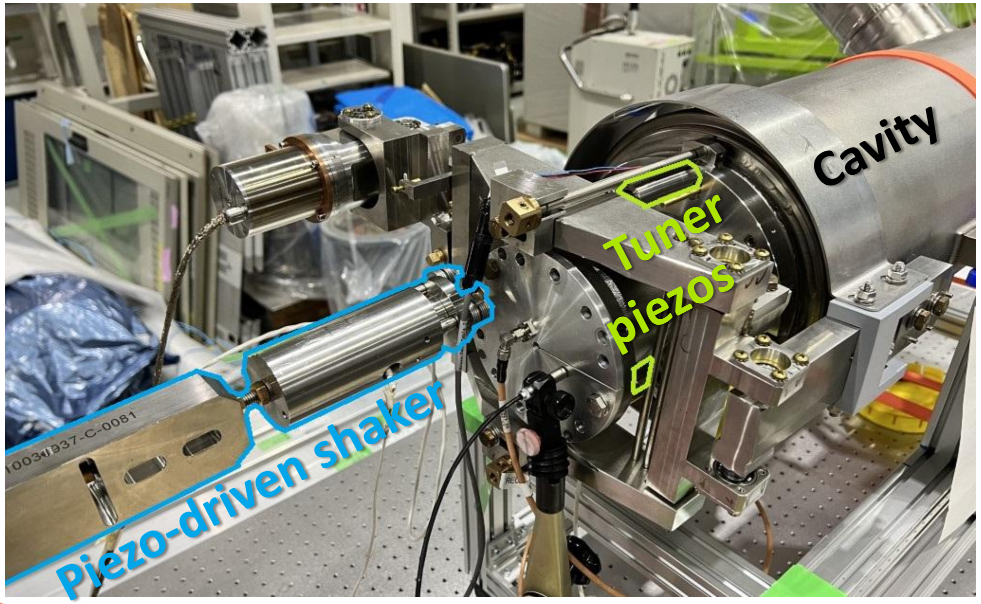
- KEK lend from Fermilab an LCLS-II cavity and LCLS-II tuner
- Joint setup and test at KEK
  - Slow tuner test (not full range)



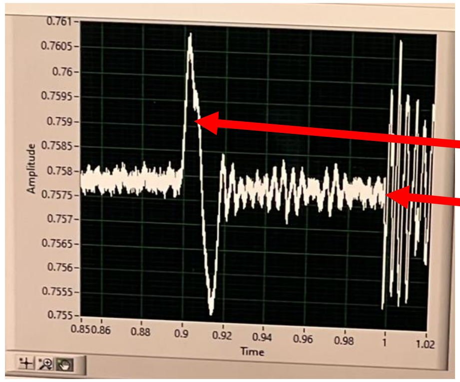
30 kHz
~
0.1 mm

Collaboration with Fermilab under the US-Japan Collaboration Program in HEP

- Cavity at room temperature and atmospheric pressure
- Simulated LFD by piezo-driven shaker
- Compensation by tuner piezos
- Successfully demonstrated 1 Hz operation



Phase detector output voltage vs time:

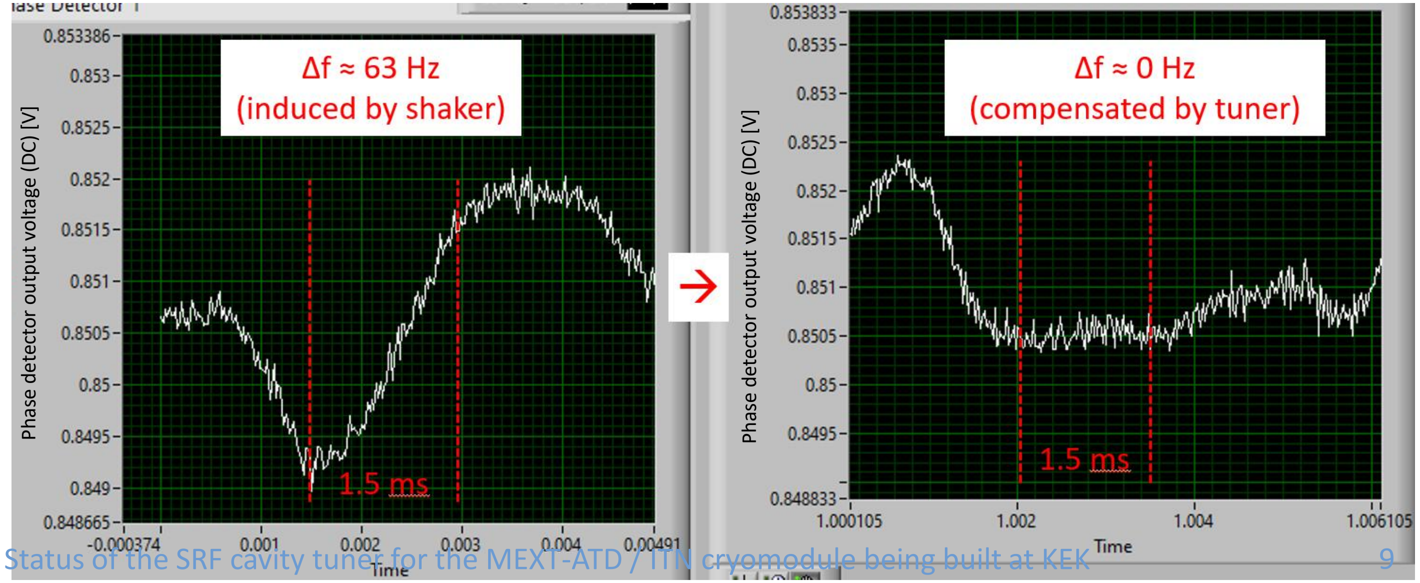


Example drive with 1 Hz repetition rate:

- Piezo 50 Hz sine (LabView/DAC)
- Shaker pulse (2 ms) (function generator)

