Tuning systems for superconducting cavities at Saclay

The tuning systems developed at Saclay

MACSE:	1990: tuner in LHe bath at 1.8K
TTF:	1995 tuner at 1.8K in the insulating vacuum
SOLEIL:	1999 tuner at 4 K in the insulating vacuum
Super-3HC:	2002 tuner at 4 K in the insulating vacuum
CARE SRF/EUROFEL:	2005 - 2007
piezo tuner	piezo tuner at 1.8K in the insulating vacuum

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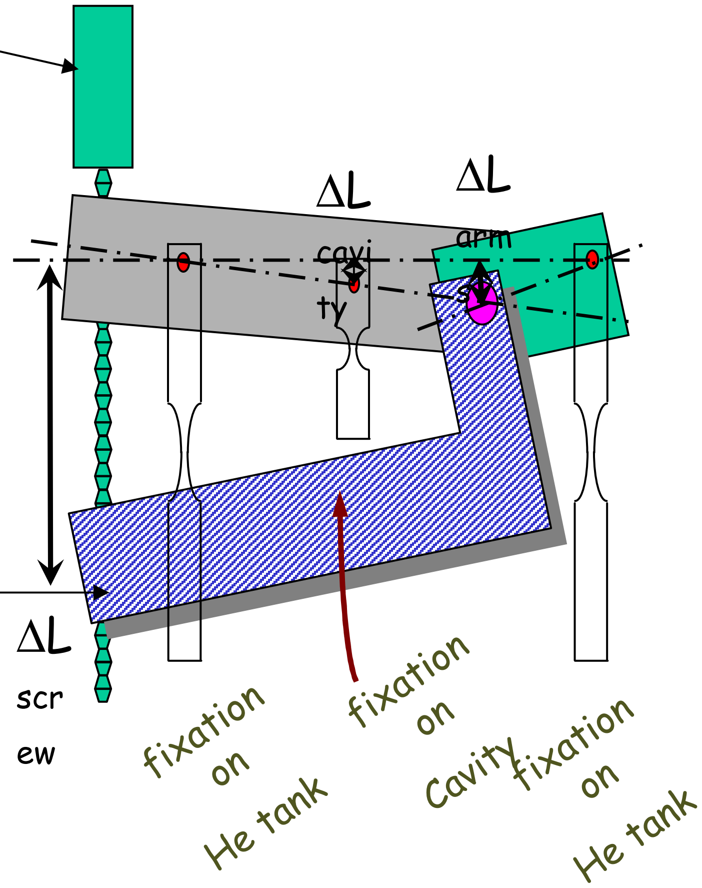
All tuners developed at Saclay are based on the same principle

Example of the TTF tuner

A stepper motor + a Harmonic Drive gear box

A double lever system

Screw-nut system



The main characteristics of this system:

- no mechanical connection between 300K at the cold mass
- the lever ratio can be easily adapted to the application
- very high resolution (~ 1 nm !)
- disadvantage: maintenance

The tuning systems developed at Saclay

Tuning is made by changing the length of the cavity in order to put the frequency within 1/20 of the width of the resonance curve

<u>Three ranges of deformation:</u>

1. At 300K the tuning is not accurate enough, the bandwidth is too wide. After cooling at 4K the cavity is put at the operating frequency
   F = 1.3 GHz and $Q_L = 5\ 10^6$ => bandwidth = 260Hz
   => resolution needed better than 13 Hz
2. In operation for small adjustments caused by mechanical and pressure instabilities.

(items 1 and 2: Slow tuning)

3. Lorentz forces and microphonics compensation => Fast tuning with piezo stacks

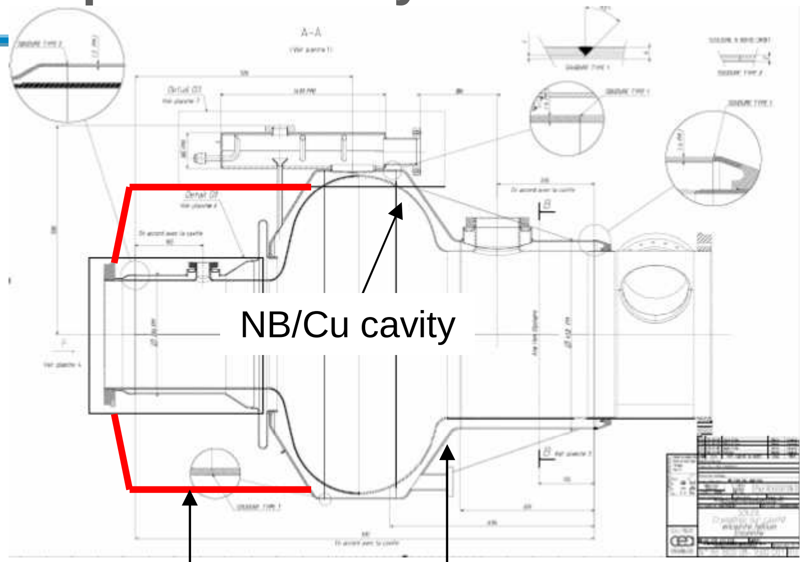
The tuning systems developed at Saclay

Example of the SOLEIL cavity:

Cavity pumped, P_{ext}=1bar => F_0=351.00 MHz

at 4,5K => F_{op}=352.2 MHz

The tuning operation needs to take into account several effects:



The difference in thermal shrinkages of Cu and SS causes 0.35mm elongation of the cavity

Fabrication tolerances:	±100 kHz
ΔF due to chemical treatment:	- 0.92 kHz/µm
ΔF due to the air ε:	+ 104 kHz (depending on the humidity)
ΔF due to the LHe pressure (1.2 bar):	- 5.5 kHz (free cavity)
ΔF due to copper thermal shrinking:	+ 1160 kHz
ΔF due to the expansion of the cavité:	+ 186 kHz/mm

Stiffness of the copper cavity (17 kN/mm) and of the tuner/helium tank system (~50kN/mm)

<u>Constrains:</u>

1. The tuner needs to be always compressed in order to suppress the mechanical plays:
   => the cavity is always stretched
   => additional effect of atmospheric pressure on the small flange of the cavity
2. The maximum deformation of the cavity shall never exceed the plastic deformation of the copper

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MACSE:

Cryomodules with Nb cavities 1,5 GHz at 2 K

two tunings systems in LHe bath at 1.8K

- A slow tuner: a stepper motor + gear box + lever system
- A fast tuner: a magnetostrictive rod

Advantages of working in Lhe bath:

- cooling down ~ homogeneous
- reproducibility of thermal shrinkage conditions
- better dimension stability at cold
- The superfluid helium = lubricant of the ball bearings
- Only electrical feedthrough (motor cables)

Disadvantages:

- Bad access for maintenance
- Hope that the superfluid helium is a good lubricant !

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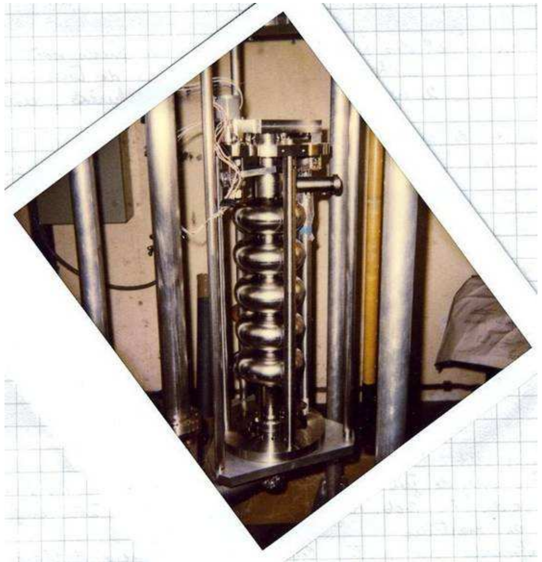
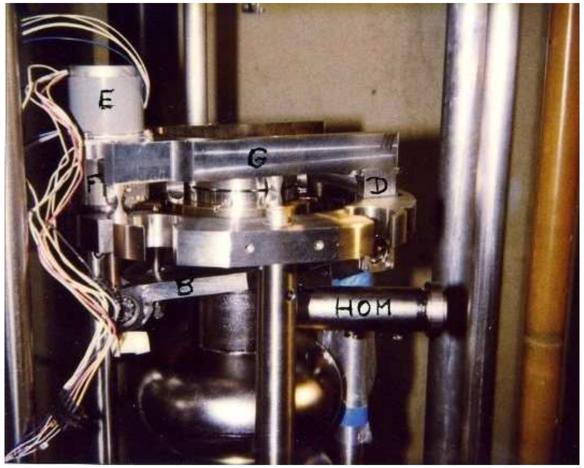
MACSE:





Slow tuner = lever system + screw nut + gear box + stepper motor

⇒ very precise : measured resolution < 1Hz
(theoretical resolution : 0.7Hz/step)
=> small backslash

