Piezo characterization, tests and operation at FLASH

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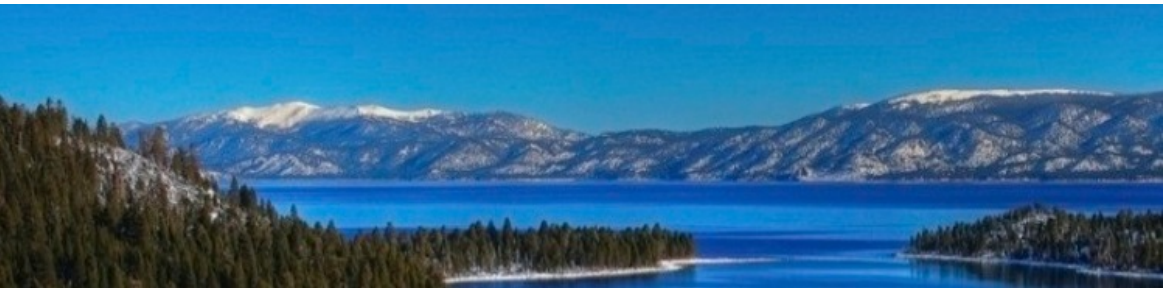


LLRF13 Lake Tahoe, 1-4.10.2013

Agenda

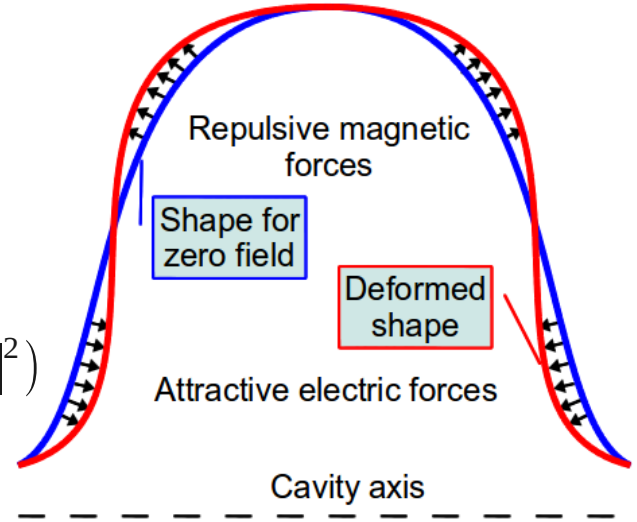
- Application of piezo tuners at SRF cavities
- Piezo's reliability
- Why bipolar piezo driving?
- Piezo's parameters and characterization at cryo conditions
- Piezo life time test
- Piezo operation at FLASH
- Conclusion

Application of piezo tuners at SRF cavities

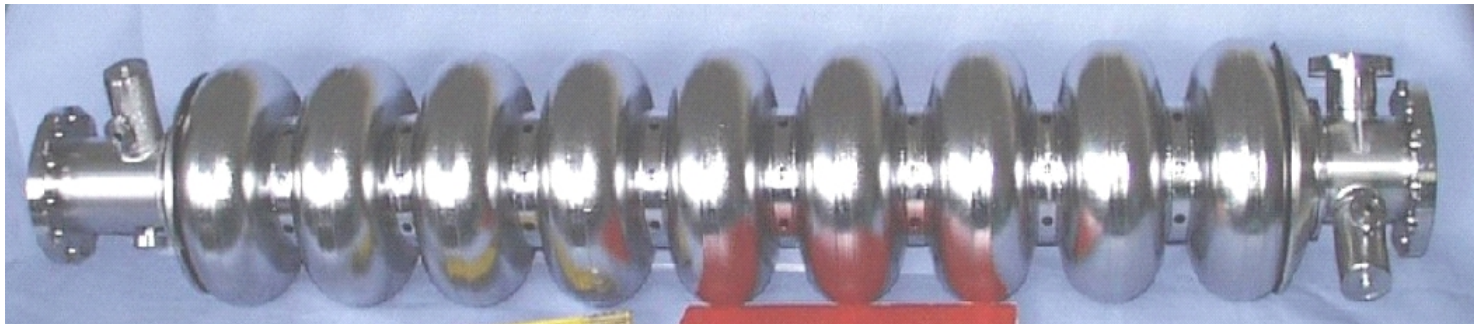
- Compensation for Lorentz Force Detuning (LFD)

$$P_s = \frac{1}{4}\left(\mu|\vec{H}|^2 - \varepsilon_0|\vec{E}|^2\right)$$

$$\hat{\Delta} f_0 = -K\,E_{acc}^2$$



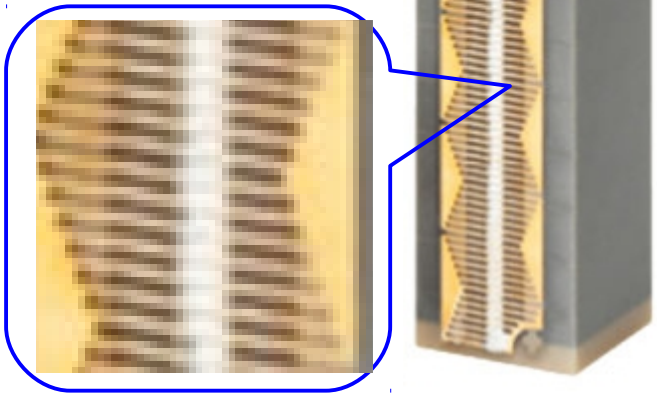
- Cavity fine tuning (±70V → ~600Hz)
- Microphonics measurements and compensation



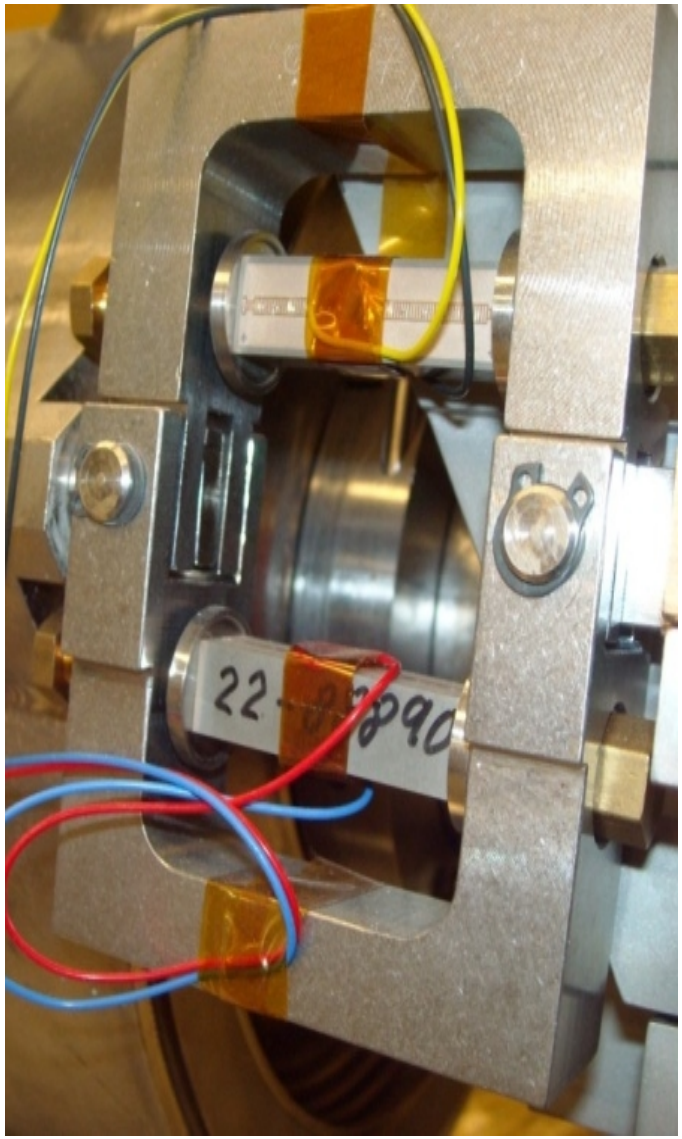
Piezo's and piezo tuners

Manufacturer	Noliac	PI Ceramics
ratings		
Model	SCMAS/S1/A	P-888.90
Cells	8	8
Voltage range [V]	0 ÷ 200	-20 ÷ 120
Blocking Force [kN]	6	3@120V
Size [mm^3]	10 x 10 x 30	10 x 10 x 35
Capacitance [uF]	6	12

Manufacturer: **NOLIAC**
Dimensions: **10x10x30mm**



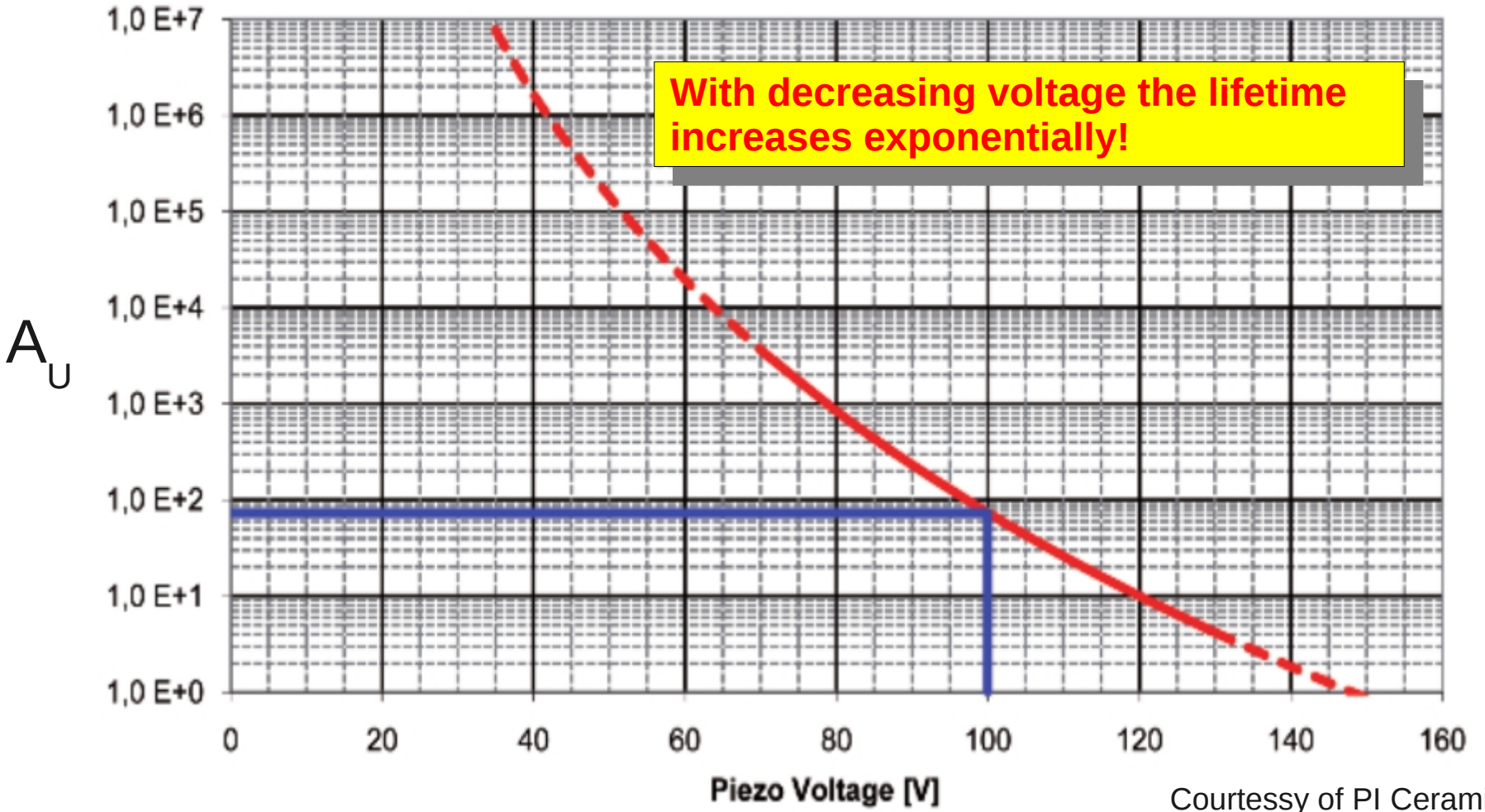
Manufacturer: **PI**
Dimensions: **10x10x36mm**