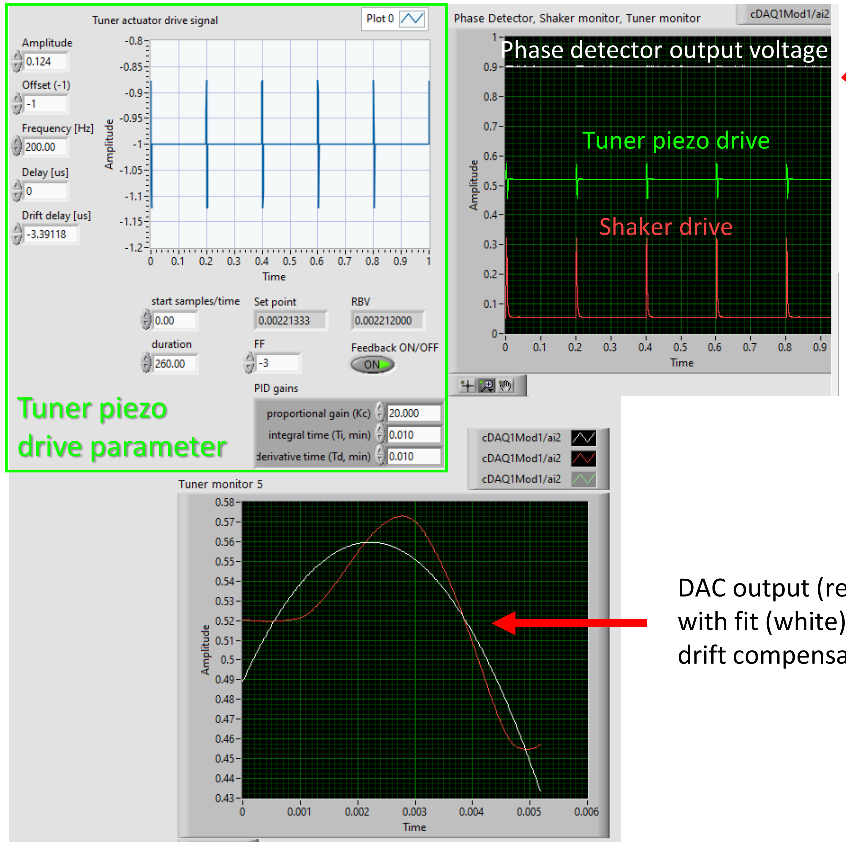
1) only shaker

2) shaker plus tuner piezos



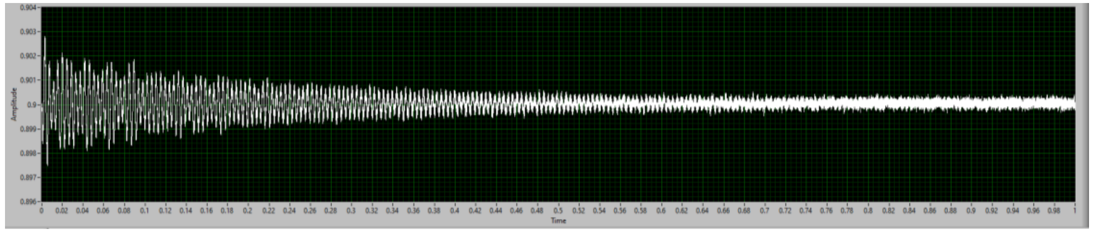
Further development at KEK for 5 Hz operation

- ILC prototype CM will be operated at a 5 Hz repetition rate
- Lorentz Force induced vibrations are overlapping
- Wrote new LabView code to allow stable 5 Hz operation
- Suppressed DAC drift with PID controller

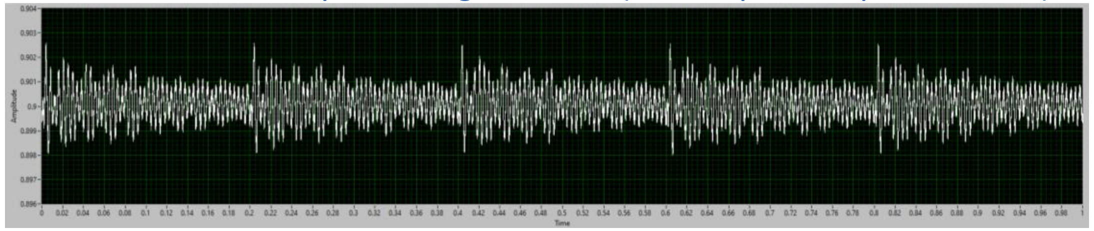


DAC output (red) with fit (white) for drift compensation

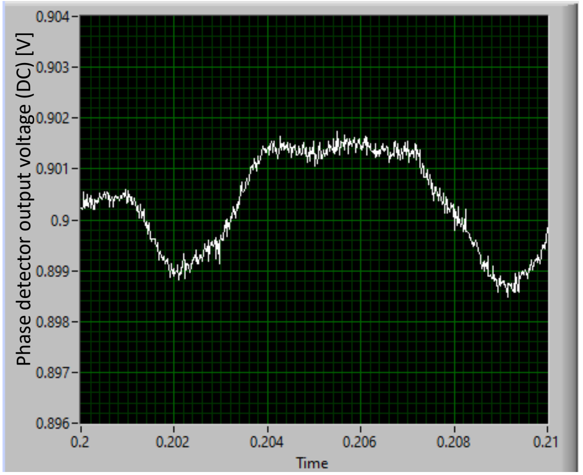
Phase detector output voltage vs time (shaker pulse rep. rate: **1 Hz**)



