Piezoelectric stack based system for Lorentz force compensation

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Outline

- Electromechanical tuners variety
- Active elements
- Current problems and achievements

Three main purposes of tuner system

Slow tuner

•Pre-tuning is necessary stage to reach proper frequency. Cavity with couplers are assembled at room temperature, during cooling down and pumping the cavity shape is deformed. Required system might work slow but must be able to change the cavity length in range of several millimeters (corresponds to a few MHz of detuning compensation). The pretuning phase will be performed i.e. once a week or even month.

Fast tuner

•Lorentz Force compensation. During pulsed operation the cavity is reloaded with frequency of 1.3GHz. The current, which flows through cavity walls, interacts with electromagnetic field inside cavity and as a result changes its shape and its resonant frequency. Detuning depends on accelerating field gradient ($\Delta f_{static} \sim E_{acc}^2$) and might be equal even 1000Hz. The Lorentz force is repetitive and periodic. The system needs to act quite fast (up to 2kHz). It will be operated each pulse (repetition rate up to 20Hz)

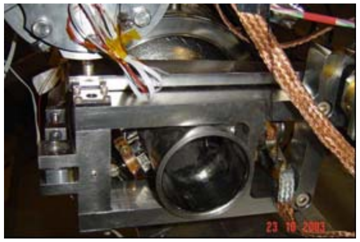
•Microphonics is a vibration of environment. It is fully stochastic. The detuning caused by microphonics is below 20Hz. A feedback loop is required. The system should work permanently.

Electromechanical tuners variety

Electromechanical systems for Lorentz force & microphonics compensation and for pre-tuning stage

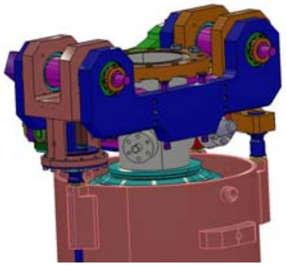
CEA-Sacley current design

- Double lever system
- Stepping motor PHYTRON with Harmonic Drive gear box
- $\Delta Z=\pm 5mm$, $\Delta f=\pm 2.6MHz$
- Theoretical resolution 1.5nm
- Stiffness ~100kN/mm
- Ready for piezoelectric and magnetostrictive actuator



CEA-Sacley new design

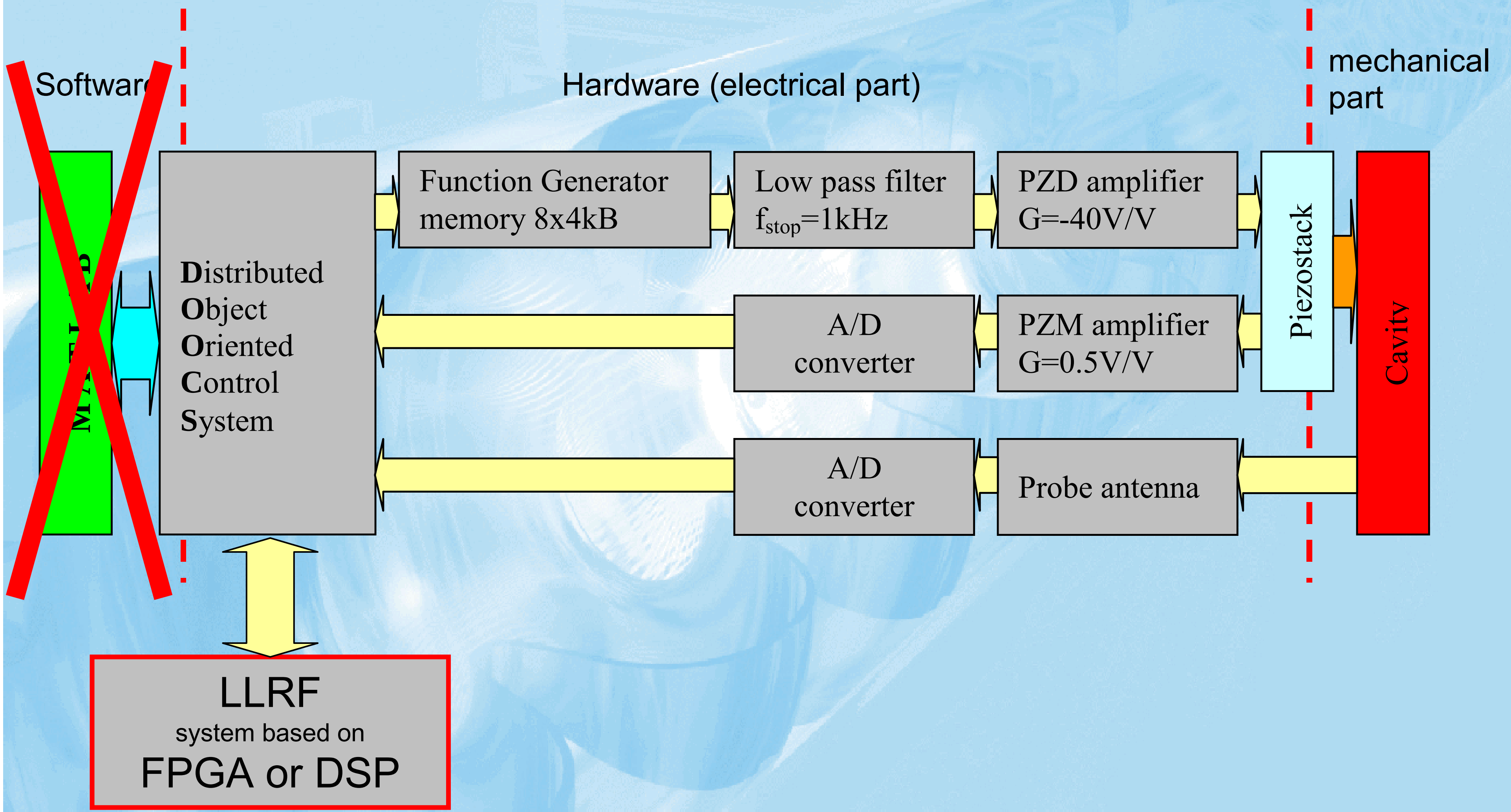
- Double lever with a screw-nut system
- Stepping motor PHYTRON or SANYO with Harmonic Drive gear box
- $\Delta f=\pm 2MHz$ @RT, $\Delta f=\pm 460kHz$ @2K
- Ready for piezoelectric and magnetostrictive actuator
- preload force for active elements is almost decoupled with motor position