Piezo reliability

$$MTTF = A_U * A_T * A_F$$

A_U – voltage factor
A_T – temperature factor (constant for cryho conditions)
A_F – humidity factor (constant for cryho conditions)



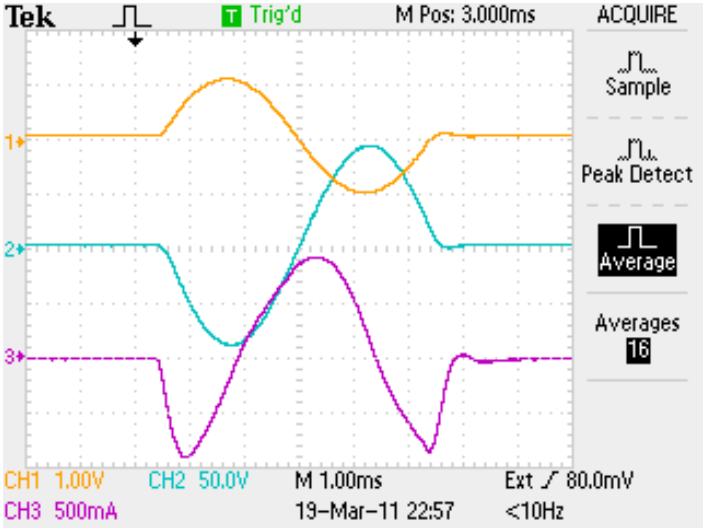
Courtessy of PI Ceramic GmbH

Discussion with PI engineers (after piezo failure at ACC7)

- Was piezo broken by overcurrent? Overvoltage? Bipolar operation?
  None seems to be the reason

- We need for LFD compensation the peak-to-peak voltage. For unipolar operation the maximum piezo voltage is ~2x higher than for bipolar mode.
  This can be a limiting factor →go bipolar for cryho temperatures

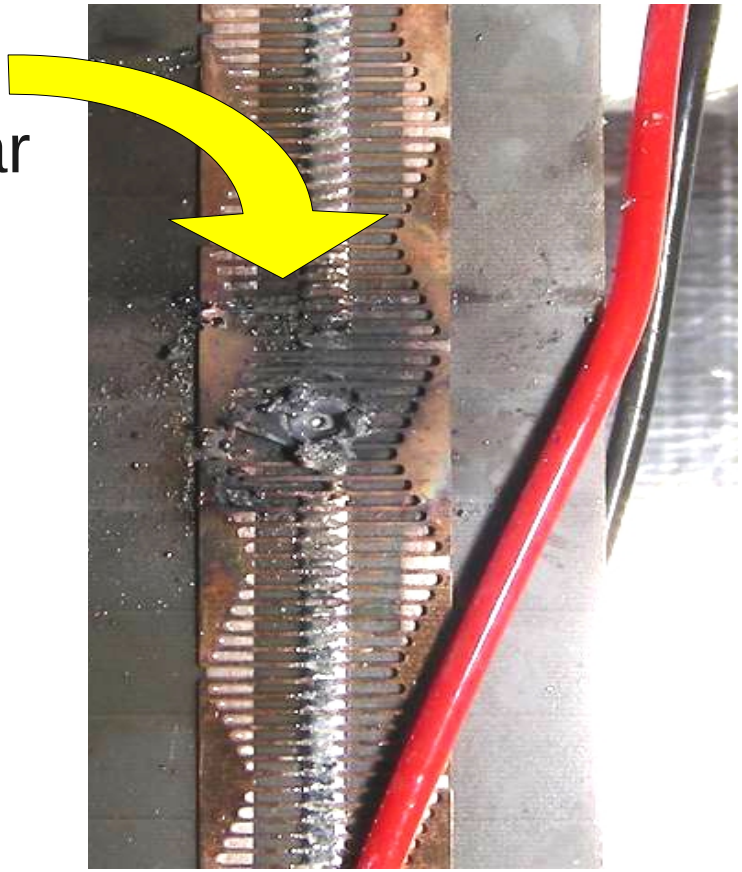
- We need DC voltage on piezo to tune cavities. Is it safe for piezos to drive them with several tens of Volts for the long time?
  This is not an issue but remember about voltage dependency.



Comment: limit the current slewrate.

Piezo driving

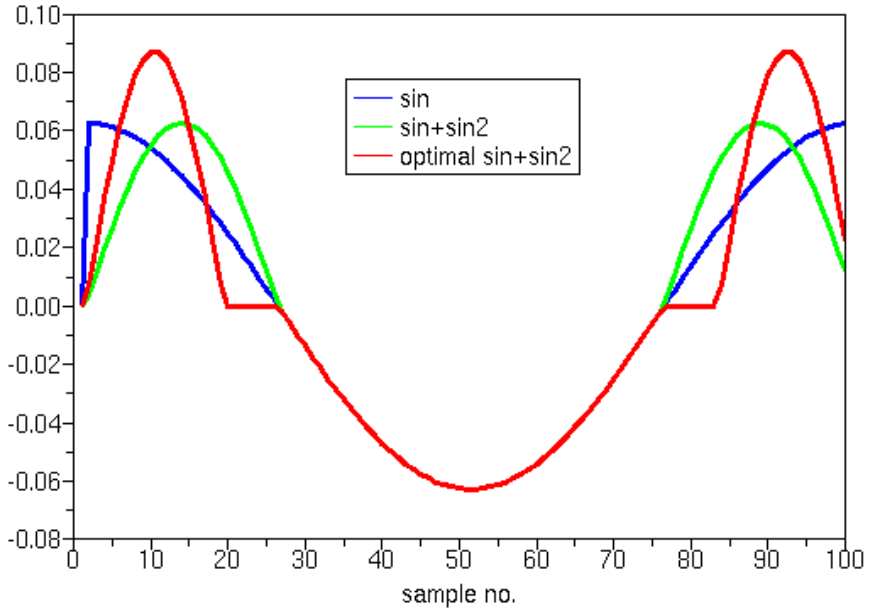
- We need for LFD compensation the peak-to-peak voltage. For unipolar operation the maximum piezo voltage is ~2x higher than for bipolar mode. That reduces reliability.
- Bipolar driving while piezo is worm is dangerous. Piezo can be broken with relatively low voltage. Therefore bipolar driving must be done together with temperature checkout

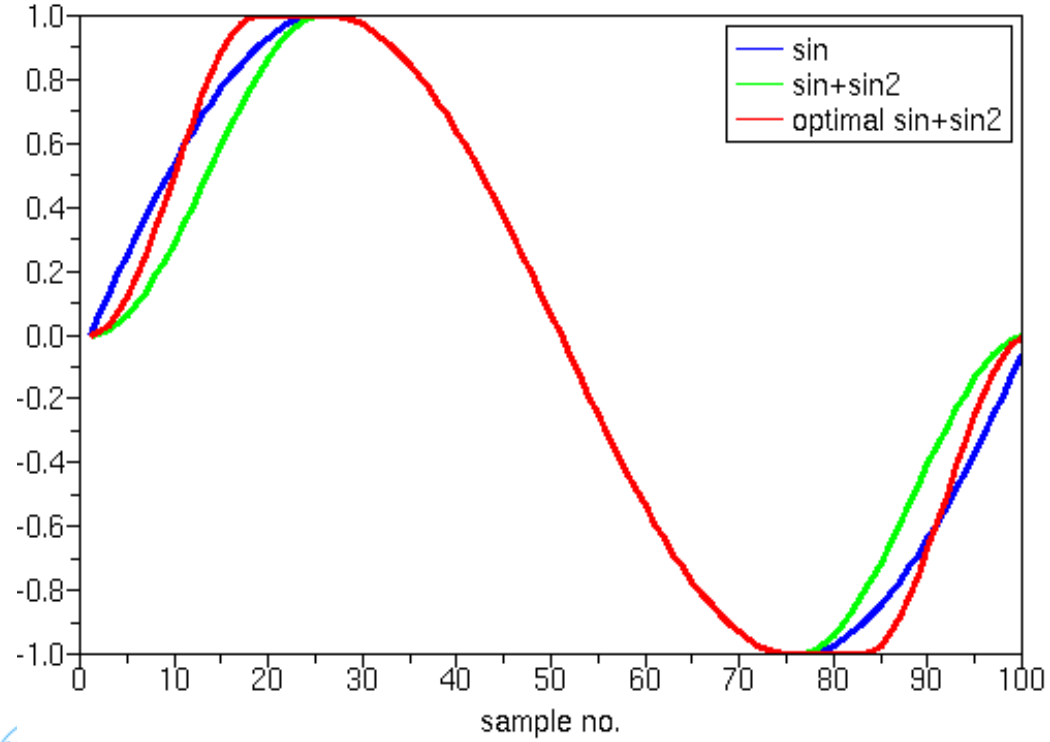


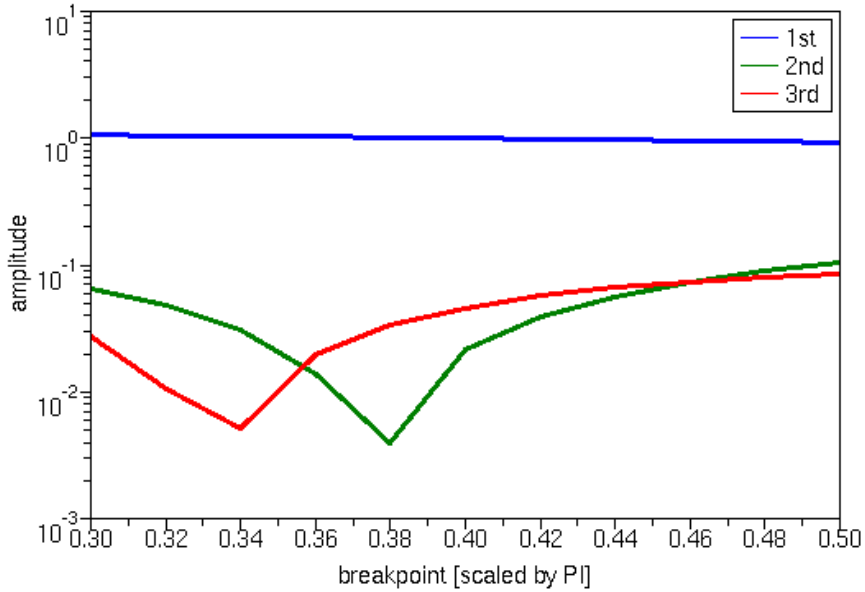
Note: limiting the voltage to ±50V may also benefit from looser safety requirements. ±50V still allows to compensate LFD up to ~40MV/m (pulse ±45V was sufficient to compensate LFD at 42MV/m)