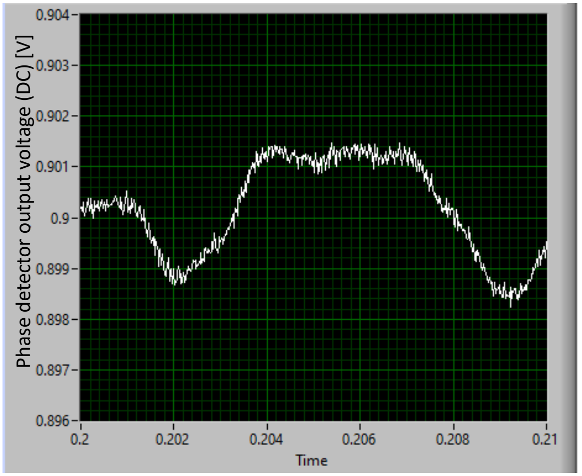
Phase detector output voltage vs time (shaker pulse rep. rate: **5 Hz**)



Phase detector output voltage vs time (shaker pulse and compensation rep. rate: **5 Hz**)

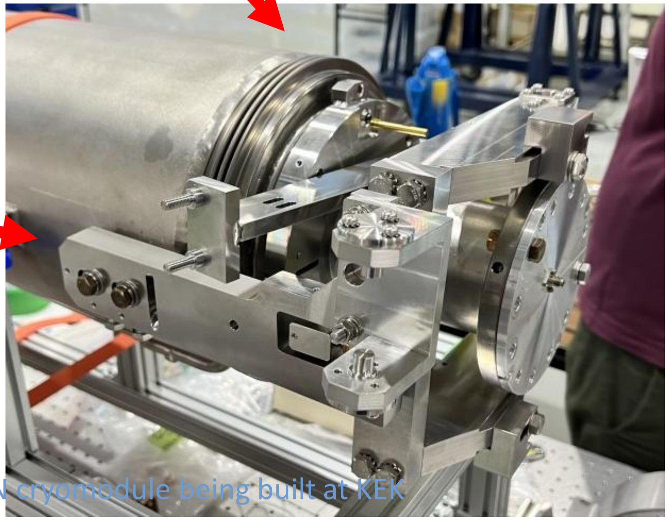


126 min. later



First domestically produced ITN tuner prototype

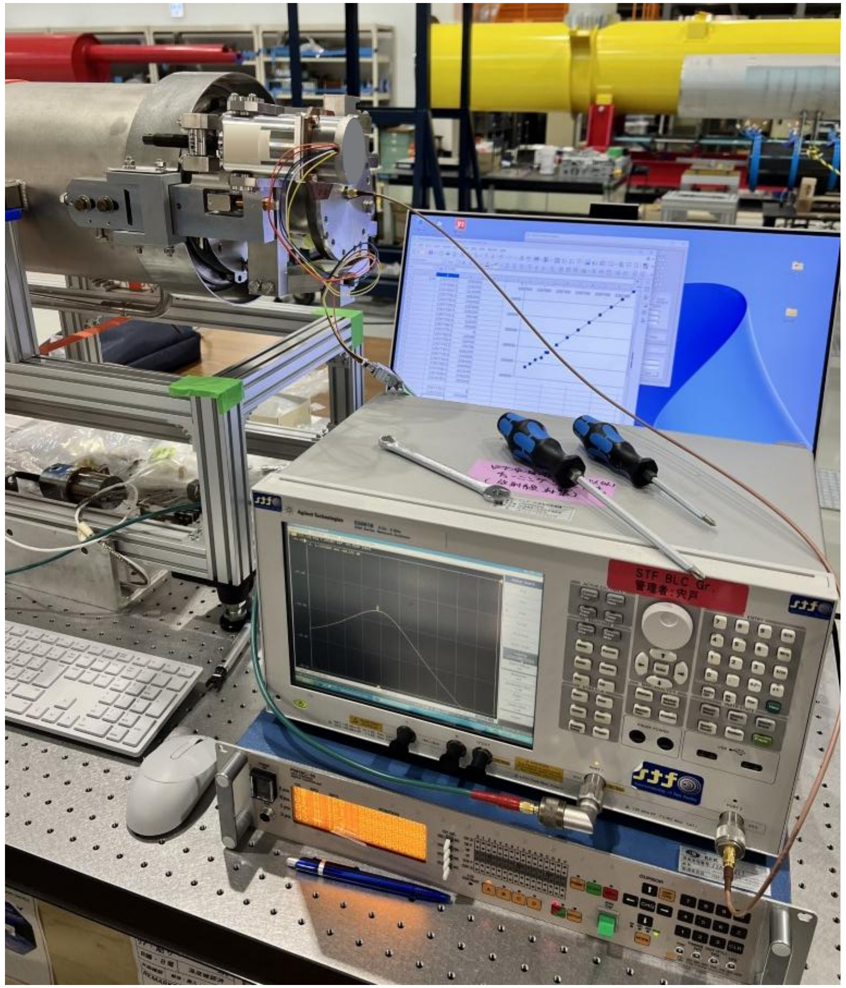
- Difference to LCLS-II tuner
  - All metric
  - Stainless steel screws
  - Bearings only for room temperature test
- Pre-assembly and assembly on LCLS-II cavity went smoothly