This tuner worked well but for a short time: MACSE was stopped a short time after its commisionning dapnia cea saclay

TTF

9 cells Nb cavities at 1.3 GHz

The main differences with the MACSE environment:

- Separate helium tank
- No fast tuner

Saclay developed a tuner that worked in vacuum and at 2K:

=> Development of a harmonic drive gear box and a stepper motor working at 2K and in vacuum

The helium tank is the mechanical reference
It is made out of Titanium

* thermal shrinking Nb = Ti
* EB welding Nb/Ti

The tuning systems developed at Saclay

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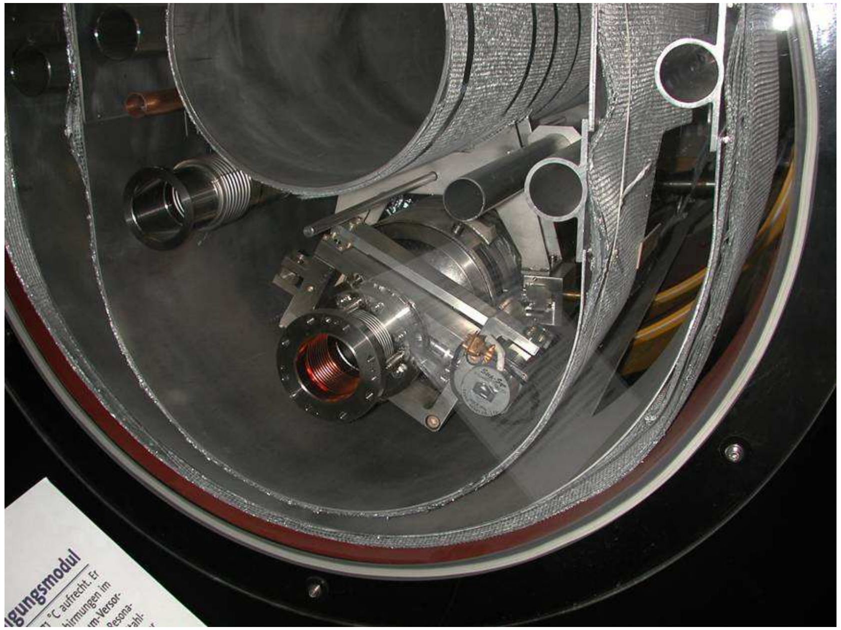
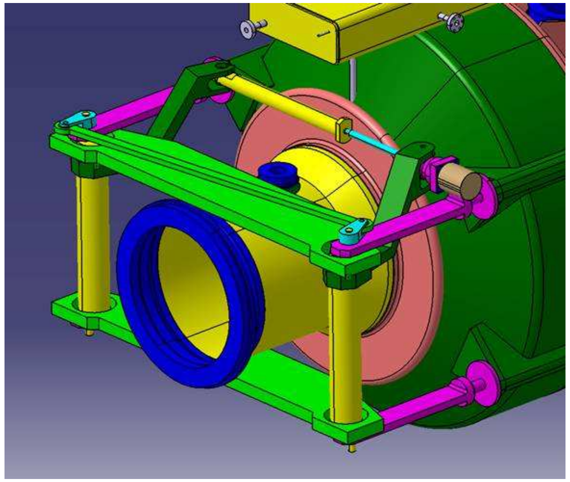
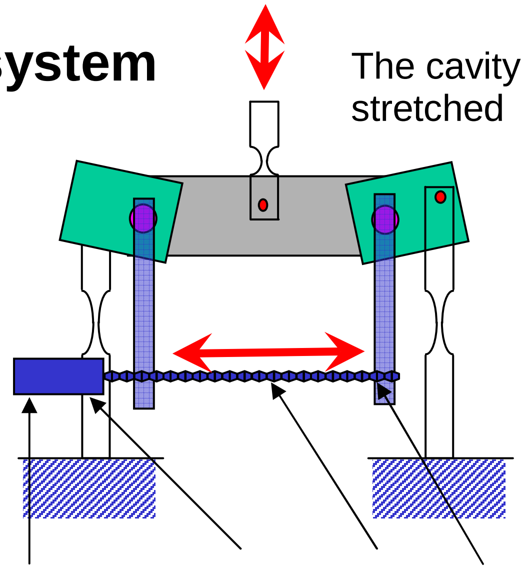


TTF cavity equipped with:
- the titanium helium tank
- the tuning system
- the magnetic shield
- and some cryogenic pipes