Limiting the current slew-rate

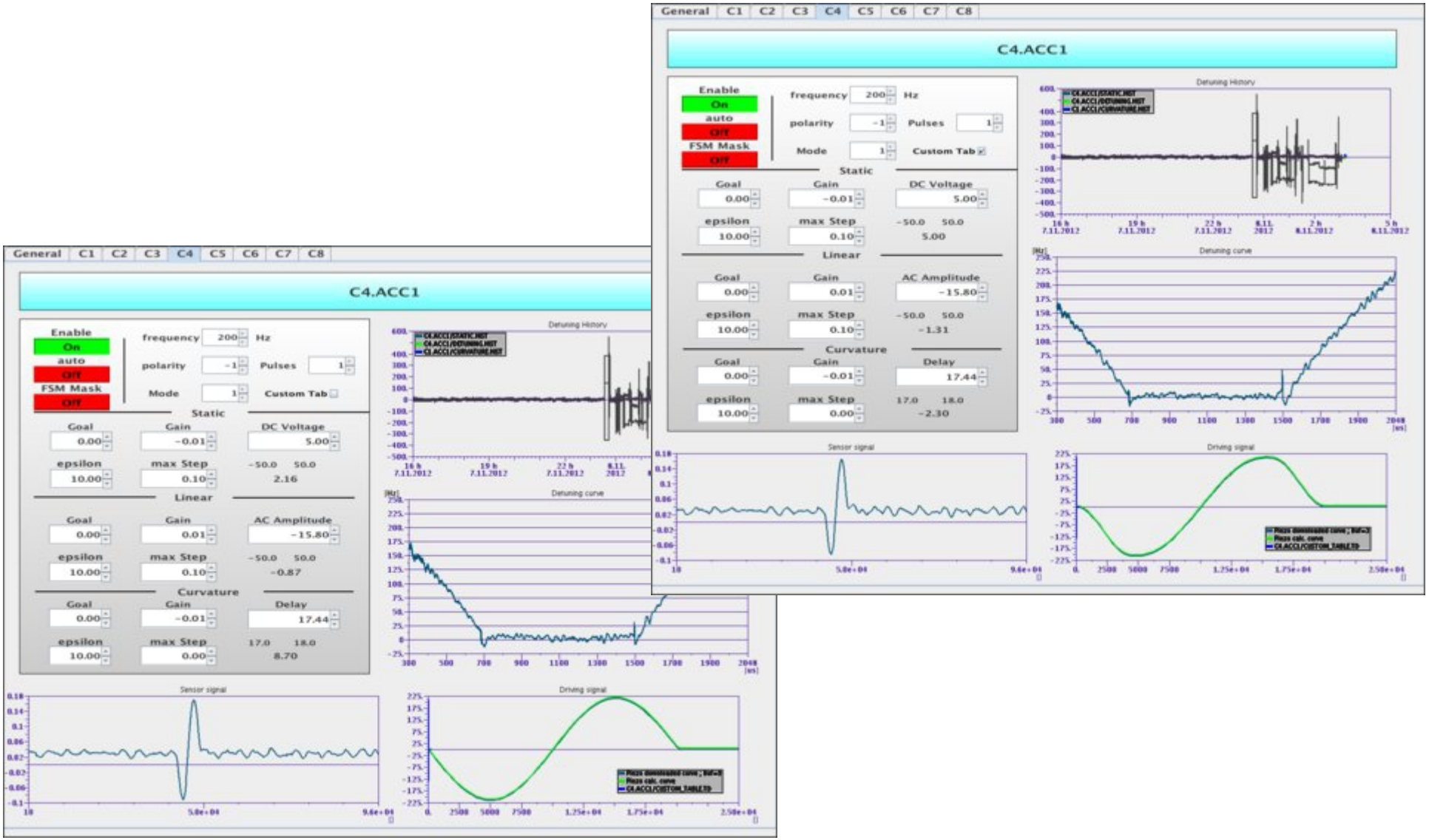
- In order to reduce the current slew-rate the beginning of the sinus curve (the first quarter) can be changed to its square optionally followed by constant (maximum) value



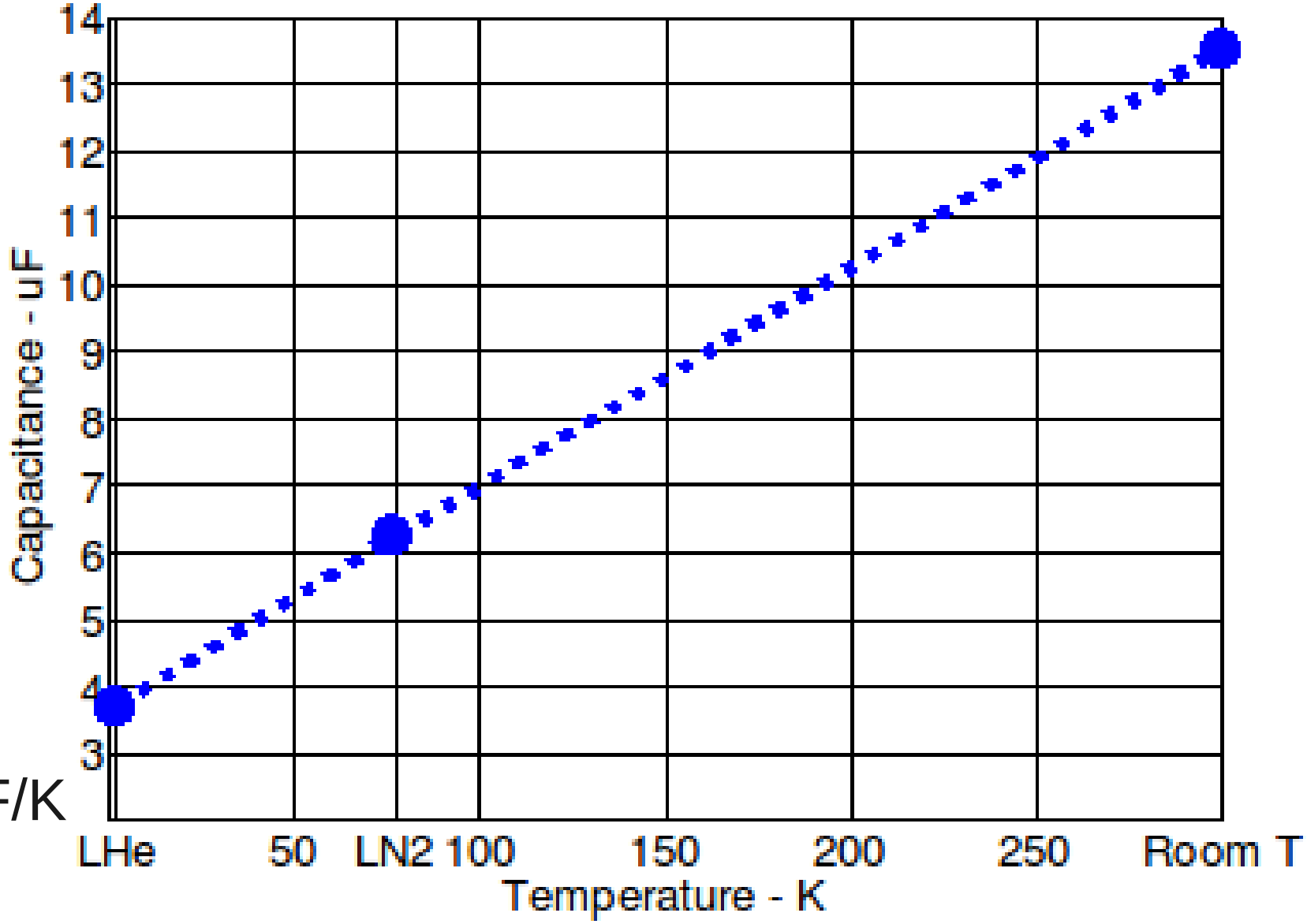




Sinusoidal and modified pulse in LFD compensation



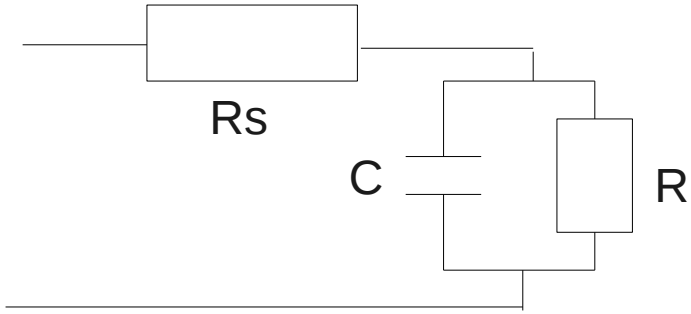
Piezo capacitance dependence on temperature