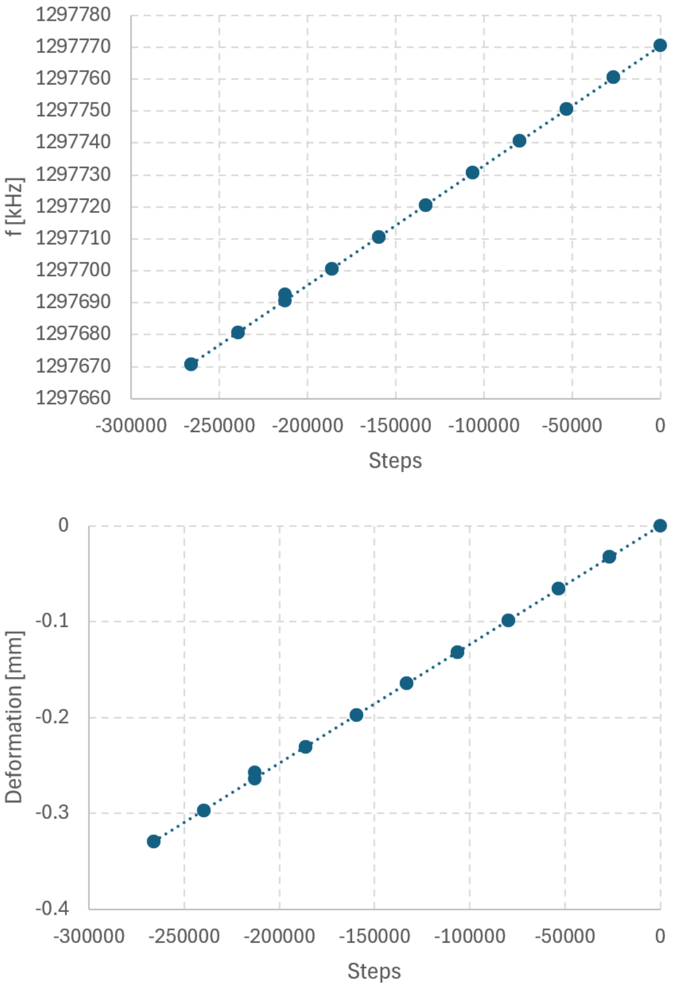
First time tuning of an LCLS-II cavity with a domestically produced ITN tuner while using motor B

- Usage of piezo dummies
- Cavity pre-loaded by 50 kHz
- Tuned cavity by 100 kHz by slow tuner

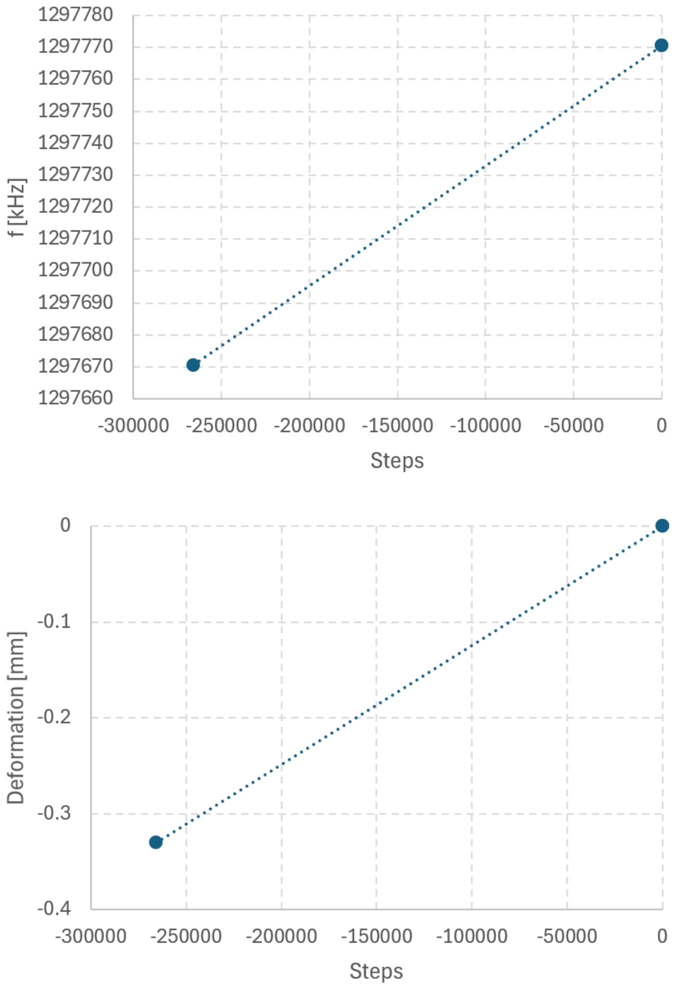
→ Motor B also works with ITN tuner



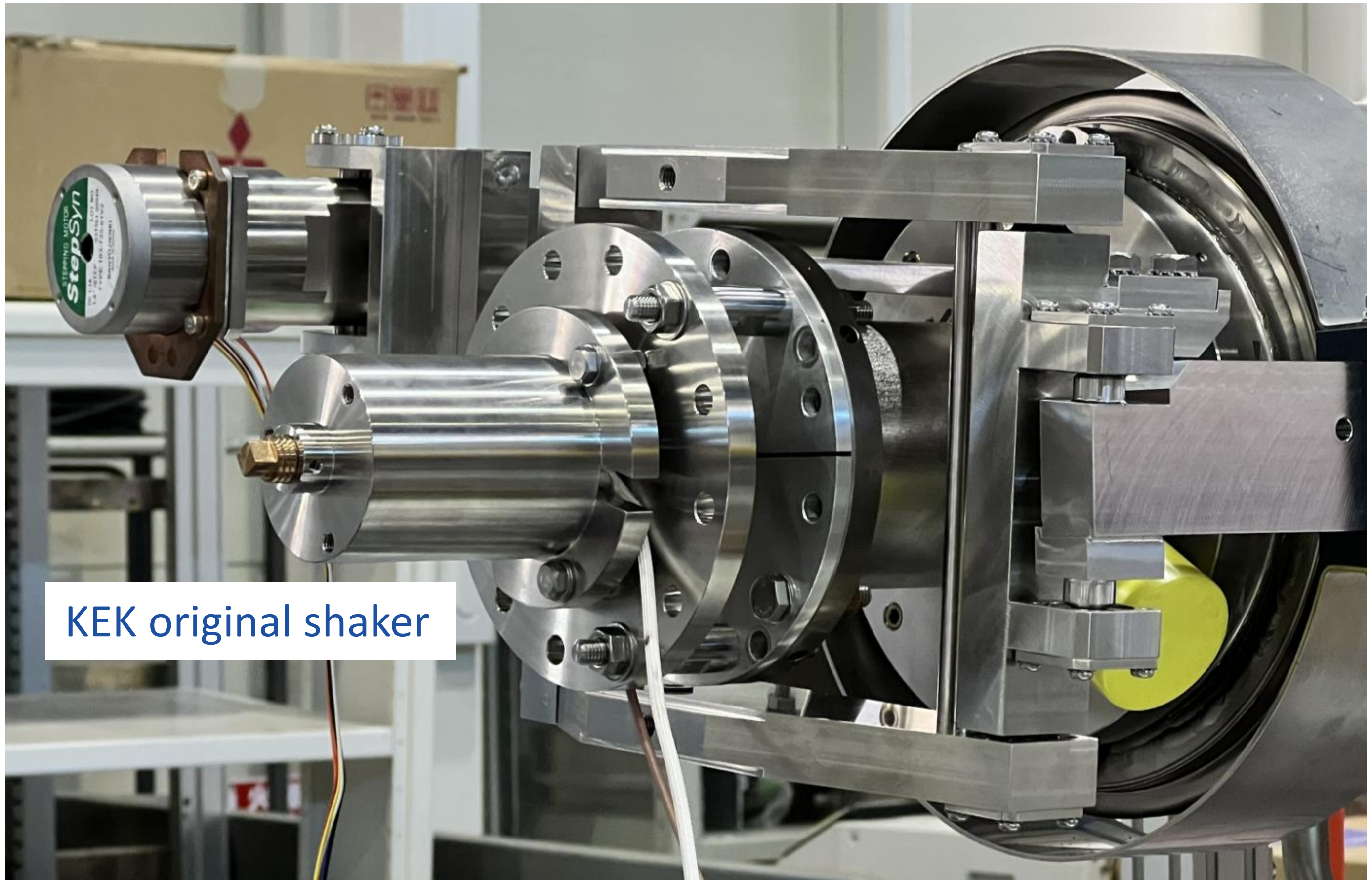
Scan of steps (back and forth)