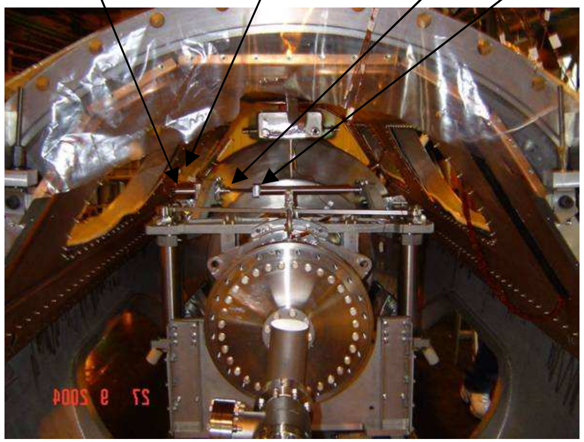
TTF cavity inside the cryomodule

The SOLEIL tuning system





Stepper motor + gear box + screw + nut



The main differences with the TTF environment:

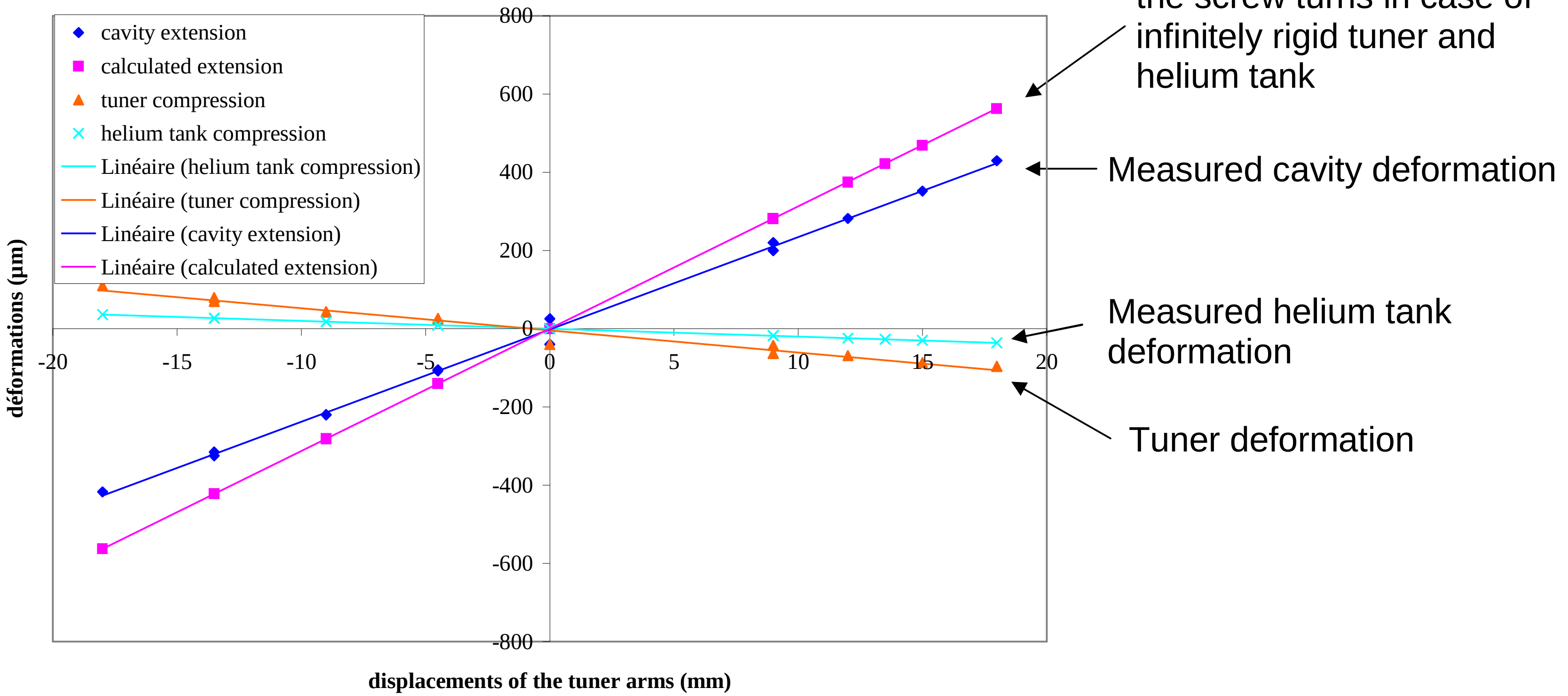
- The size
- Maximum strength ~ 30kN
- Nb/Cu cavity
- Helium tank in Stainless Steel

Characteristics:

- Stiffness ↗
- weight ↘

The tuning systems developed at Saclay

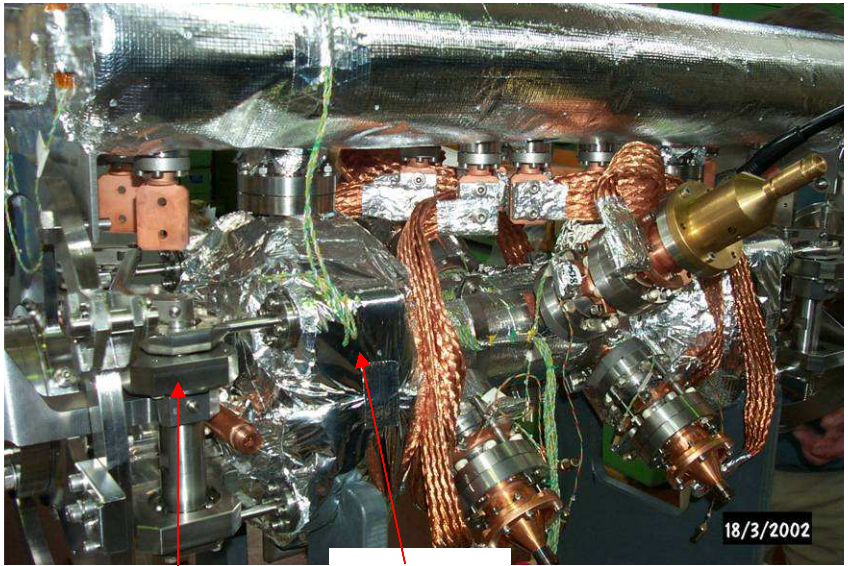
Estimations of the mechanical deformations due to the SOLEIL cavity tuner



Stiffness of the cavity is: 17 kN/mm

$\Rightarrow$ Stiffness of the helium tank = 200 kN/mm

$\Rightarrow$ Stiffness of the tuner = 70 kN/mm



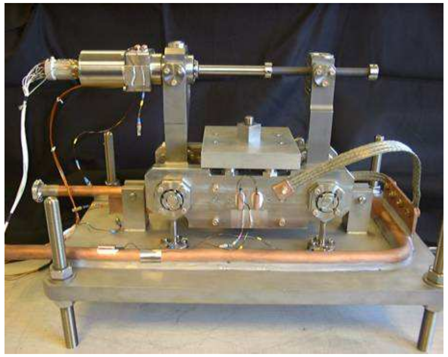
Cavity

Just enough space for the tuner !

Super-3HC

Two cryomodules with 3rd Harmonic cavities at 1.5GHz

For ELETTRA and SLS



Characteristics:

- wide ranges of detuning (for ELETTRA)

=> Lever ratio increased ~ 1/120 to increase the number of turns of the screw at each large detuning

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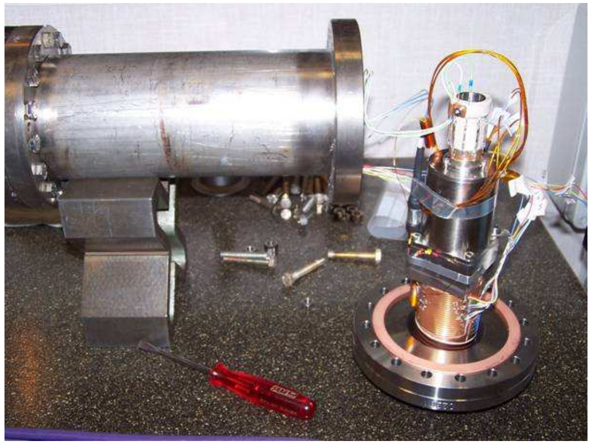
Problems of the gear box lifetime

at ELETTRA: we need to change the Harmonic Drive gear boxes every ~ 1.5 year corresponding to about 30.10^6 motor full step (200 steps/turn).

=> Improvement of the reliability of the gear box:

Development at Saclay of a little cryostat for the test of motors and gear boxes in vacuum and at cold (77K and 4.2K if needed)



Test in progress:

A very promising system is being tested at 77K:

PHYTRON planetary gear box with a stepper motor specially developed for working at cold

Today: 60.10^6 steps were done without loosing any motor step. We are still going on (until 100.10^6 full motor steps) dapnia cea saclay

Problems of the screw/nut damaging on the SOLEIL tuners:

This problem was revealed by the use of the encoders that were mounted recently on the stepper motors of the SOLEIL tuners.