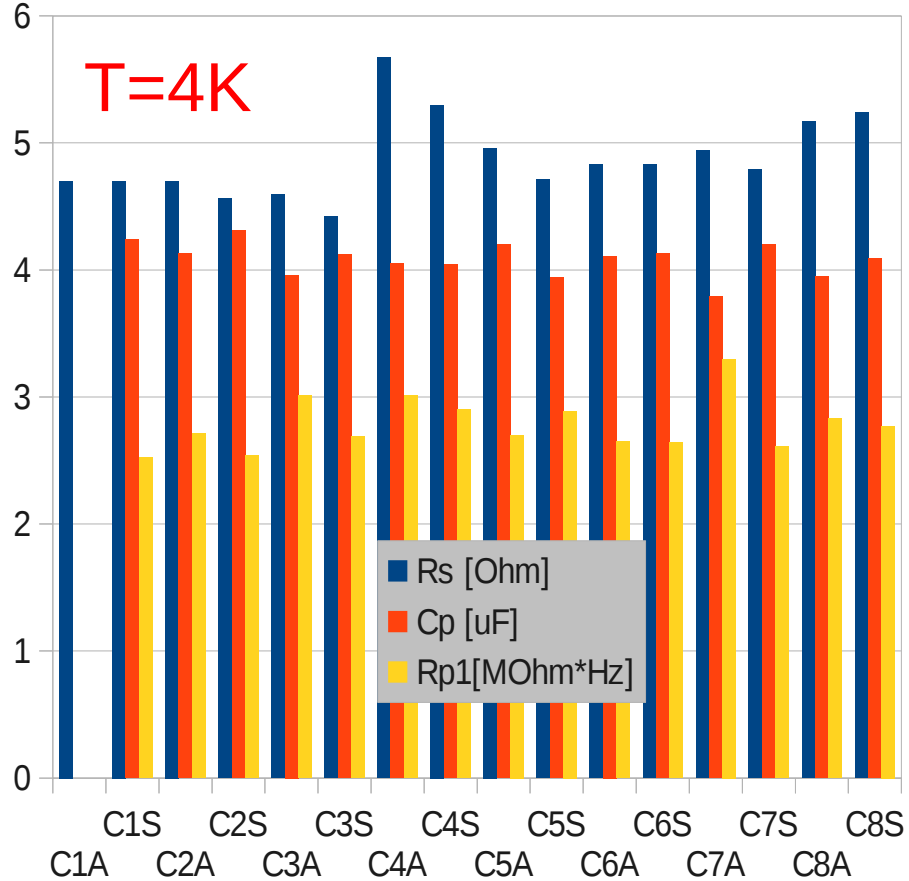


$C=C_0+k_cT$

$k_c \sim 0.03uF/K$

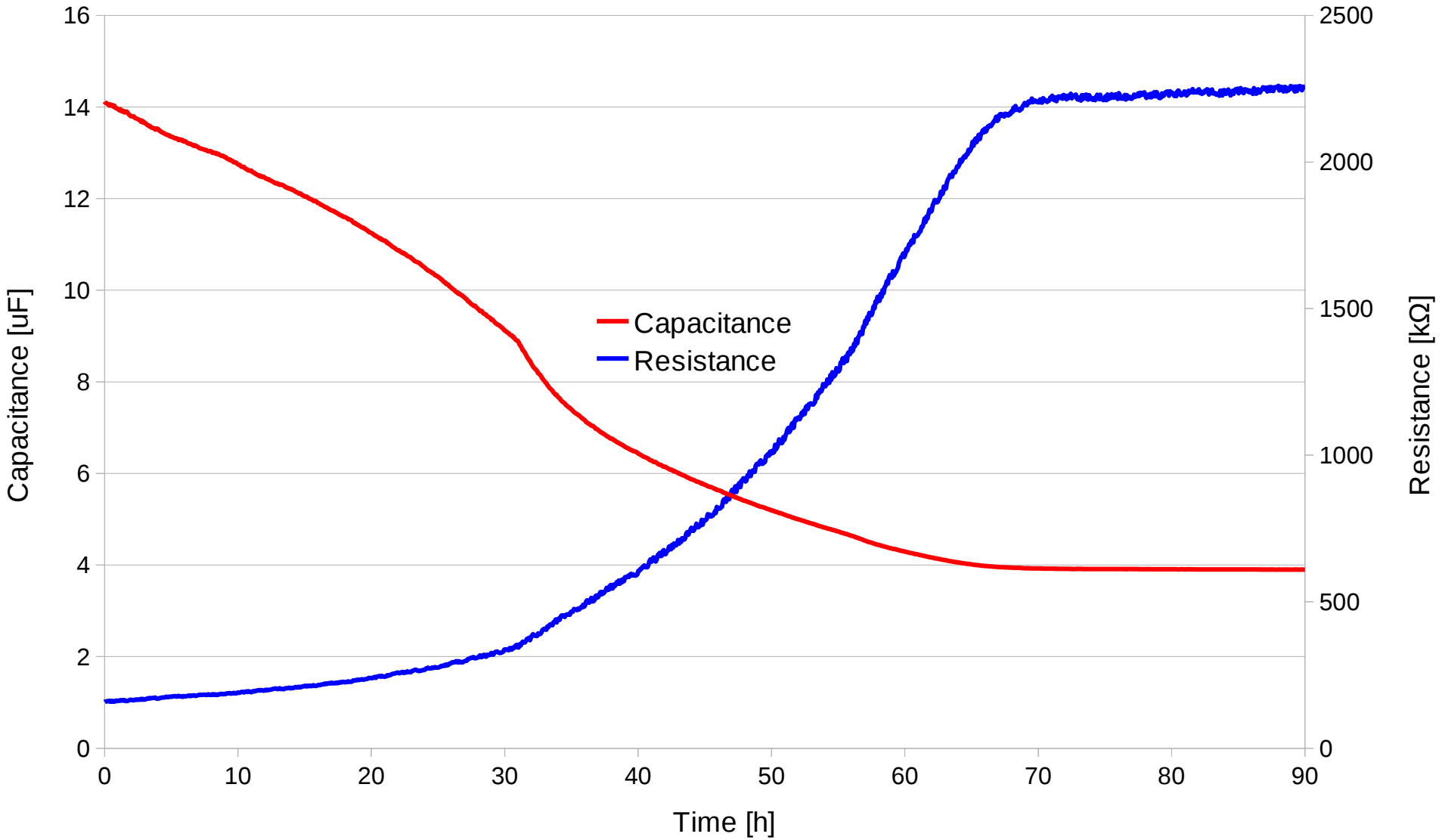
Piezos at ACC7 (at 4K)



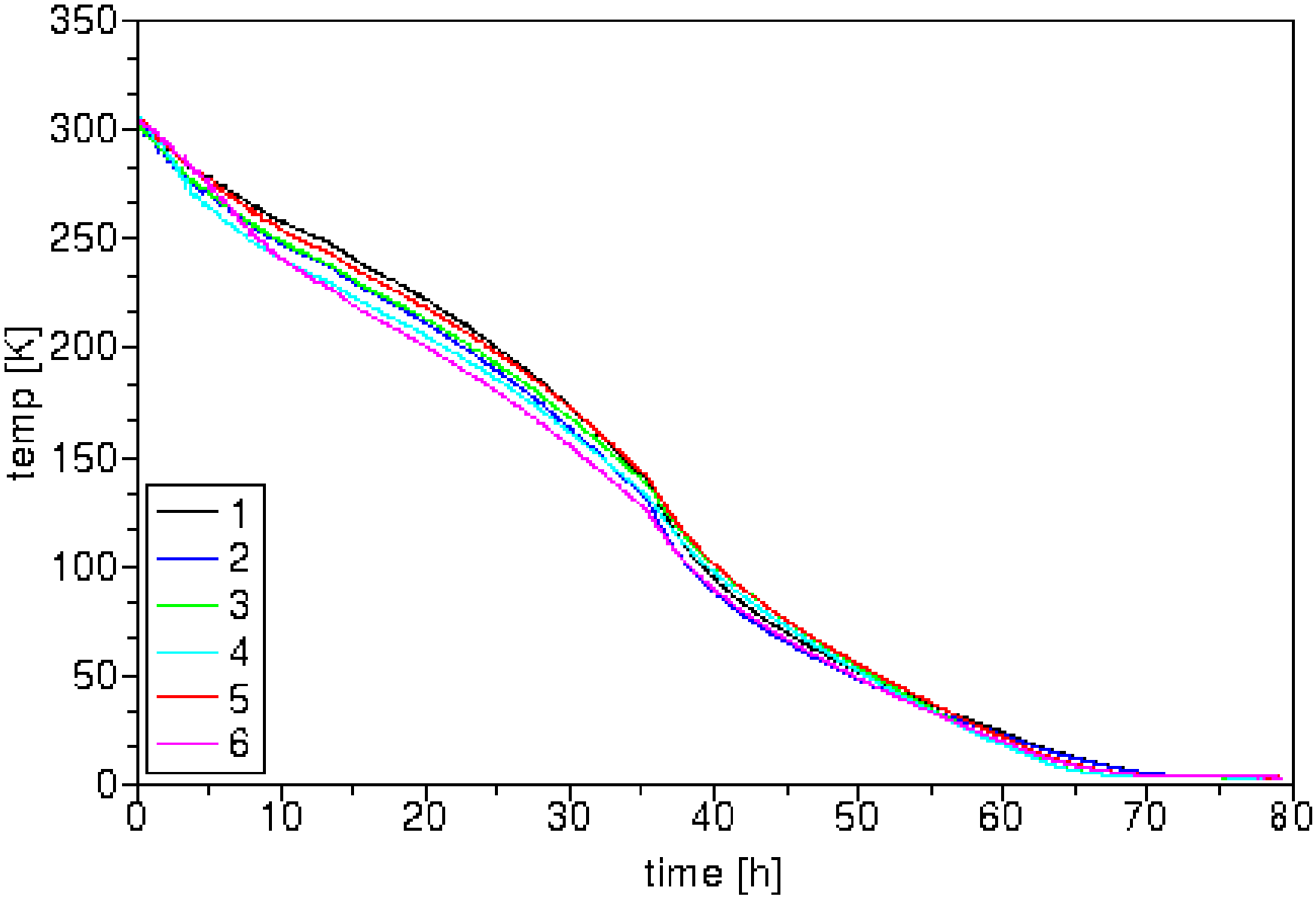


ACC7	Rs [Ohm]	Cp [uF]	Rp1[MOhm*Hz]
C1A	4.7	broken	broken
C1S	4.7	4.24	2.52
C2A	4.7	4.13	2.71
C2S	4.56	4.31	2.54
C3A	4.59	3.96	3.01
C3S	4.42	4.12	2.69
C4A	5.67	4.05	3.01
C4S	5.3	4.04	2.9
C5A	4.96	4.2	2.7
C5S	4.71	3.94	2.89
C6A	4.83	4.11	2.65
C6S	4.83	4.13	2.64
C7A	4.94	3.79	3.3
C7S	4.79	4.2	2.61
C8A	5.17	3.95	2.83
C8S	5.24	4.09	2.77

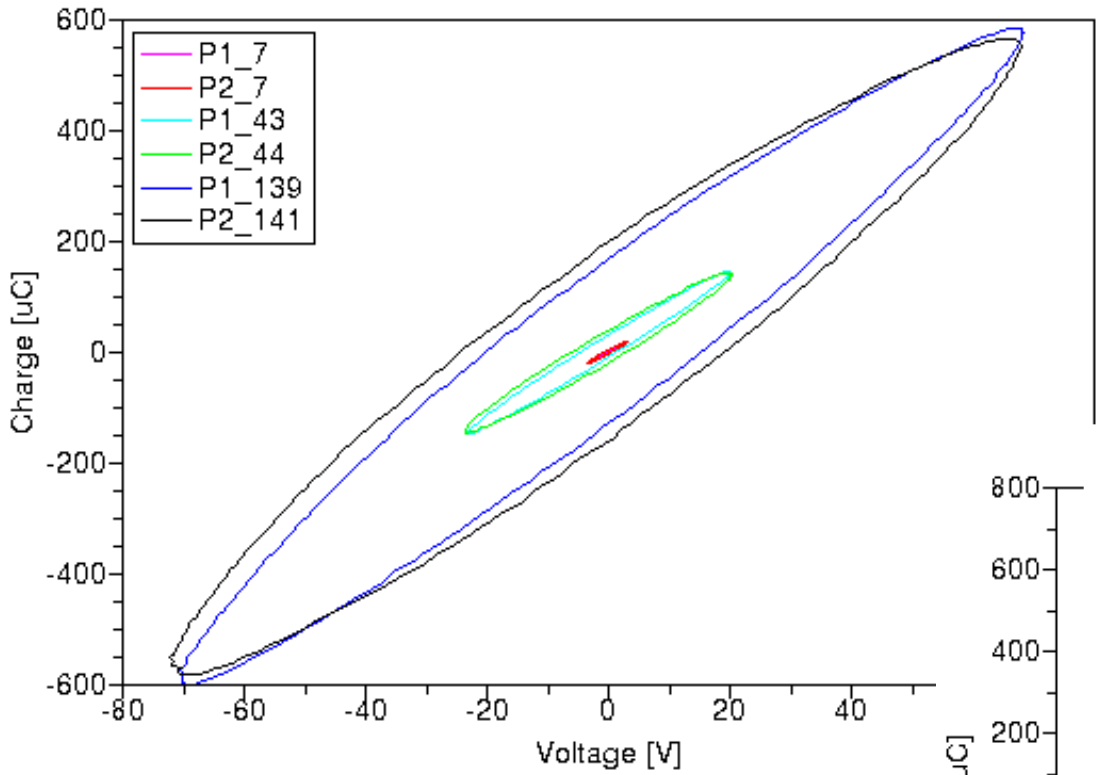
Cooling process (CMTB, cav.1, actuator)



Cavity temperature during cooling (calculated from piezo capacitance)



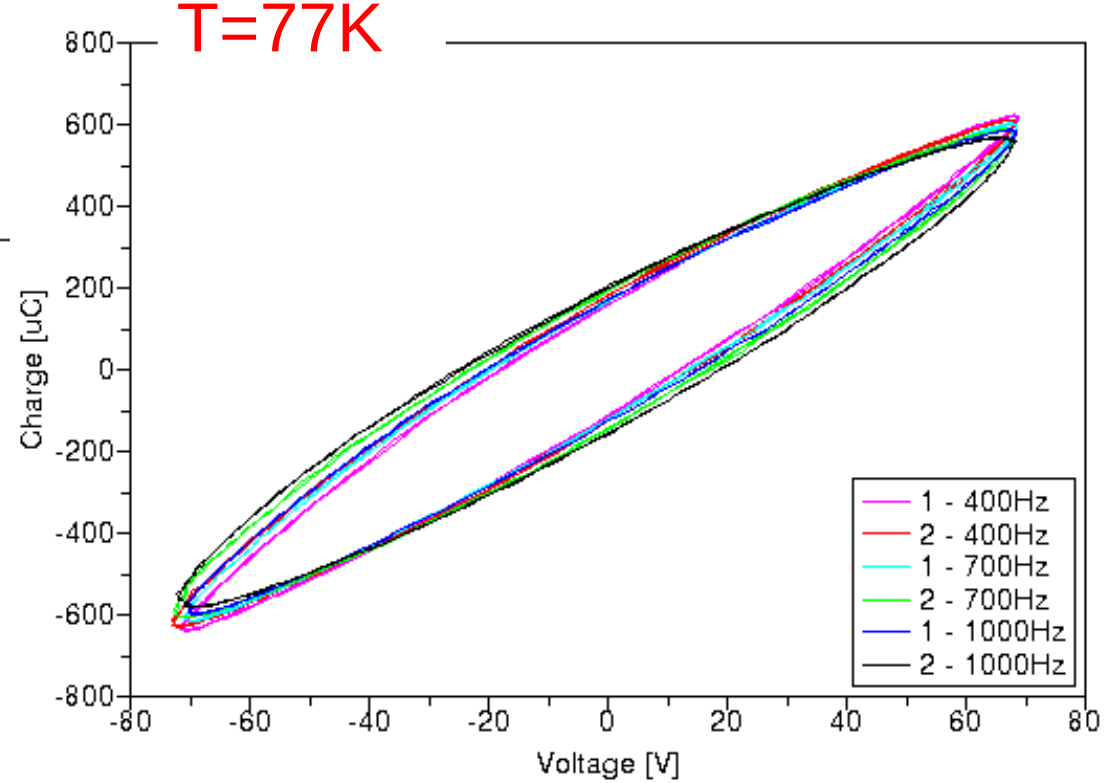
Piezo capacitance



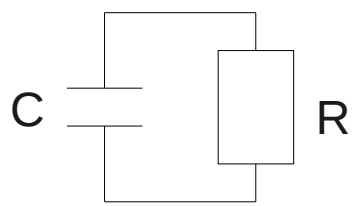
$E \sim V^2$

E=~30mJ/cycle at ±70V (that gives ~0.3W at 10Hz single pulse)