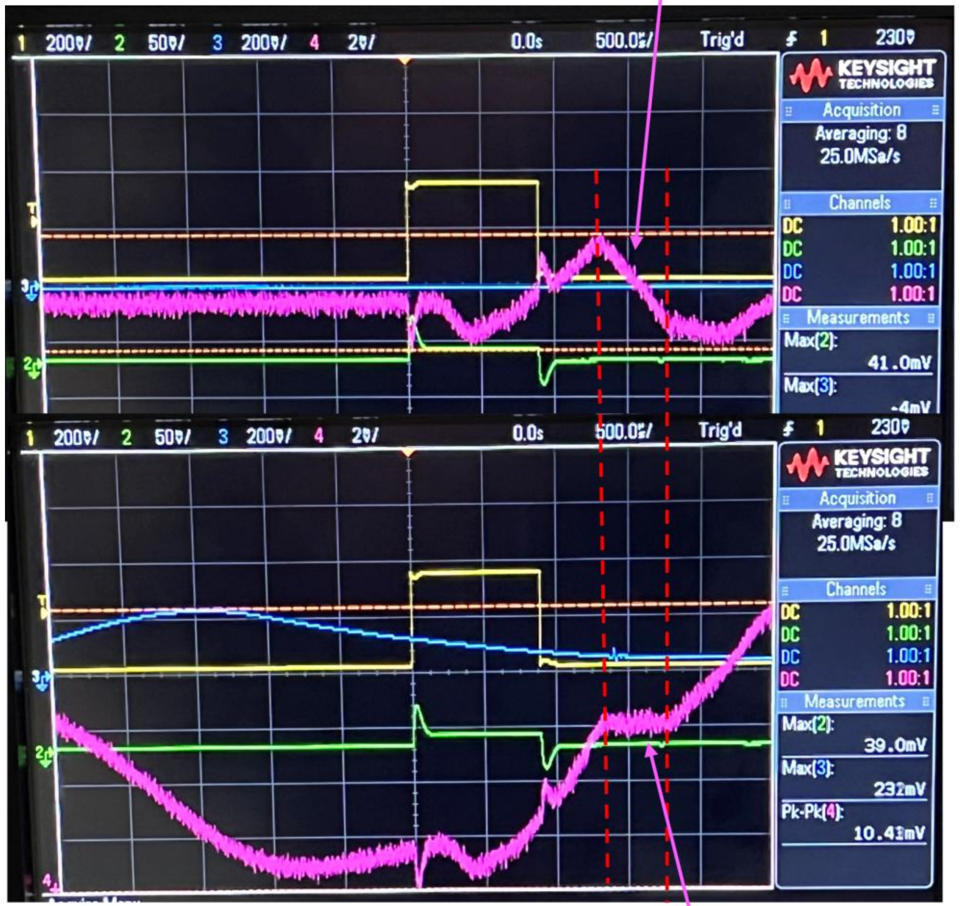
Full way in one go (back and forth)



