ILC-GDE SCRF Meeting

Fermilab, 21-25 April 2008

The Blade-Tuner

Status & Perspective

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Outline of the talk

Brief historical review

- –The Superstructures Blade Tuner
- –Modified He tank

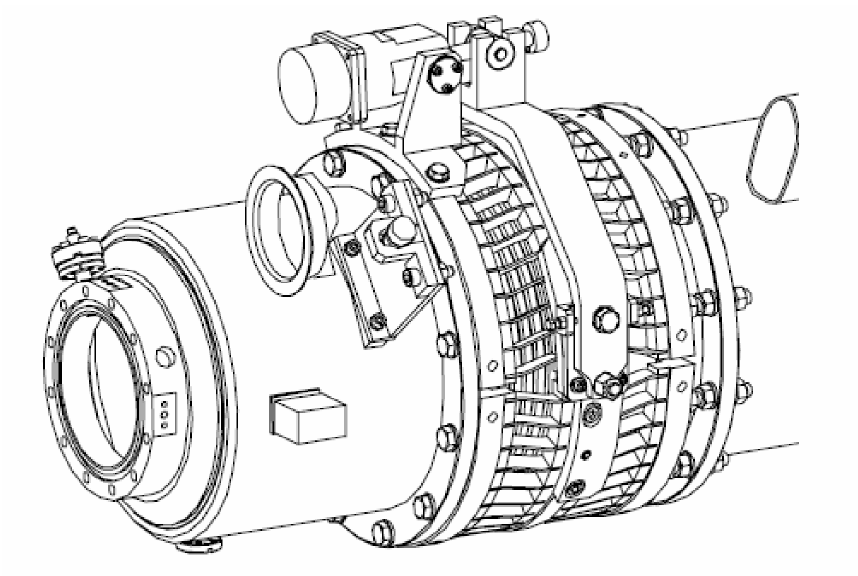
The ILC Blade Tuner prototype (ver. 3.0.0)

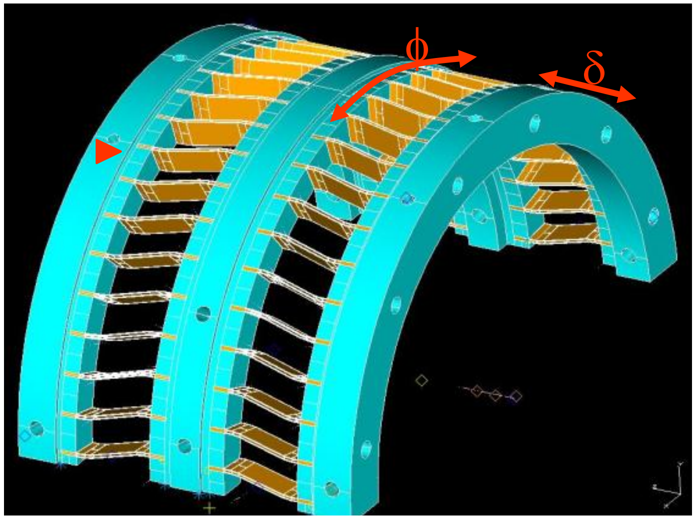
- –Tuner design and tuning actions
- –Cold tests of the stainless steel prototype at DESY and BESSY
- –Conclusions from this BT prototype tests

The Revised Blade Tuner (ver. 3.9.4)