T=77K

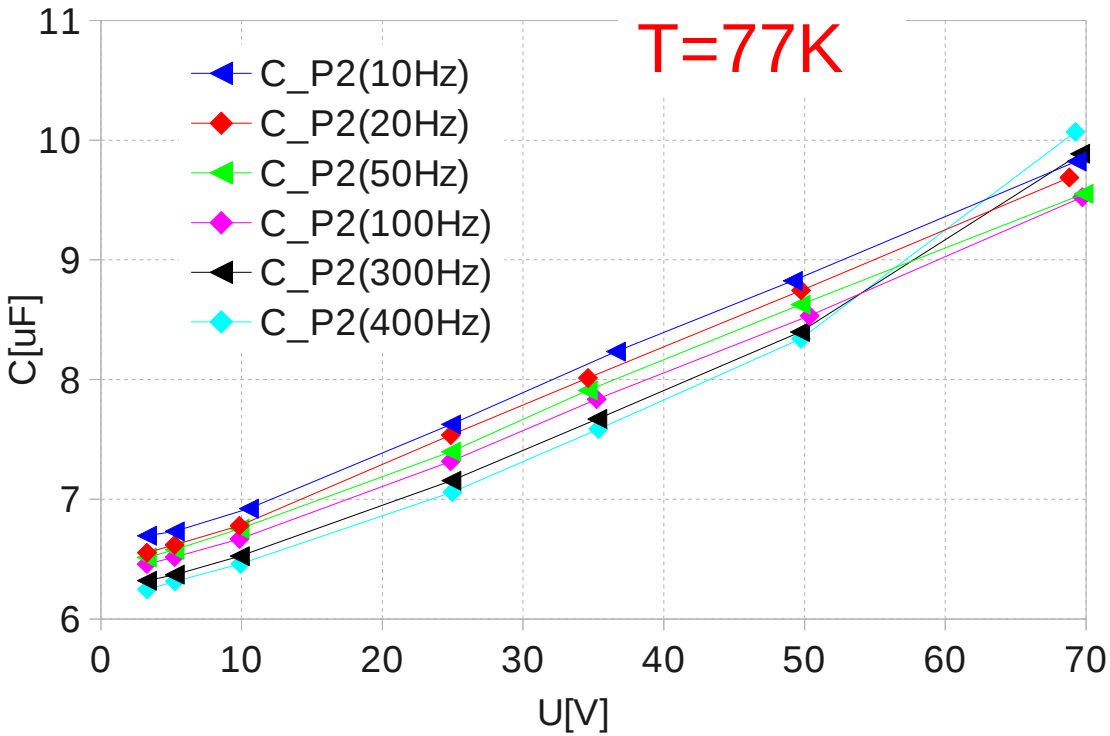


$$C = \frac{dQ}{dV}$$



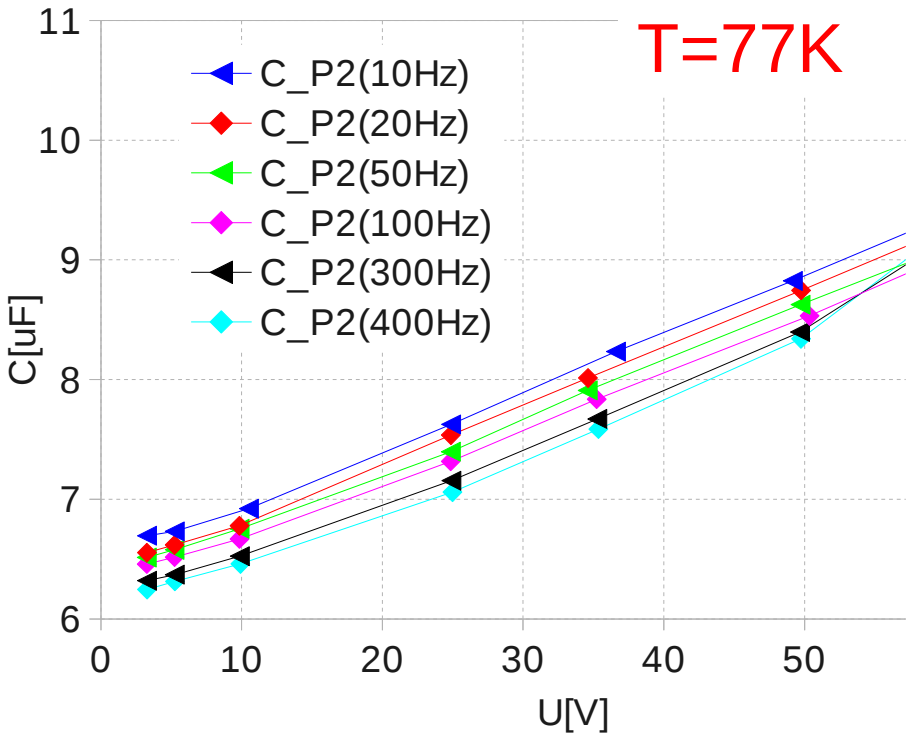
$$Y_p = \frac{1}{R_1} f + j 2 \pi f C \qquad Z_p = \frac{Z_1}{f}$$