By KEK shaker simulated LFD compensation test



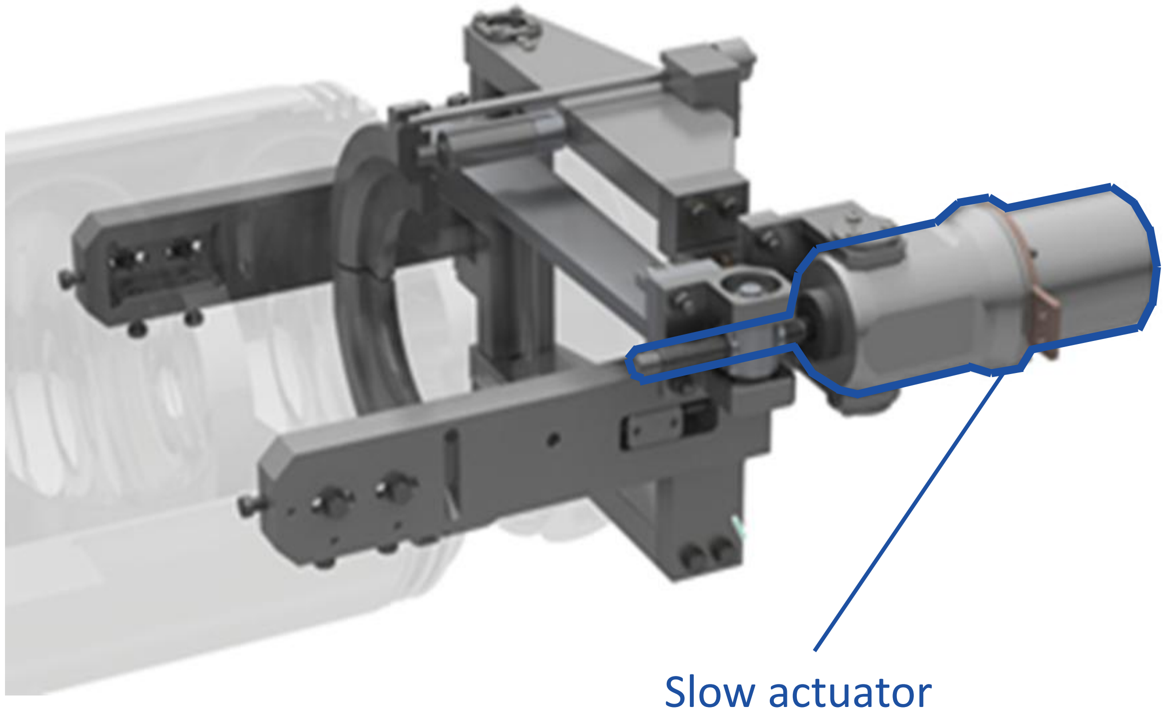
Δf = 0.5 kHz



Δf = 0 kHz

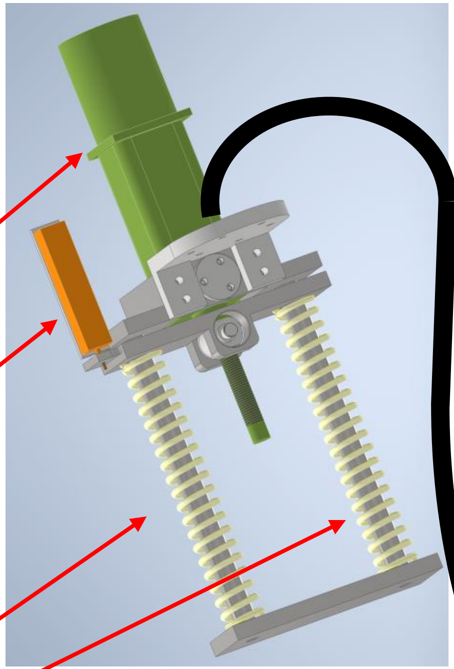
Status of slow actuator (stepper motor & gear)

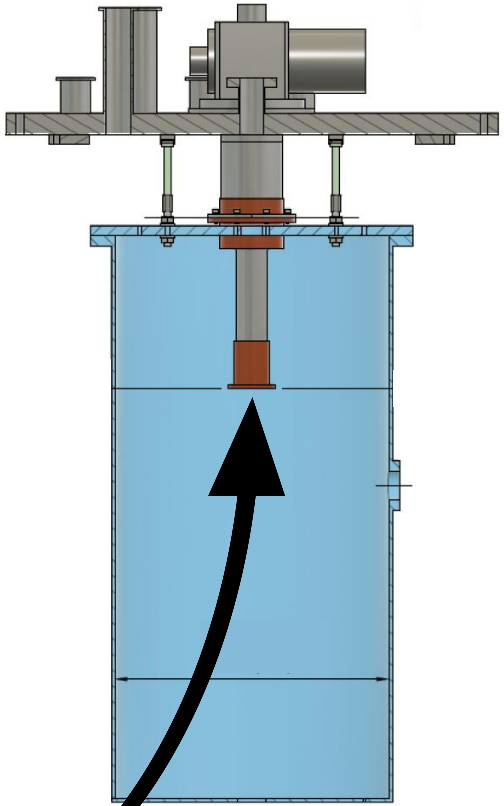
- LCLS-II tuner uses stepper motor A
  - Specifications exceed our need drastically
  - Discrepancy between budget and quoted cost
- Basically, no alternatives available on the market
  - Motor must operate at cyrogenic temperatures (~20 K)
  - And in vacuum (10^{-5} Pa ~ 10^{-6} Pa)
- European XFEL tuner uses stepper motor B
  - Received one unit from DESY for testing purposes
  - Product reached already end of life
  - Started discussion with company towards a new product



Plan of qualification of new slow actuator

- Slow actuator test
  - Before CM assembly
  - Within cryo-cooler cryostat
    - Operation at cyrogenic temperatures (~20 K)
    - Operation in vacuum (~10^{-6} Pa)
  - Motor with gear
  - Potentiometer to measure displacement
  - Two springs simulate cavity and tuner





Requirements of fast actuator (piezos)