UMI Milan tuner Coaxial

- Three coaxial rings connected by blades
- Stepping motor for pre-tuning stage
- Piezos up to 72mm length
- Shorter dead zone between cavities 350→283mm (total accelerator length reduction by 5%)
- Expensive (factor of 2-3)
- Stiffer than others (easily upgradeable)

Control System setup



Control Panel for Piezo in ACC1 Cav5, VUV-FEL

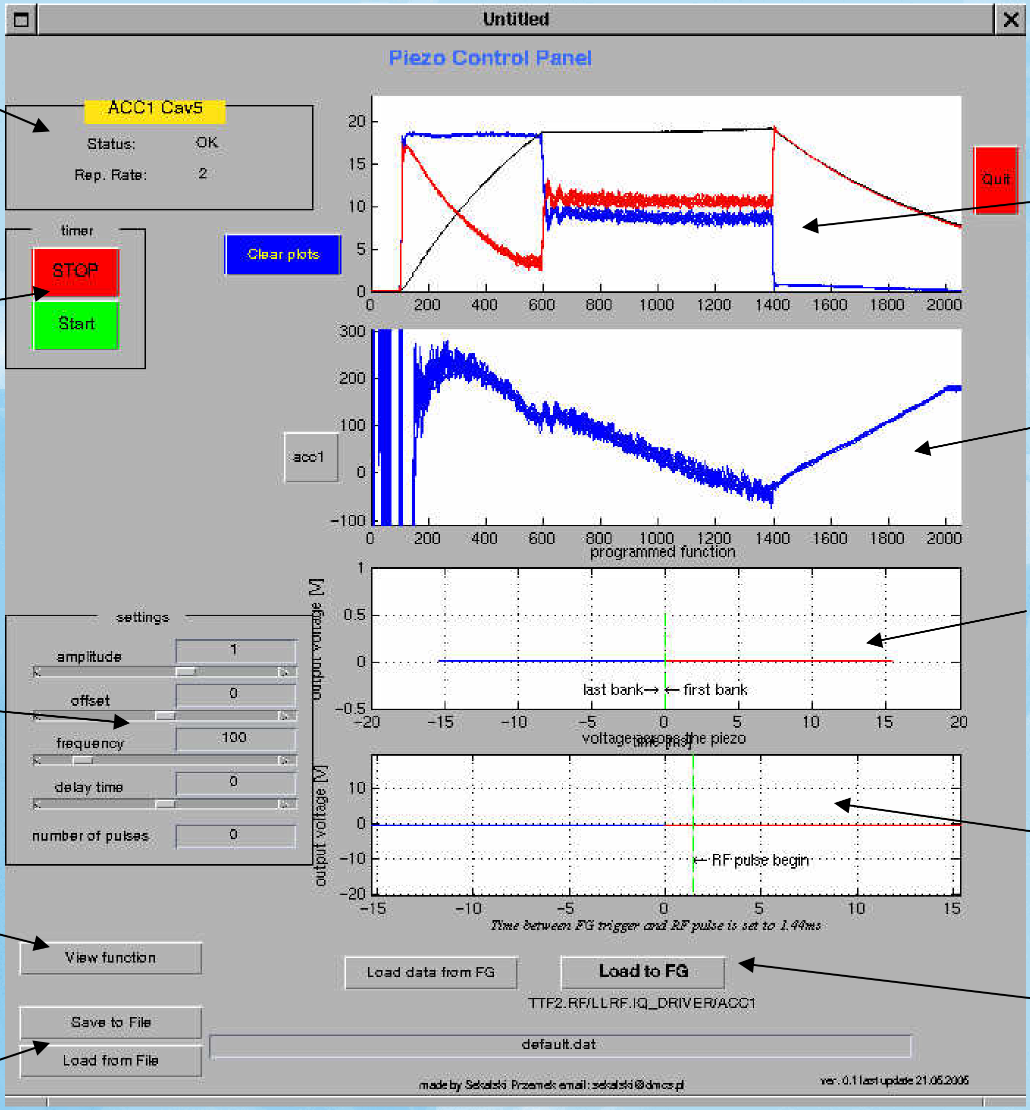
Info

Start/stop timer

Settings for pulse shape

Pulse creation

Save/load settings



Forward power, reflected power and probe

Calculated detuning (single pulse method)

Function generator output voltage

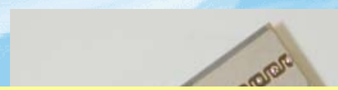
Voltage supplied to piezo