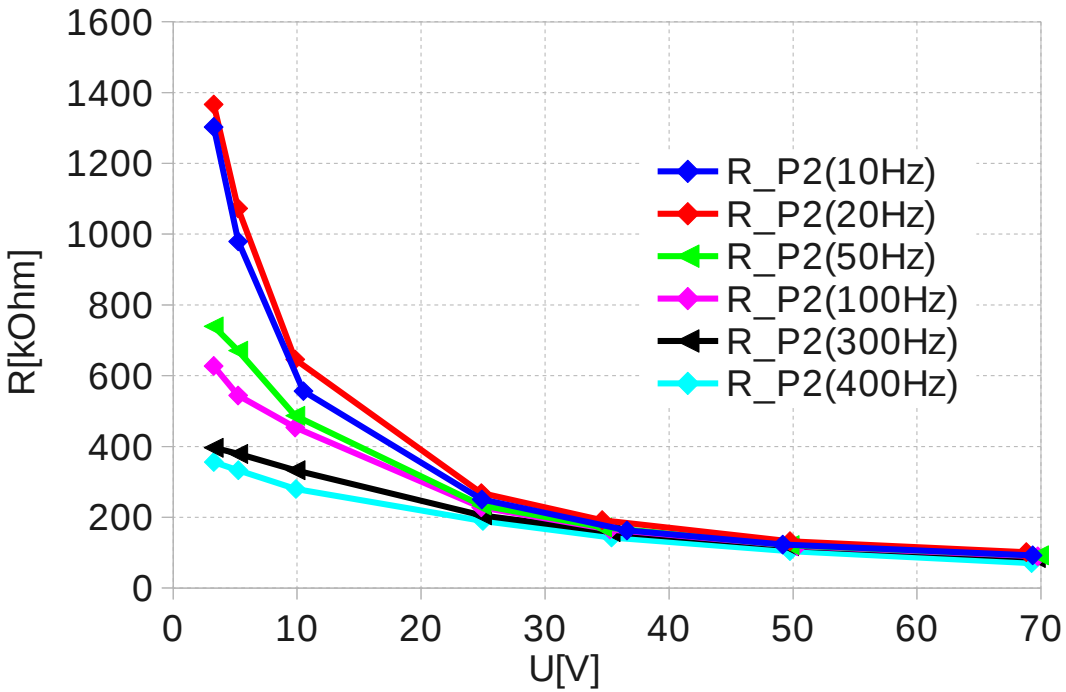
Piezo electrical parameters



T=77K

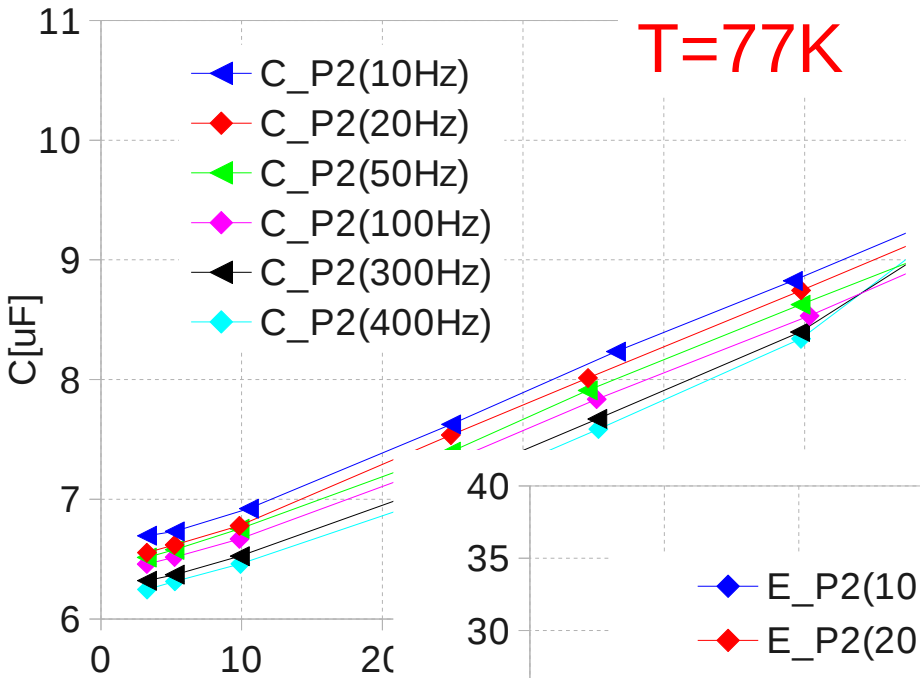
Piezo electrical parameters

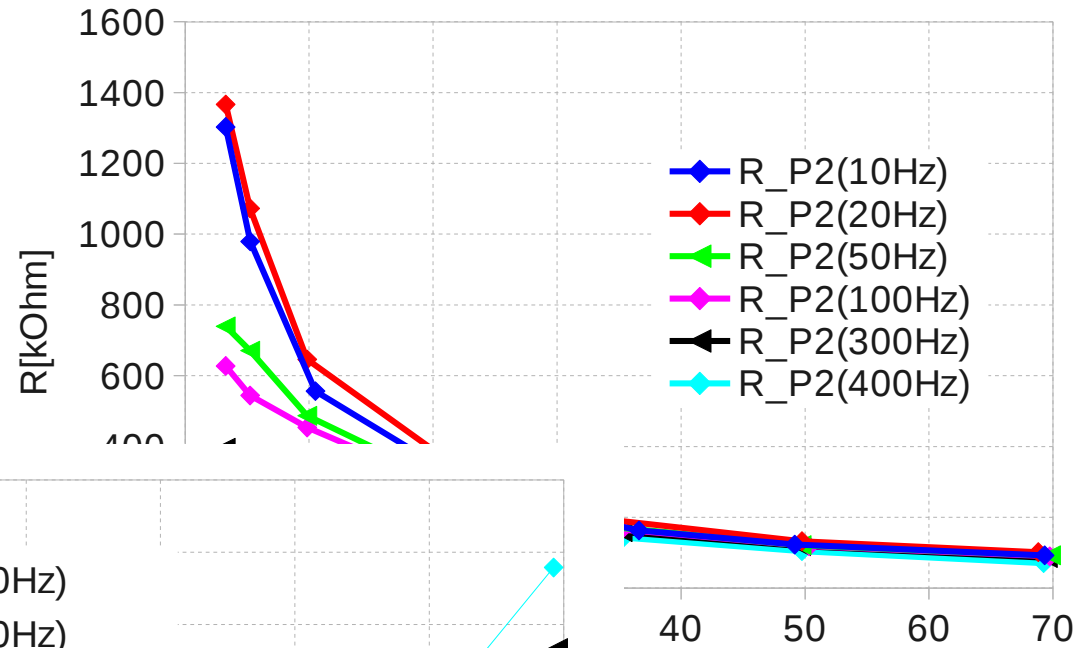


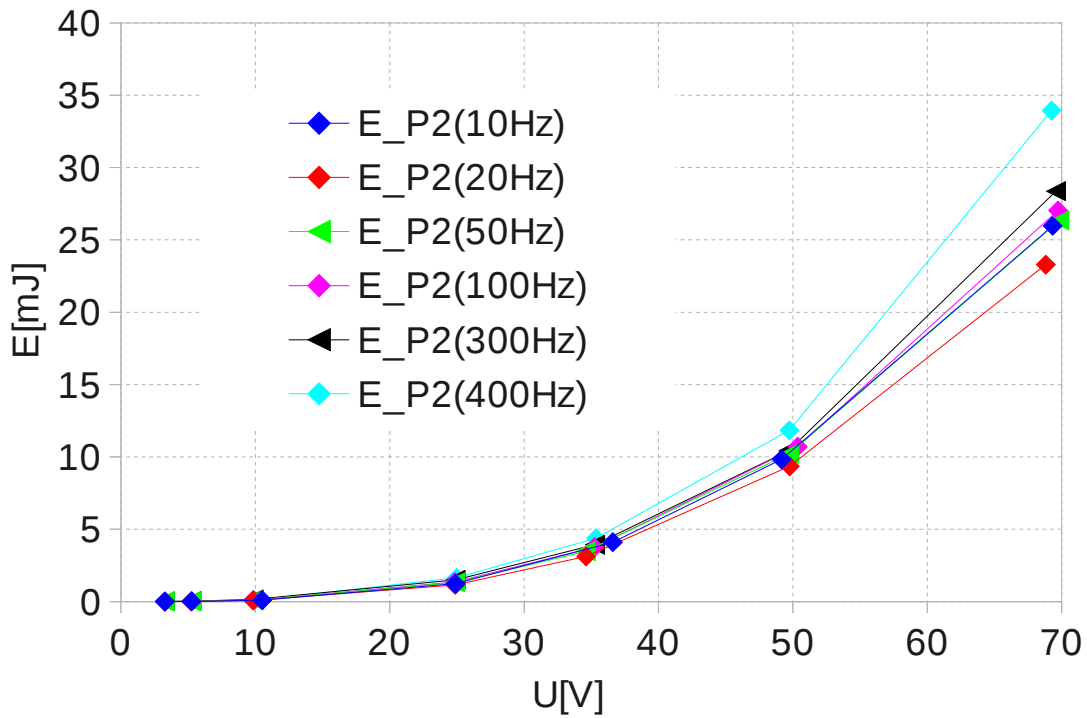


T=77K

Piezo electrical parameters

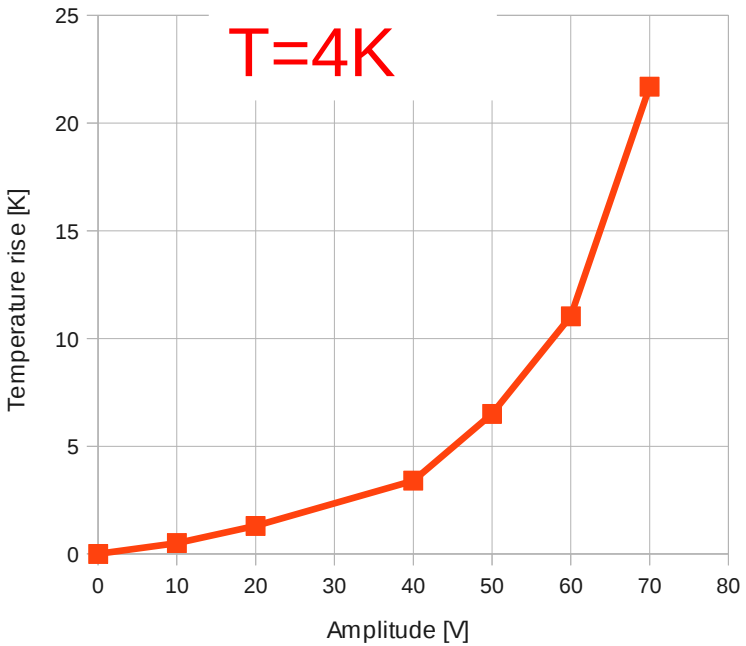


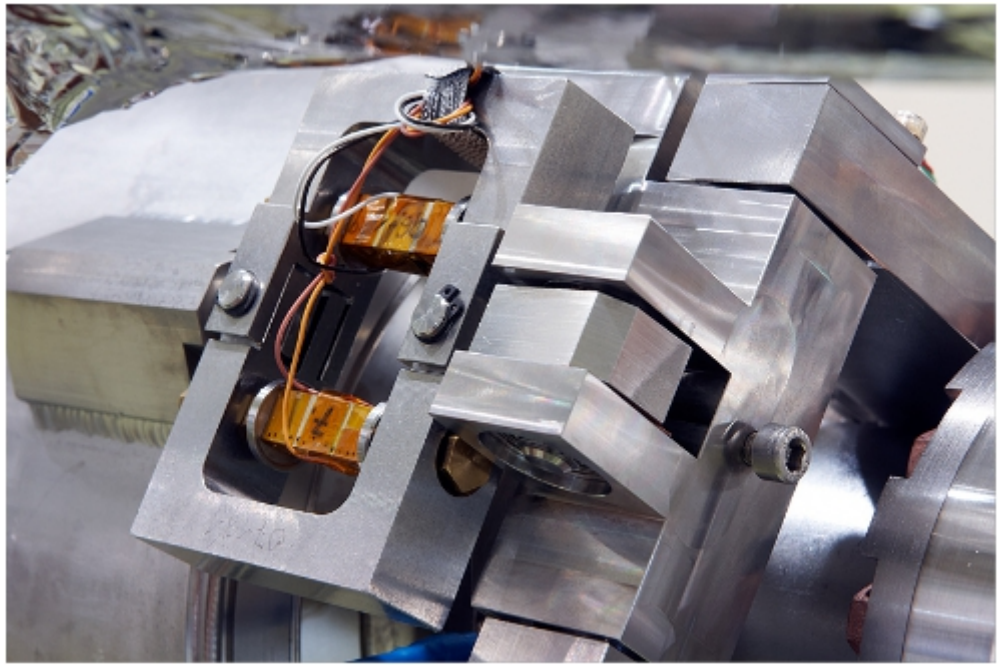




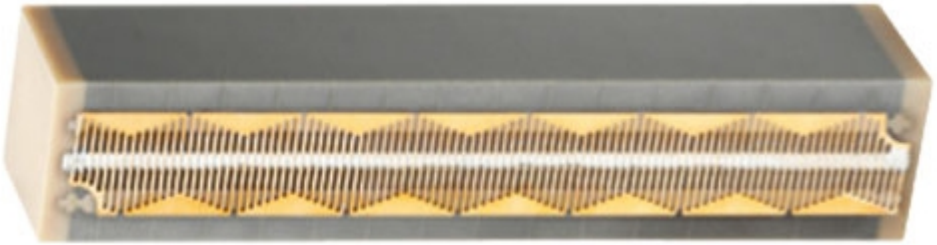
T=77K

Heat dissipation at piezo

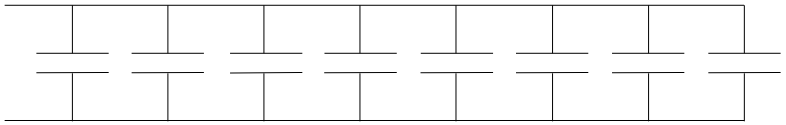




Temperature rise in function of pulse amplitude, single pulse, 10Hz repetition rate



In case of nonuniform current distribution at piezo structure the positive thermal feedback may happen! I↑ T↑ Z↓(C↑,R↓) I↑....



Long term tests of piezo operation

- For unipolar mode it was performed by A.Bosotti & R.Paparella in 2005 – piezo survived successfully the equivalent of 10 years of operation in a cryomodule.
- For bipolar mode a new test was proposed in 2012
  - Stage I: energize the piezo with the reference bipolar driving signal in a cryomodule-like scenario, at 2 K temperature, in order to measure the equilibrium temperature of the piezo stack.
  - Stage II: if the equilibrium temperature for the reference bipolar driving signal in the worst case is confirmed to be still below or close to 77 K, operate the piezo submerged in LN2 and execute continuously the long run at the highest possible repetition rate

First phase (02.2012)

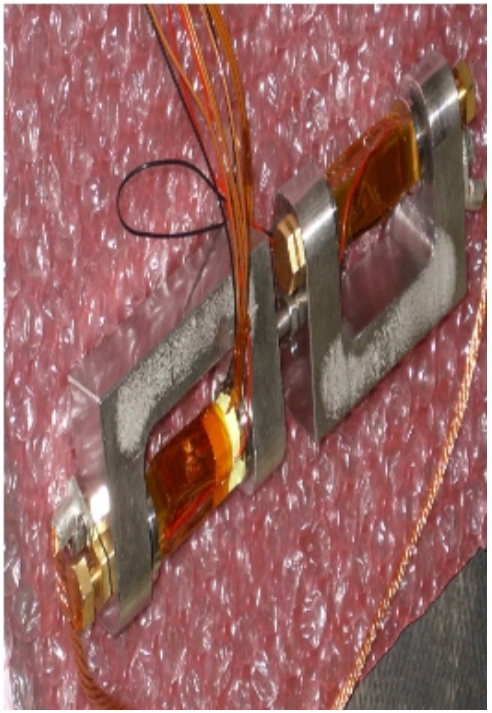
Vacuum chamber

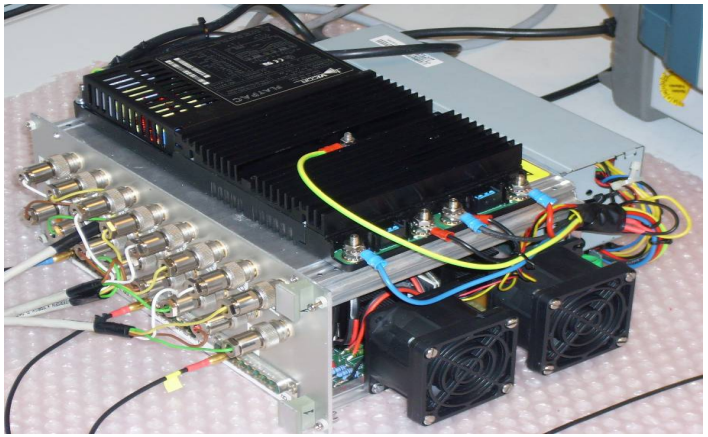
Cryostat

Results

Repetition rate [Hz]	Driving signal p-p Amplitude		Temperature	
	Piezo 1 [V]	Piezo 2 [V]	Piezo 1 [K]	Piezo 2 [K]
5	200	0	6.2	4.4
10	200	0	6.5	4.4
100	200	0	25	4.9
200	160	0	75	6.6