	Parameter	Specification
		ITN
Fast actuator	Lorentz Force Detuning compensation of gradients up to	40 MV/m
	Maximal LFD residuals	50 Hz at 31.5 MV/m flat-top
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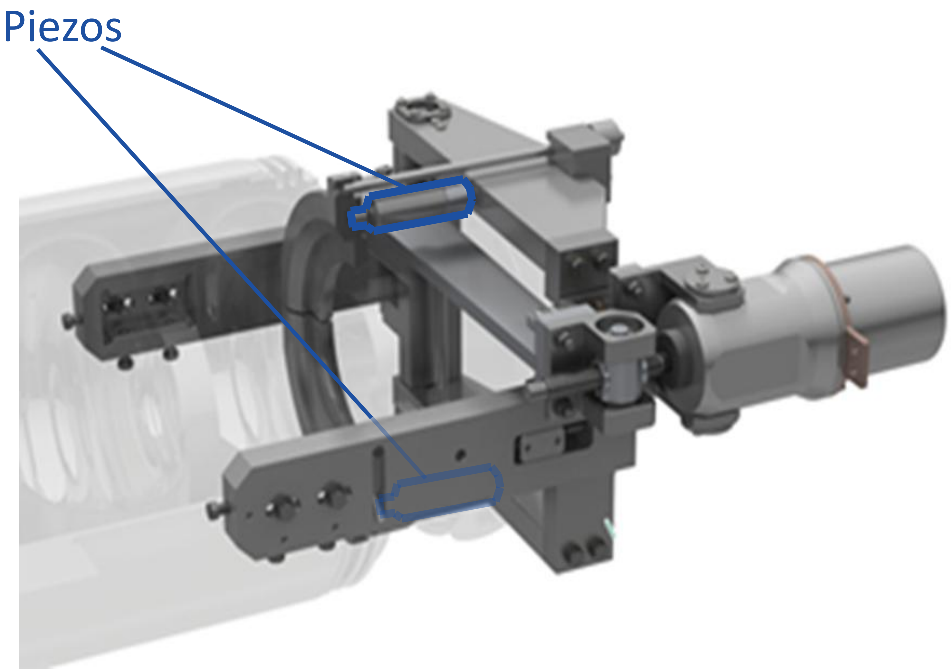
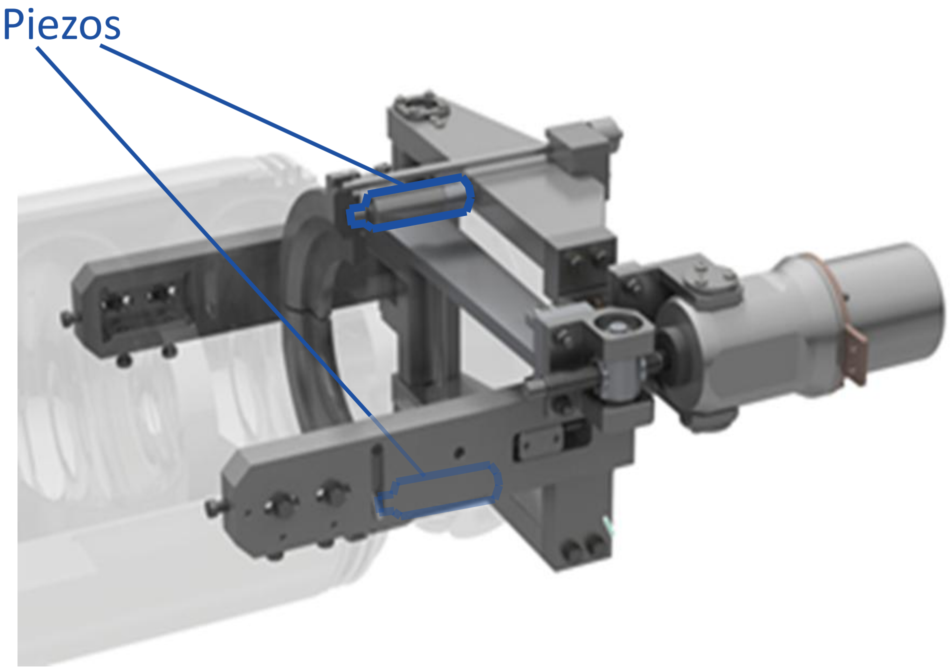


Options of fast actuator (piezos)

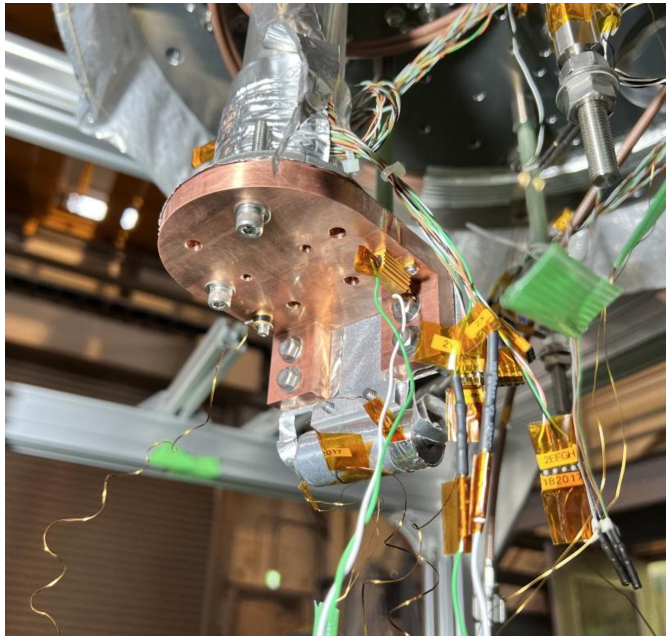
- Fermilab develop a special piezo setup
  - Encapsulation with non-magnetic metal
  - Ball joints between piezos and tuner and cavity (split ring), respectively
  - Etc.
  - Product still available
- Product of second company