Load settings to Function Generator

Types of actuators (1/2)

Piezoelectric actuators

PZT



Di
Ma

Look at the poster ThP60 for details

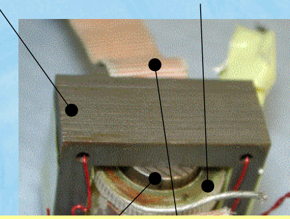
Dimensions: **7.5x7.5x50mm**
Manufacturer: **PiezoMechanik**

Dimensions: **7x7x30mm**
Manufacturer: **EPCOS**

Magnetostrictive actuators

Ferrite necessary to close magnetic circuit

Superconducting coil (Nb_3Sn)



Dimensions: **Φ10x20mm**
Manufacturer: **ENERGEN**
Material: **KELVIN ALL®**

Dimensions: **6x6x20mm**
Manufacturer: **ETREMA**
Material: **GalFeNOL**

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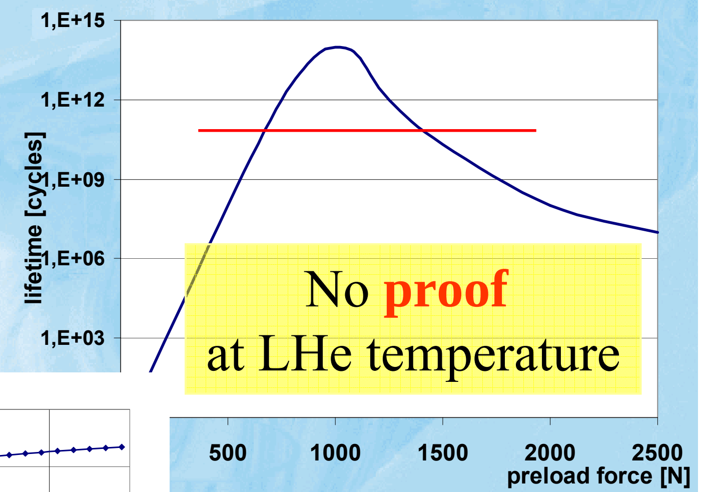
Types of actuators (2/2)