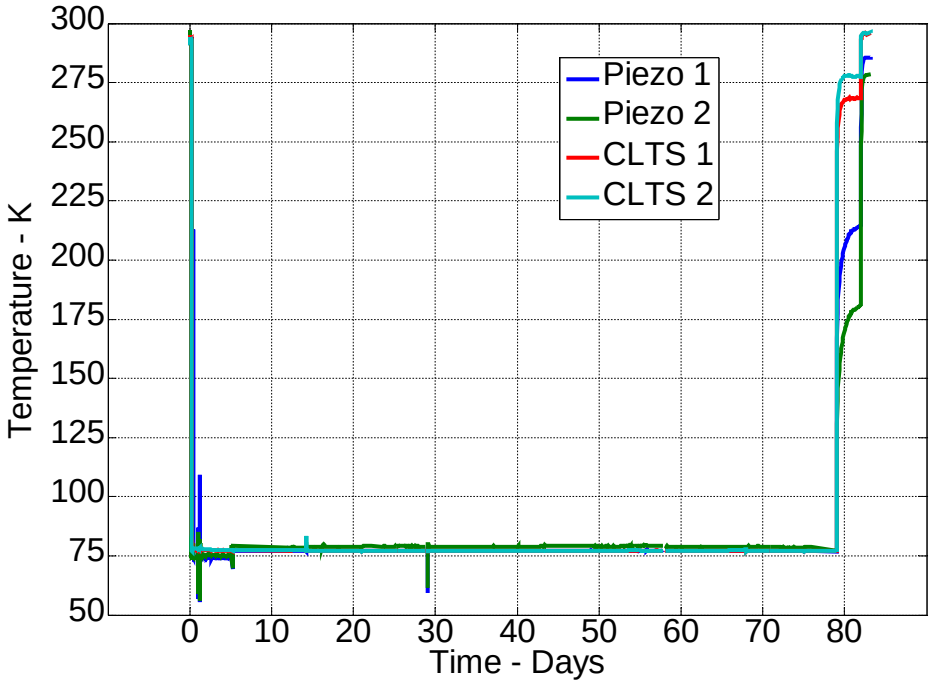
Second phase (3-6.2012)

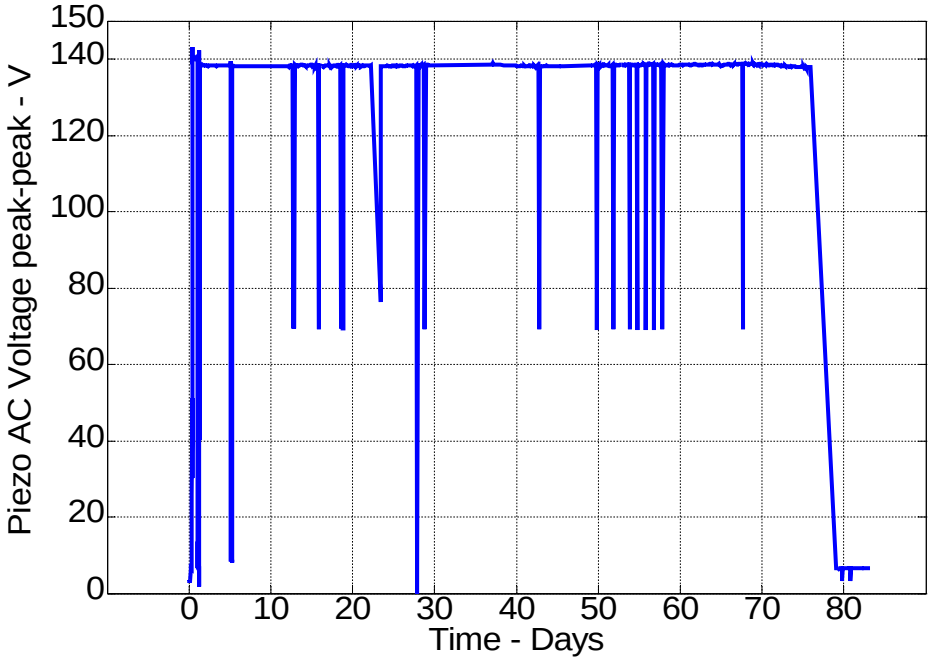


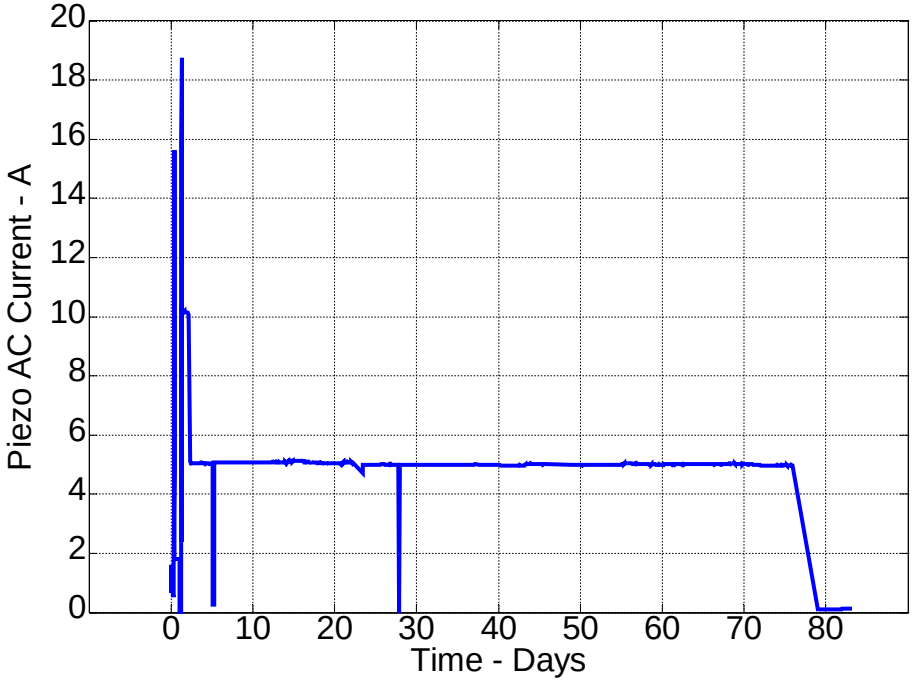


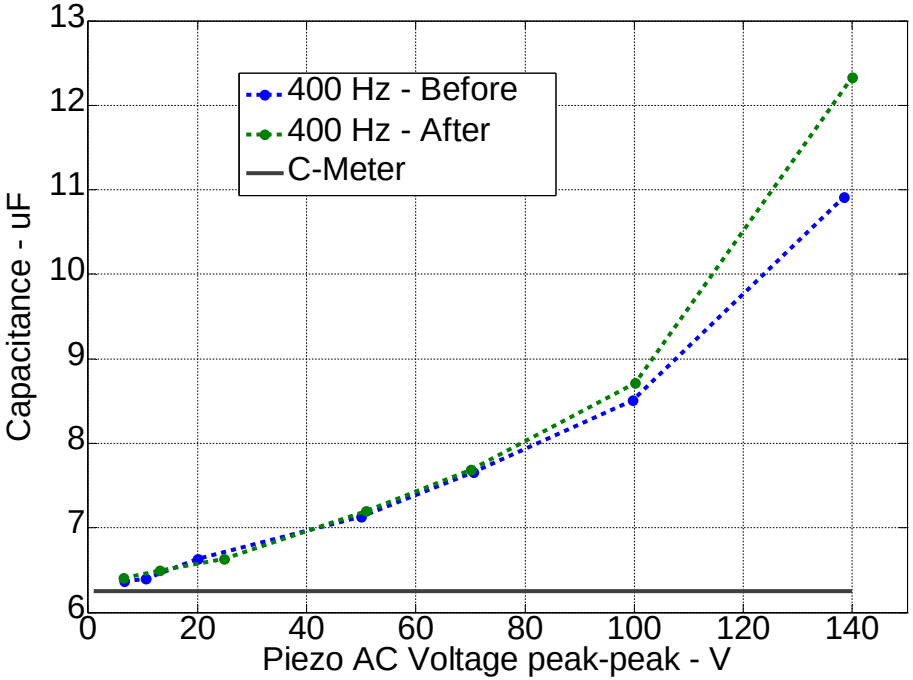
Summary of the test

Life-time test parameter	Value	Unit
Time duration	76	Days
Number of bipolar cycles	$3.3\ 10^9$	#
Excitation frequency	500	Hz
Piezo equilibrium temperature	79	K
Average AC voltage	138	V_{pp}
Average AC current	5.0	A_{pp}
LN2 loss rate (by balance)	0.25	kg/h
LN2 loss rate (by flow meter)	0.35	nl/min
Heat load (by balance)	14 +/- 1.7	W
Heat load (by flow meter)	14.5 +/- 2	W
Amount of LN2 used	515	l
Refills / transfers	8	
Piezo driver temperature	< 45	C


Temperature - K
Time - Days
Piezo 1
Piezo 2
CLTS 1
CLTS 2

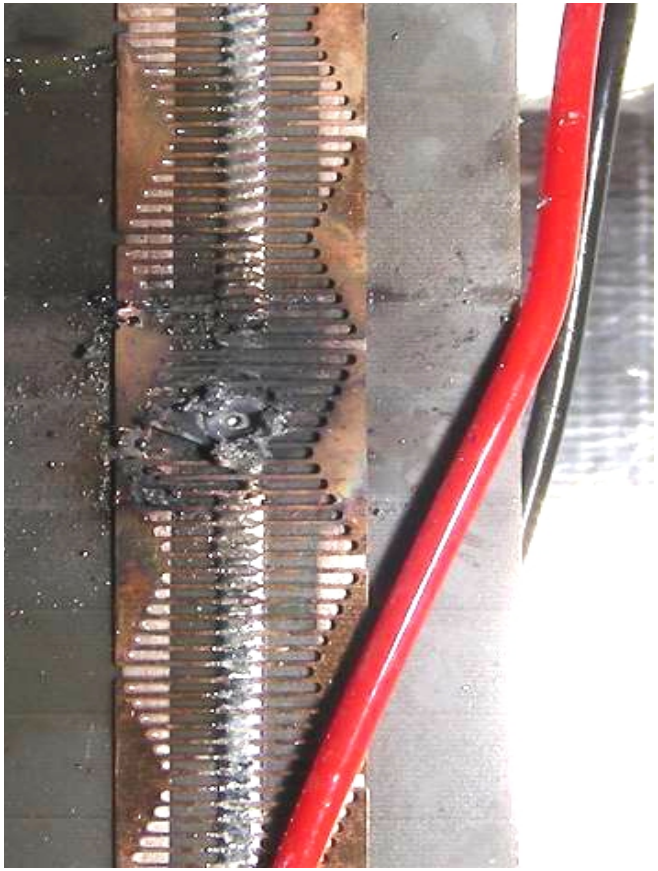

Piezo AC Voltage peak-peak - V
Time - Days


Piezo AC Current - A
Time - Days


Capacitance - uF
Piezo AC Voltage peak-peak - V
400 Hz - Before
400 Hz - After
C-Meter