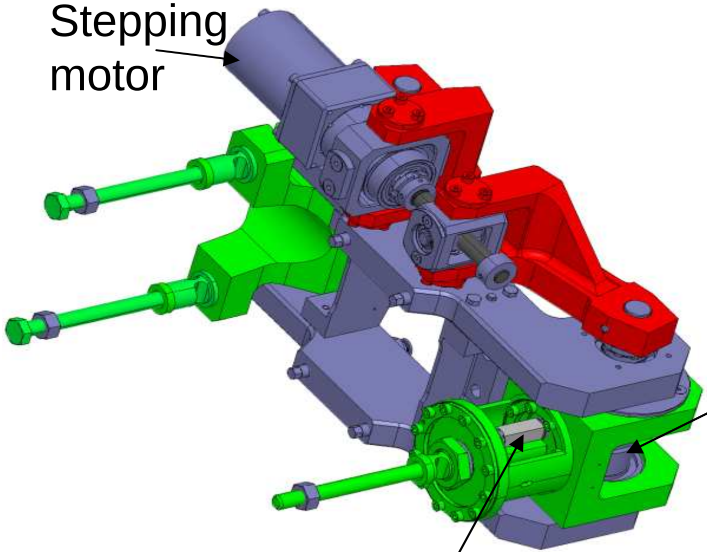
Motor steps are lost when the tuner is actuated to pull the cavity (against the strength). The system was dismounted during last summer shutdown. The surface of the screw has been damaged by the nut. It has been cleaned and remounted.

The cause is not clear. The material of the screws and nuts are the same than the Super-3HC ones, as well as the lubricant surface treatment. The strength applied on this screw is higher than in the case of Super-3HC, but it is small (~ 100kg max).

⇒ spare parts

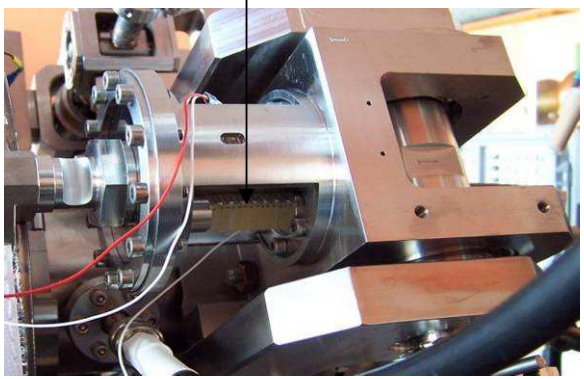
⇒ to find more reliable screw/nut systems working at cold

Stepping motor



Eccentric shaft

2 piezo stacks L=30 mm

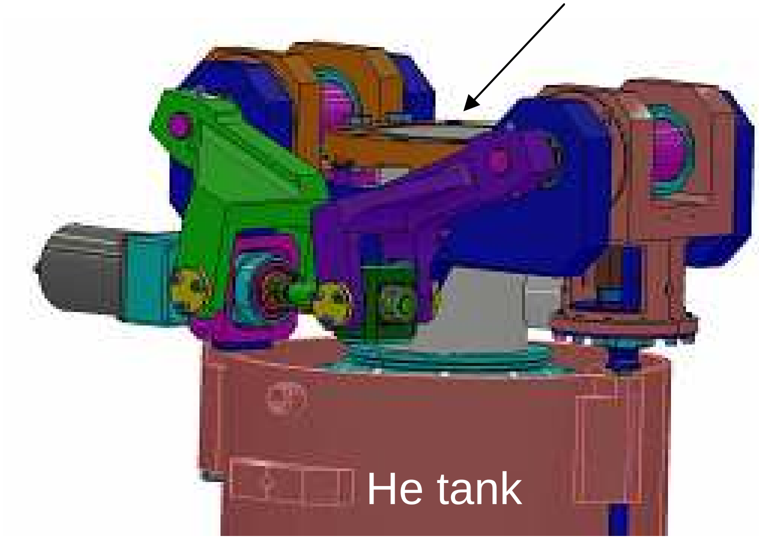


The CARE-SRF: Piezo Tuning System

Goal: compensation of the Lorentz forces detuning that is generated by the pulsed mode operation at very high gradients (35MV/m)