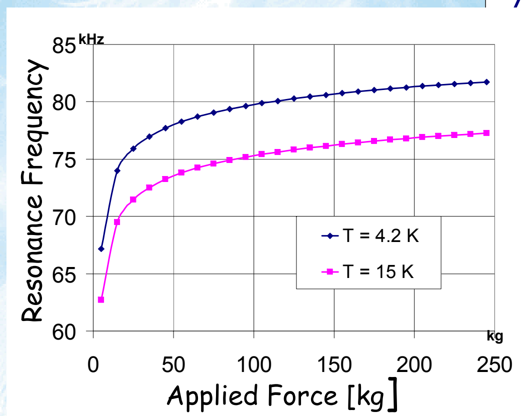
	Piezoelectric tuner	Magnetostrictive tuner
Max strain at 2K	Small, ~0.05%	Large, 0.14 -0.2% (need to be checked)
Lifetime	Large, if **preload correct** >10^{10} cycles (small damage)	Large >10^{8} cycles (no damage)
Preload	Small range, 0.7-1.5kN NOTE: few kN per 1mm (416kHz)	Large range, 0.2-10kN
Susceptibility to electric damage	High, electric break-through, safer when cooled down	Low, magnetic field driven
Stray magnetic field	Small, only from wires	Small with **niobium shielding**, <25mG at 30 mm from actuator
Cryogenic heat loss	low	Low <0.1W, can be improved, probably active cooling needed
Demonstration	yes, **with** and **without** cavity	yes, without cavity
Electronic driving system	Voltage driven,	Current driven (design effort higher)
Sensor	redundant actuator (normally sensor)	sensor needed
Price	0.8 k€ + 0.4 k€	1 k€ + 0.6 k€ ↙

Problem with piezoelectric devices preload force

The lifetime of the piezo element depends on preload force

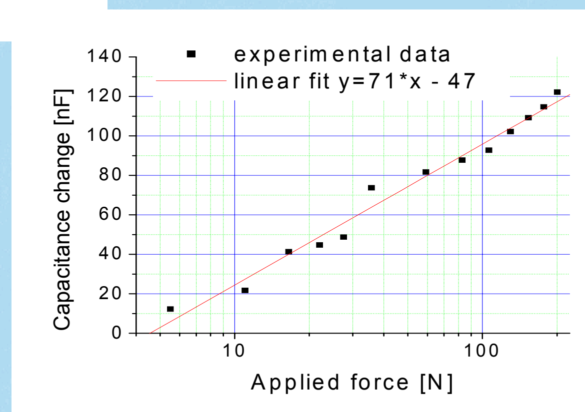


The preload force applied to piezostack implemented in cavity tuner, was roughly calculated and/or assumed but never measured

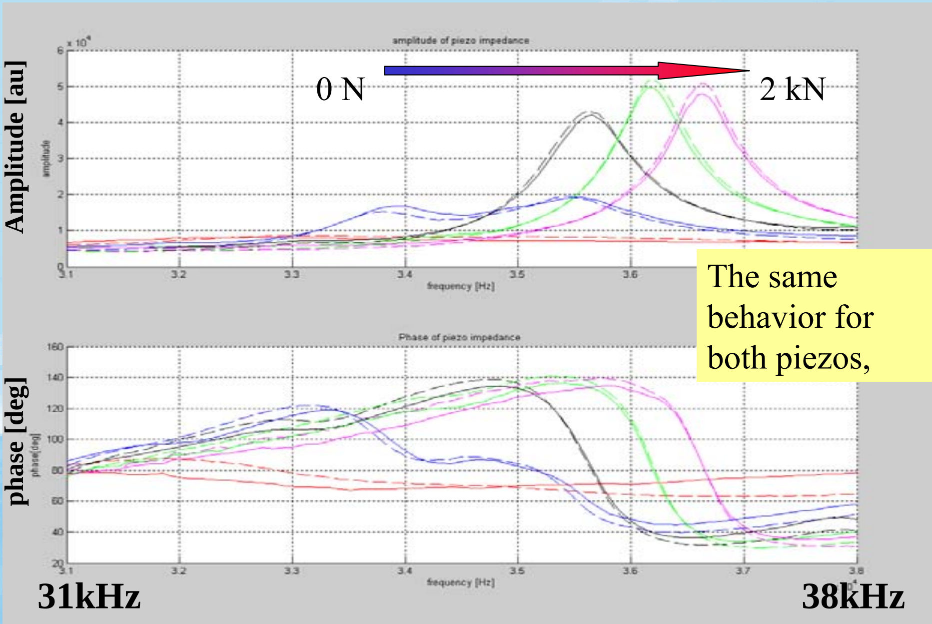


Four methods of the static force measurement at 1.8÷4 Kelvin are proposed:

1. <u>Resonance position on the impedance curve</u>
2. Capacitance change
3. Strain gauge sensor (metal)
4. Piezoresistive sensor (semiconductor crystal)