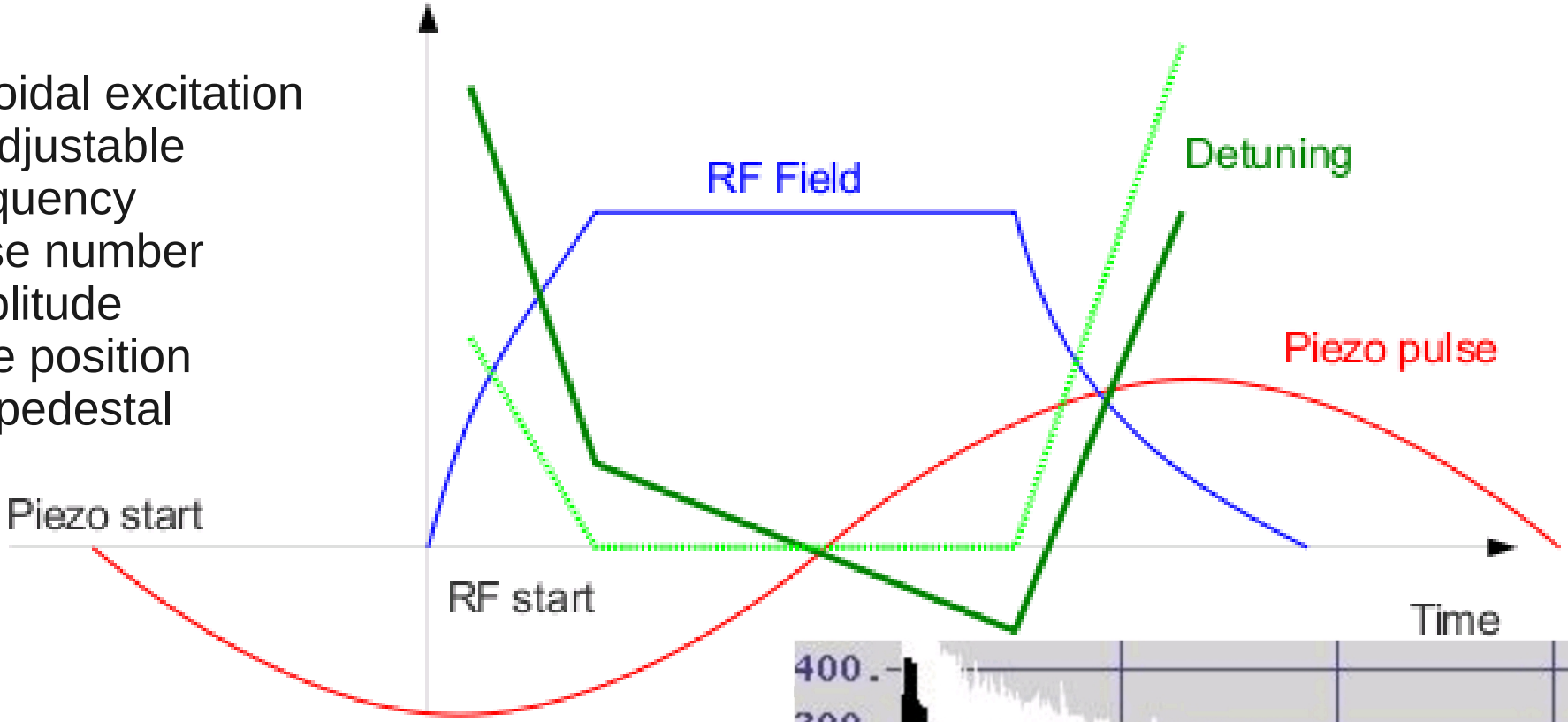
Destructive test

- After it has been proved piezo can withstand long term bipolar operation the destructive test has been performed (400Hz, rectangular waveform, ±70V).
- The operation of the piezo was not stable, after ~2 min. rapid temperature rise has occurred. Within the tiny time window allowed by the safety loop (about 2 seconds) the piezo temperature went up to 120 K before voltage shut down and the actuator failed.



Piezo control for LFD compensation

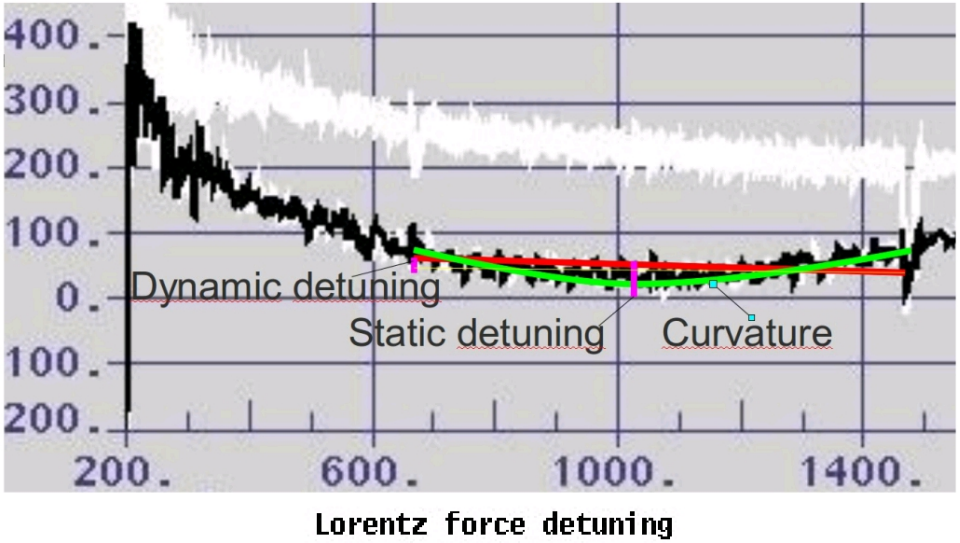
Sinusoidal excitation
with adjustable
– Frequency
– Pulse number
– Amplitude
– Time position
– DC pedestal



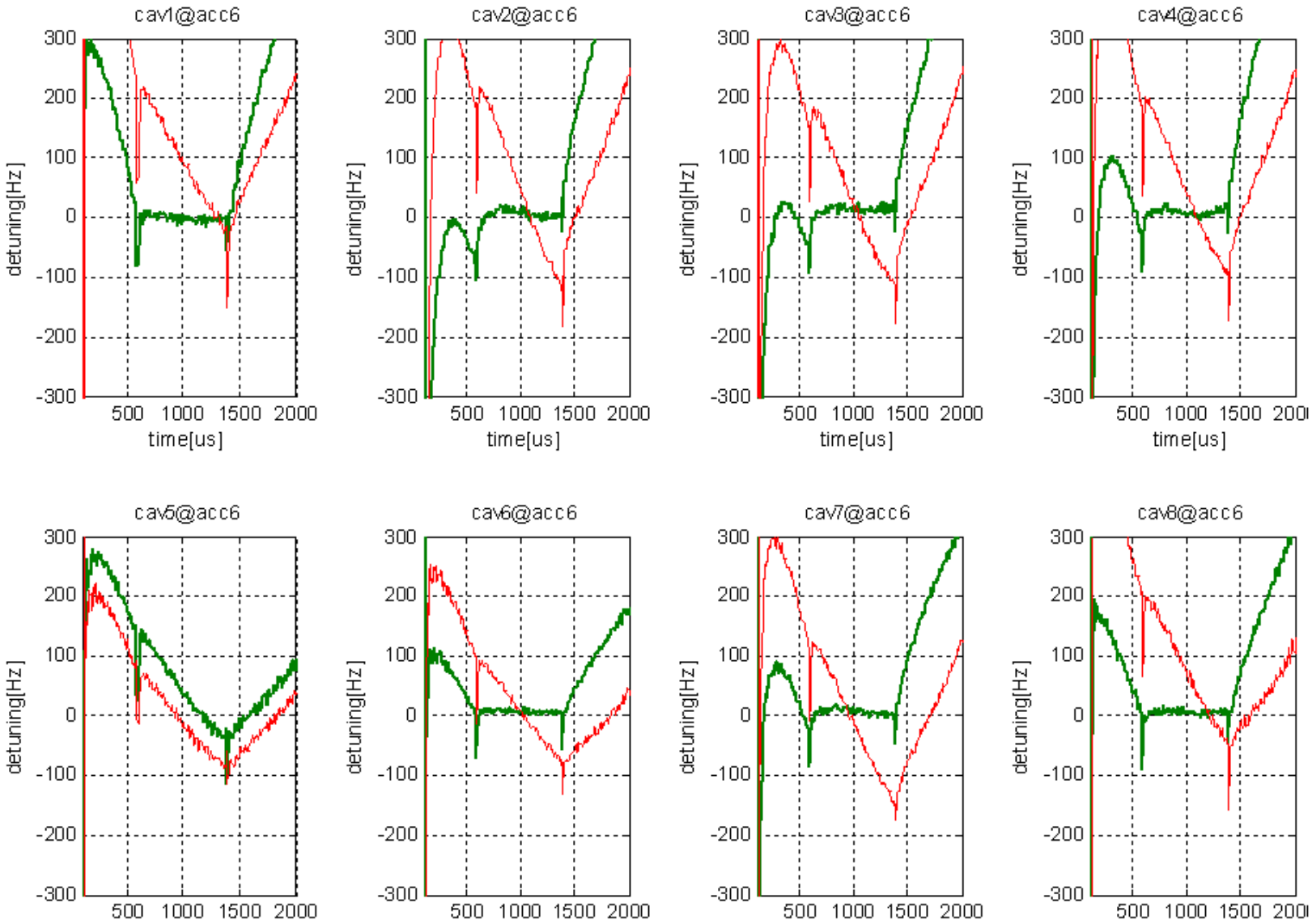
Amplitude → dynamic detuning

DC pedestal → static detuning

Time position → curvature

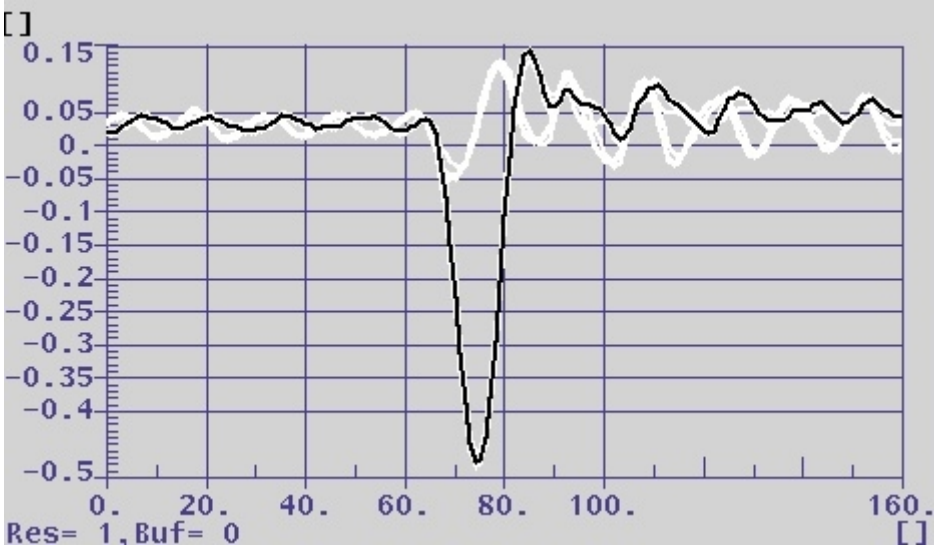


ACC6 (SP = 20 MV/m, rep = 5 Hz)



Microphonics monitoring

- Piezos can be also used as sensors measuring vibrations of the cavity.
- We have recorded many piezo sensor waveforms but until now (with old piezo control system) we were unable to correlate this signals with microphonics. There is hope in new piezo control system (uTCA compatible) with upgraded performance.



Conclusion

- Piezo tuners are used at SC accelerators to compensate LFD. That allows to achieve higher gradients and stable operation.
- Piezos in the SC module are virtually non-exchangeble, therefore the reliability is crucial.
- Piezo can be safely driven in bipolar mode, but the temperature must be constantly checked and keept low.
- Electrical parameters of the pieco (capacitance) can be used to measure piezo temperature on-line, but other effects have to be taken into account.

Thank you for your attention