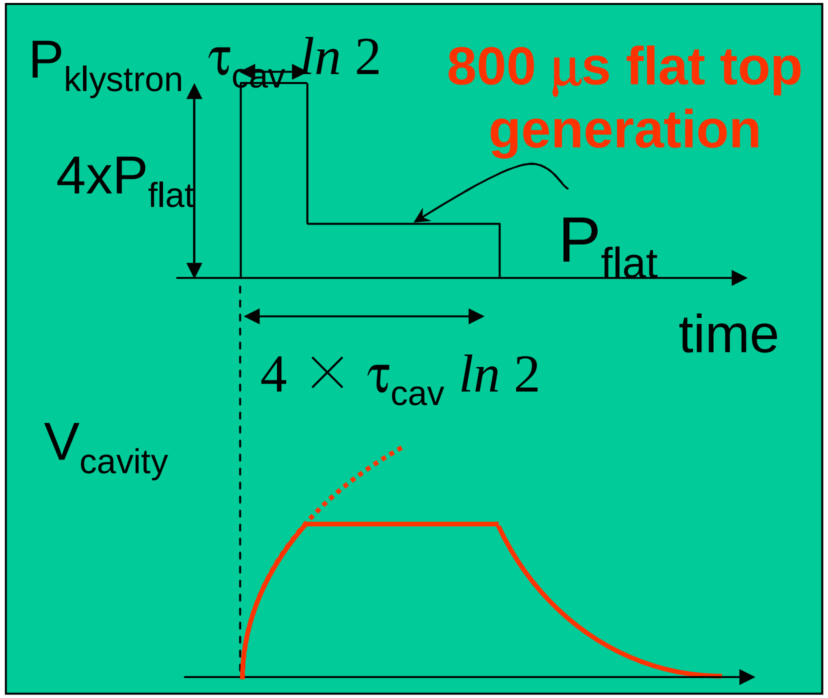
Tested on a TTF cavity

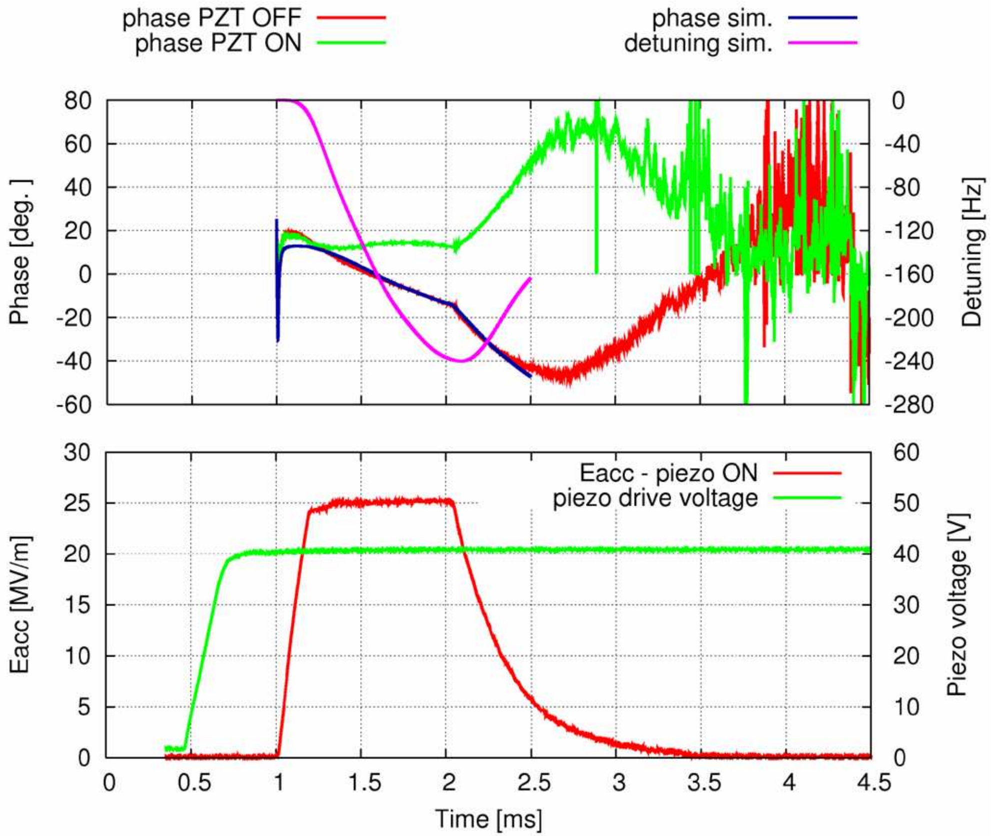
Cavity flange



CARE/SRF: Pulsed operation in CryHoLab

- RF source : 1.5 MW, 1ms pulse, 6.25 Hz max
- Rep. rate for the LFD experiments is 0.87 Hz
- DESY TTF-III coupler – Measured Q_{ext} = 1.34 10^6
- Maximum E_{acc} = 25 MV/m, limited by field emission on the test cavity (C45)
- RF pulse is different from TTF pulse:
  - Faster rise time = 200 µs instead of 500 µs
  - Same flat top 800 µs