Resonance position shift versus applied force

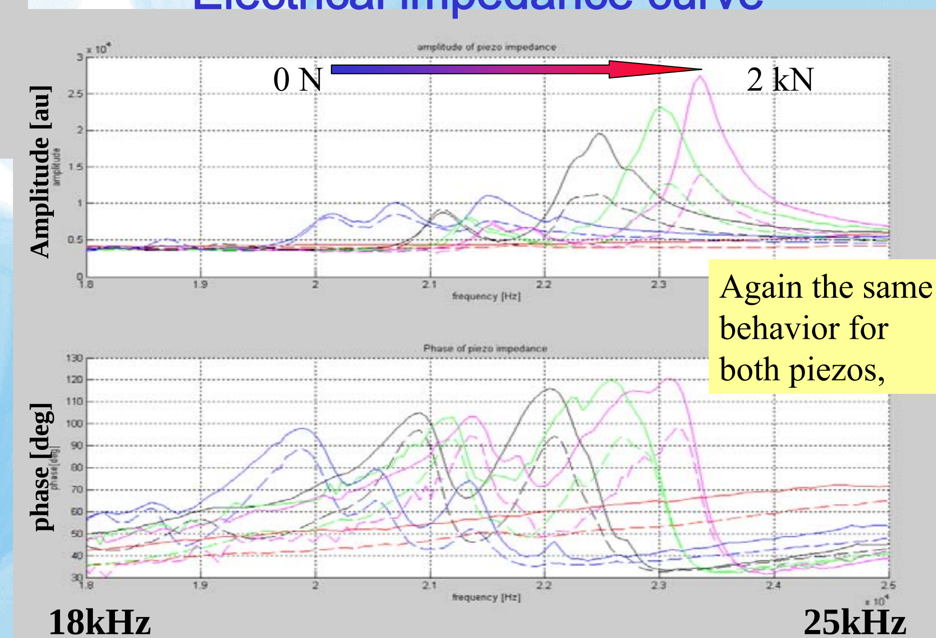


Electrical impedance curve

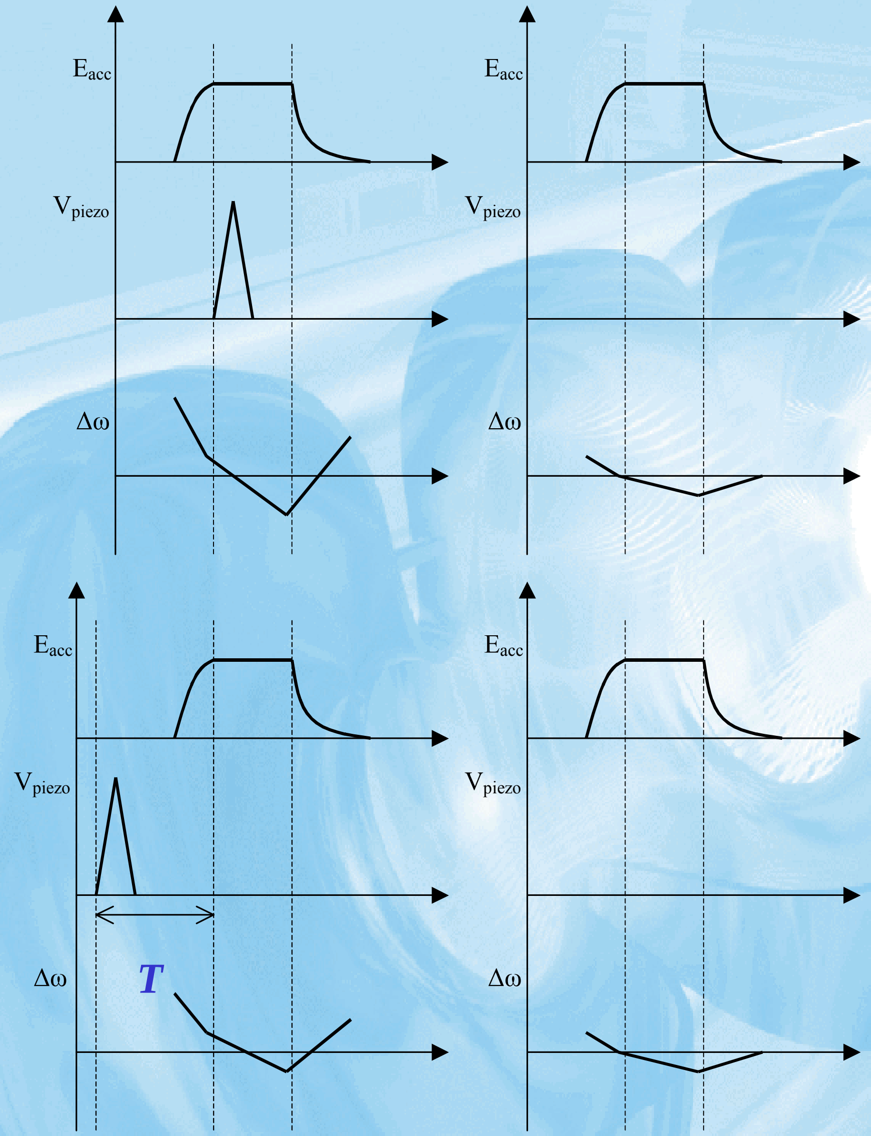
Electrical resonance around
35kHz @RT
(two NOLIAC piezostacks)