- Evaluation was required

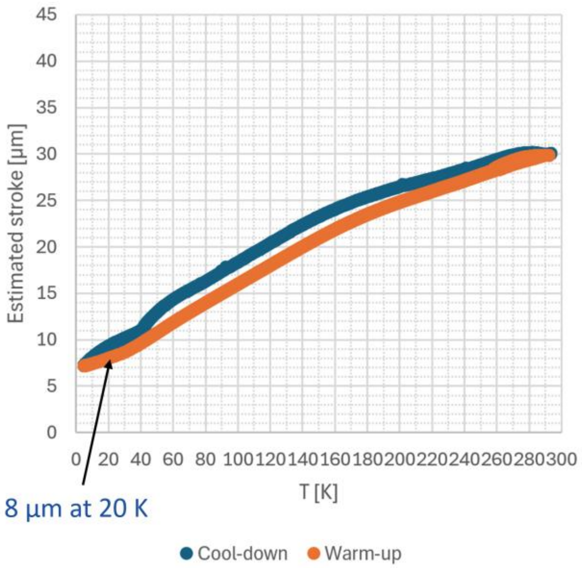


"Frequency stability of the SRF cavities (microphonics)", Y. Pischalnikov

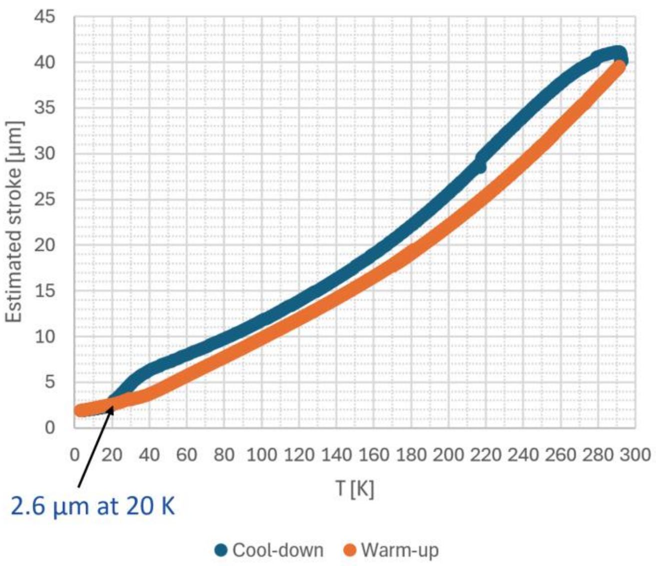
Evaluation of stroke of two candidate piezos



- Piezo used at LCLS-II



- Other candidate piezo



Estimated a required stroke of between 3.2 µm and 7.3 µm
→ We picked and ordered the same piezo as used for LCLS-II

Summary

- ILC prototype CM under construction at KEK, test end of FY2027
- ITN tuner is a derivate of the LCLS-II tuner
- Tuner body
  - 1 prototype produced in FY2024
    - Successfully tested on cavity at room temperature and atmospheric pressure
  - 4 units will be produced in FY2025
  - 3 further units will be produced in FY2026
- Slow actuators
  - Development of new product with industry
  - 1 prototype will be produced and tested in FY2025
  - 9 units will be produced in FY2026
- Fast actuators
  - 20 units will be produced in FY2025

Thank you very much for your attention! Questions?

- KEK ITN tuner team
  - Mathieu Omet
  - Kensei Umemori
  - Yasuchika Yamamoto
  - Takeshi Dohmae
  - Ashish Kumar
  - Rishabh Bajpai
  - Tomohiro Yamada
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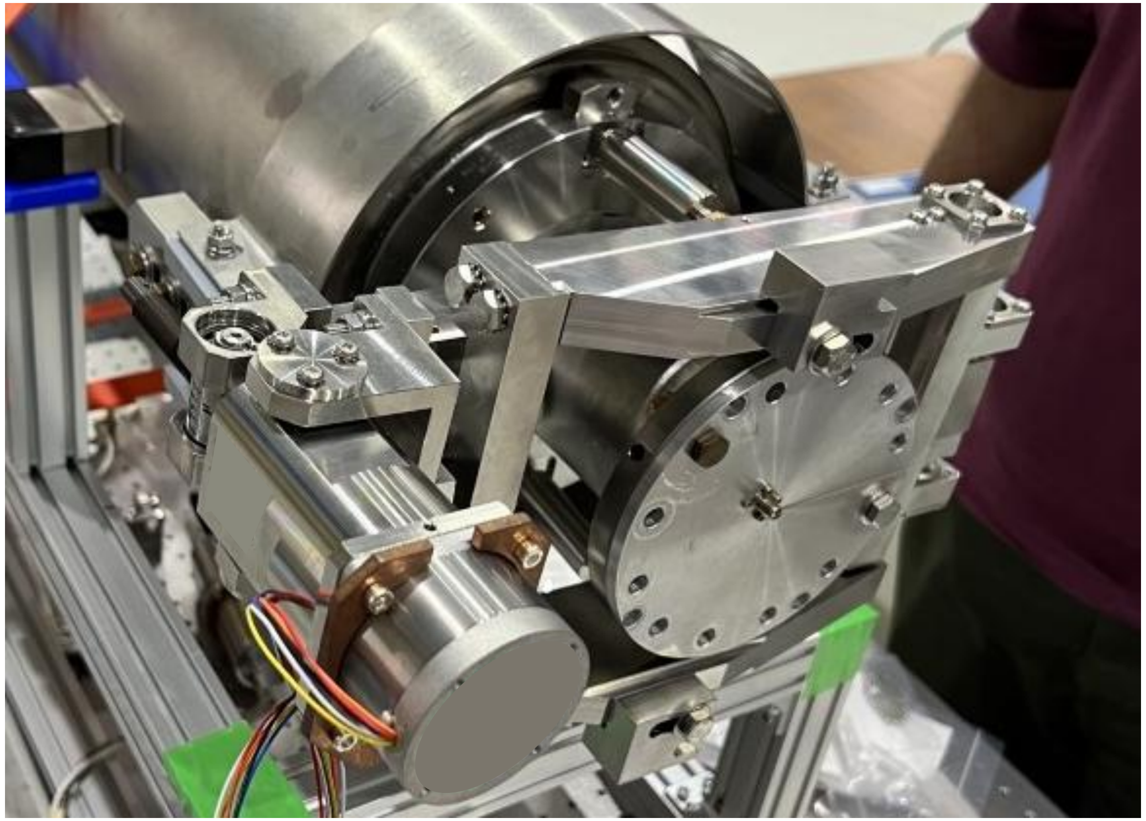
  - Sergey Belomestnykh
  - Yuriy Pischalnikov
  - Crispin Contreras-Martinez
- Acknoledgements
  - Hans Weise (DESY)



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