CARE/SRF: Pulsed operation in CryHoLab

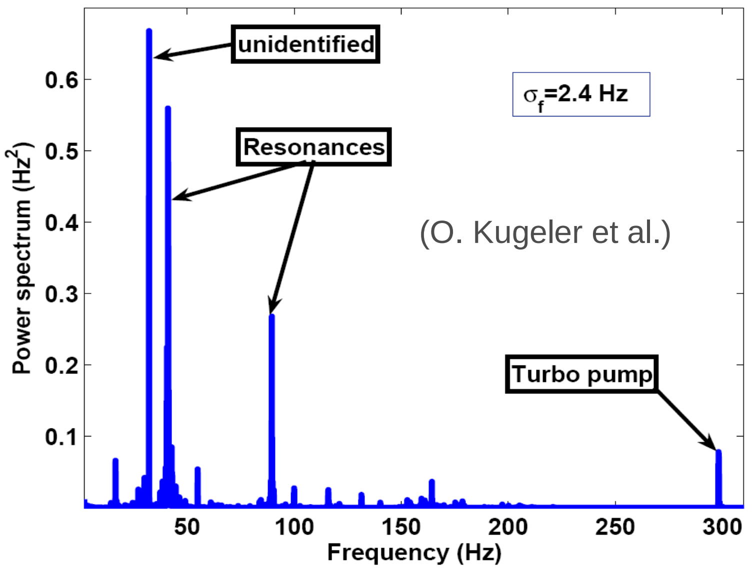
- minimize the cavity voltage phase excursion during the flat top
- Parameters for a simple PZT driving pulse : pre-delay, amplitude, rise time

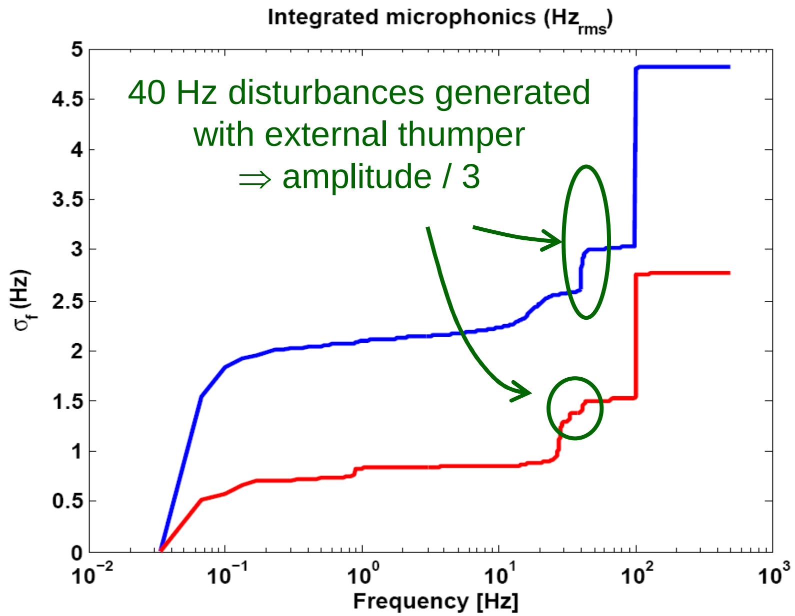
The detuning of -240 Hz is derived using a numerical model of the cavity and fitting the measured amplitude and phase.
With compensation the detuning is reduced to 20 Hz peak-peak during the flat top.

EUROFEL:

Microphonics Compensation with Feedback

Tests of the CARE/SRF tuner in HoBiCat at Bessy
(O. Kugeler, A. Neumann)





Feasibility of a feedback control for a 9-cell cavity demonstrated
But efficiency limited by the piezo tuner resolution and relatively low feedback gain for mechanical transverse modes with multiple polarizations
Compensation of microphonics with amplitude below 1 Hz seems impossible

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Futur plan:

1. Improvement of the reliability of the fragile parts of these tuners:
   - gear boxes: cryostat in operation at Saclay to perform tests at cold - new systems and new surface treatments
   - new screw/nut system

2. Development of tuners for new applications:

   12 SPIRAL2 $\lambda/4$ cavities $\beta=0.07$ at 88MHz

   We will test two versions:
   - with the motor outside the vacuum tank
   - with motor inside