Electrical resonance around
20kHz @RT
(two NOLIAC piezostacks)

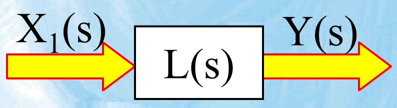
Electrical impedance curve



System identification



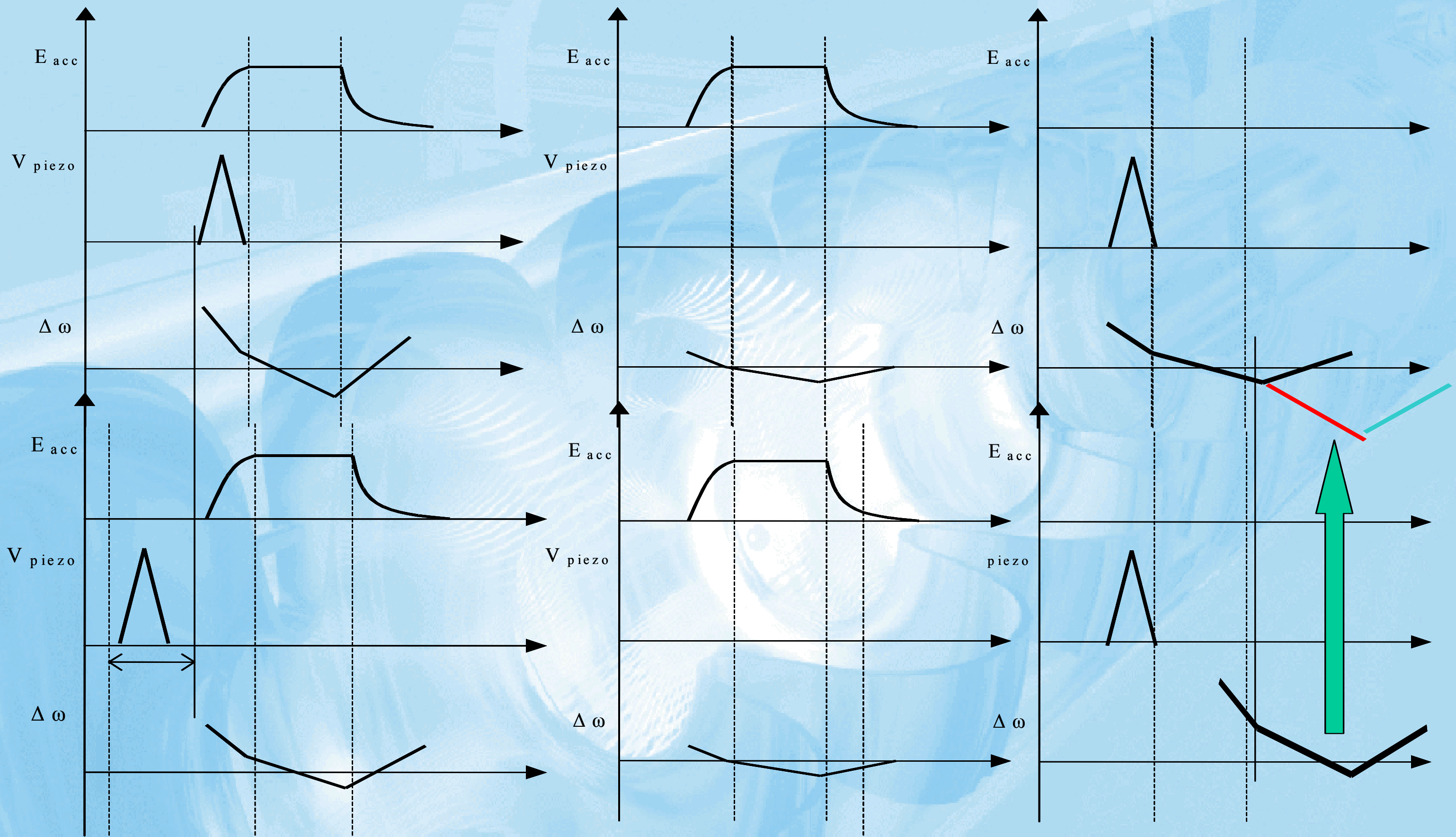
Let's assume that system is linear
Detuning caused by the piezoelement might be calculated as a difference between detuning caused by RF field with piezo action and RF field only.



Detuning is measured using forward power and probe signal. Forward power last only 1,3 ms, therefore there is need to shift piezo pulse versus RF field by ***T*** and perform next measurement.

To eliminate microphonics and other noises there is need to average data from several measurements

System identification

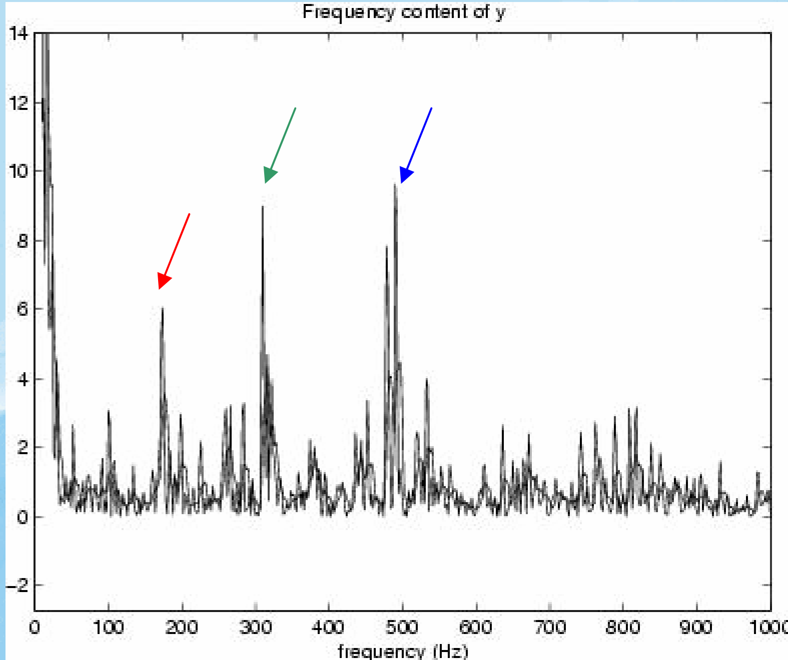


Piezostack and Lorentz force act on detuning

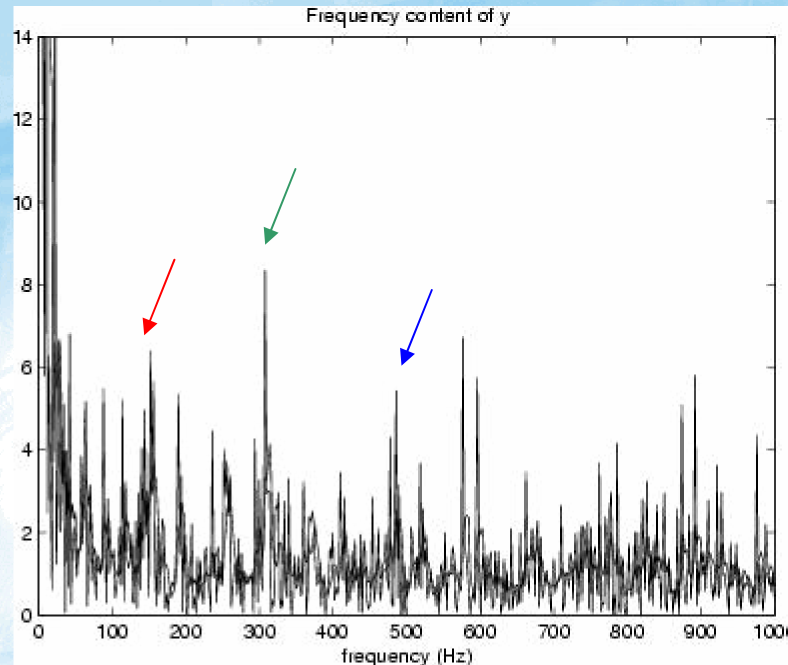
Only Lorentz force act on detuning

Subtraction of previous results is Piezo influence on detuning. (Time shift is needed for time sweep)

System identification



Spectrum of pulse response
(pulse is half sinewave 800Hz)

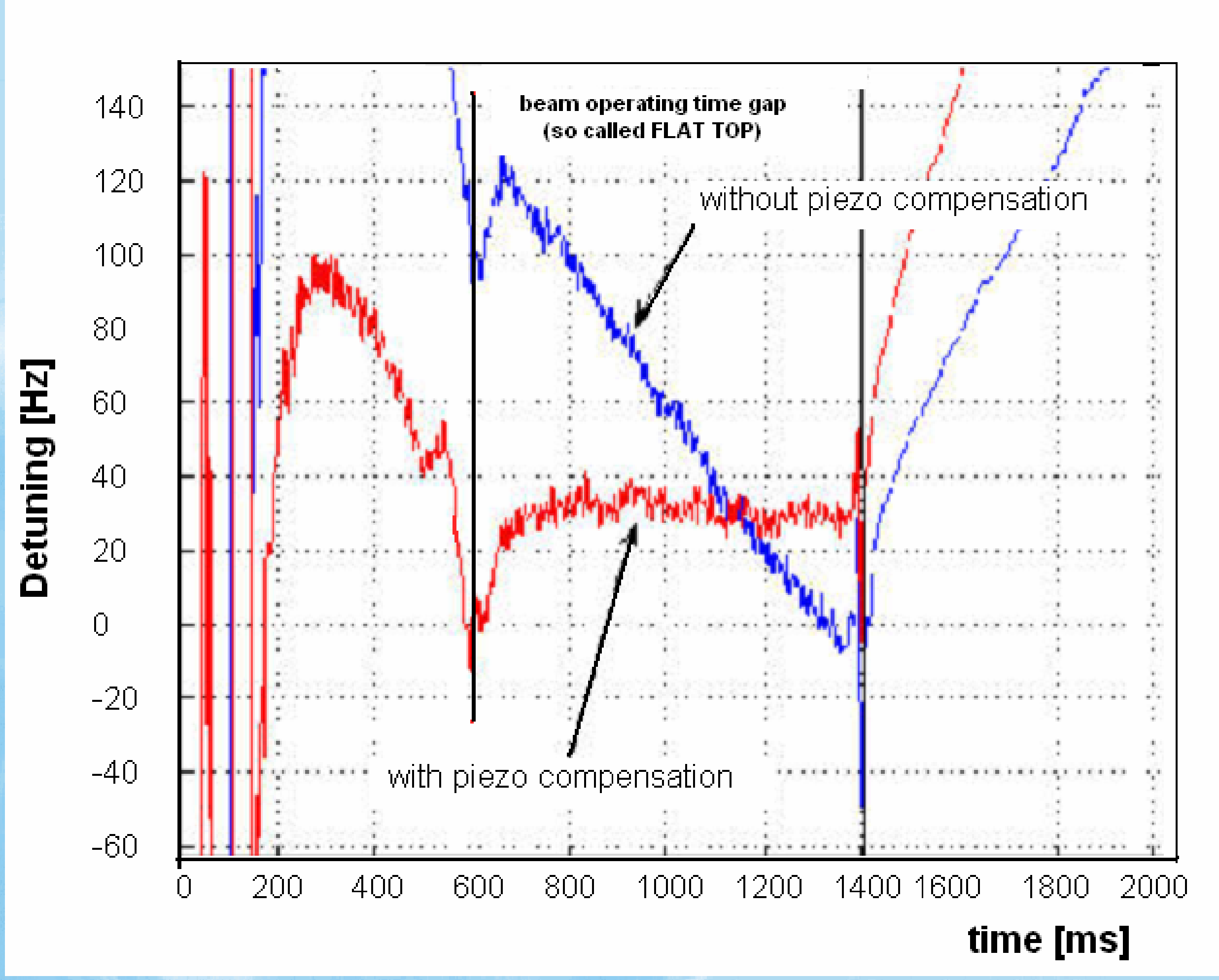


Spectrum of step response

Proper approximation will be finished soon.

Piezoelectric element control signal will be tested during next available access time (probably September 2005)

Recent results



Remaining detuning is less than 20Hz, for field gradient almost 20MV/m (VUV-FEL, module ACC1, cavity 5)

Conclusions

There are several options for cavity tuners (UMI – coaxial tuner, CEA tuners – old and new one). All tuner are simultaneously developing by CEA Sacley, France and University of Milan, Italy. A lot of problems are solved so far i.e. neutral point, **force measurement at 2K** (using i.e. resonance shift monitoring), but there are still plenty difficulties, which need to be worked out.

There are two types of actuators: magnetostrictive and piezoelectric one. The second one has been **tested with cavity with success**. The detailed study needs to be performed to compare both solutions and choose the best one. Both of types were tested successfully at LHe temperature.

First generation of CEA tuner with EPCOS piezostack is already mounted in ACC1 cavity 5 (TTF II). It is possible to reduce detuning caused by LF from 170 to 20Hz during flat-top (**almost 90%**).

The control signal is set manually nowadays. However, LF is very repetitive from pulse to pulse (according performed test the same settings are adequate for months). The **feed-forward** and **feedback** algorithm are under developing.

Acknowledgement

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Thank you for your attention