- –Geometry and design
- –Results from FEM analyses: load cases and limit loads

The Superstructure Blade Tuner

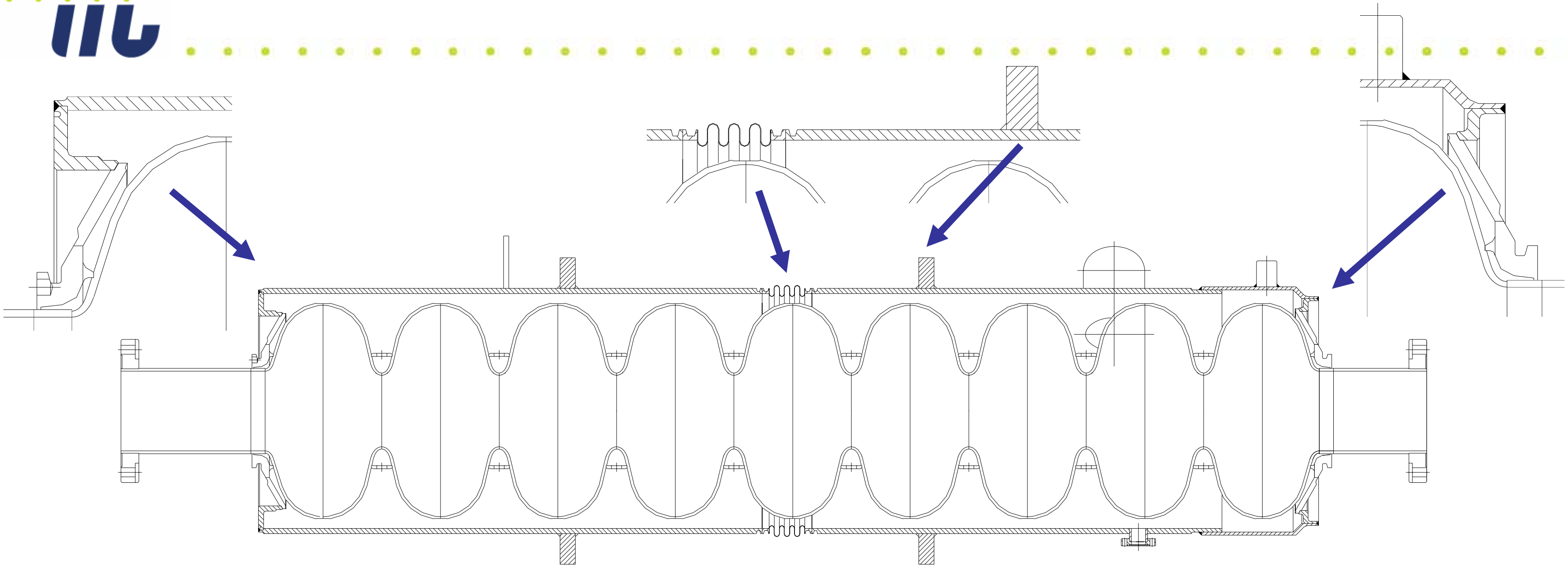


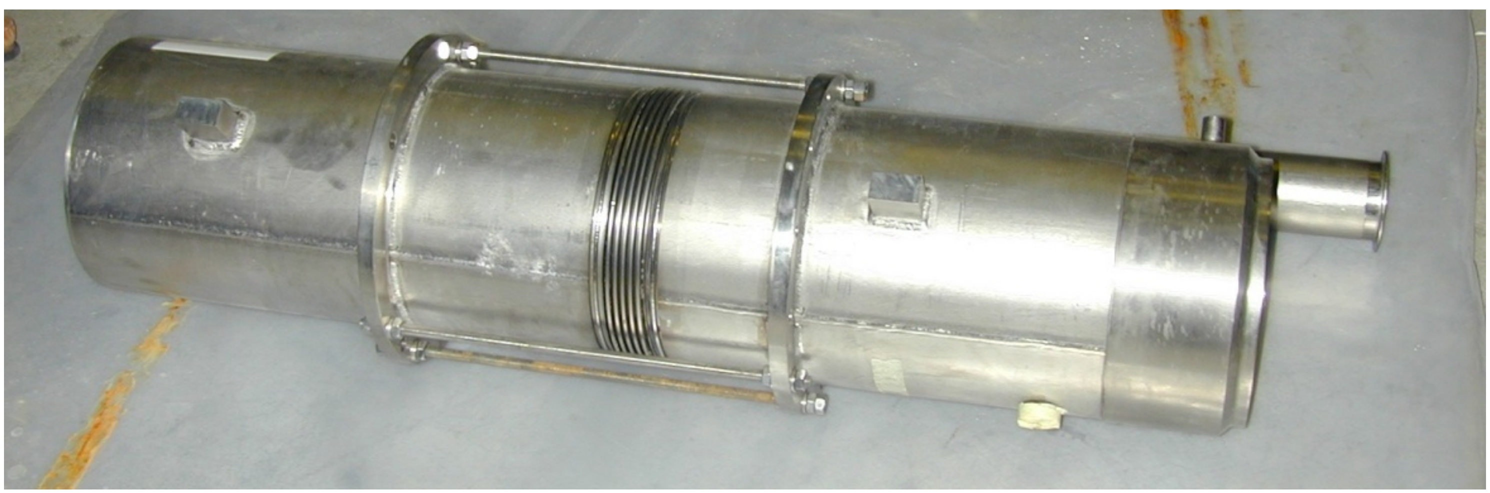


INFN Milano - LASA & DESY

Transforms the central ring rotation in a longitudinal axial motion that change the length of the cavity, i.e. its frequency

Modified Standard TTF He Tank





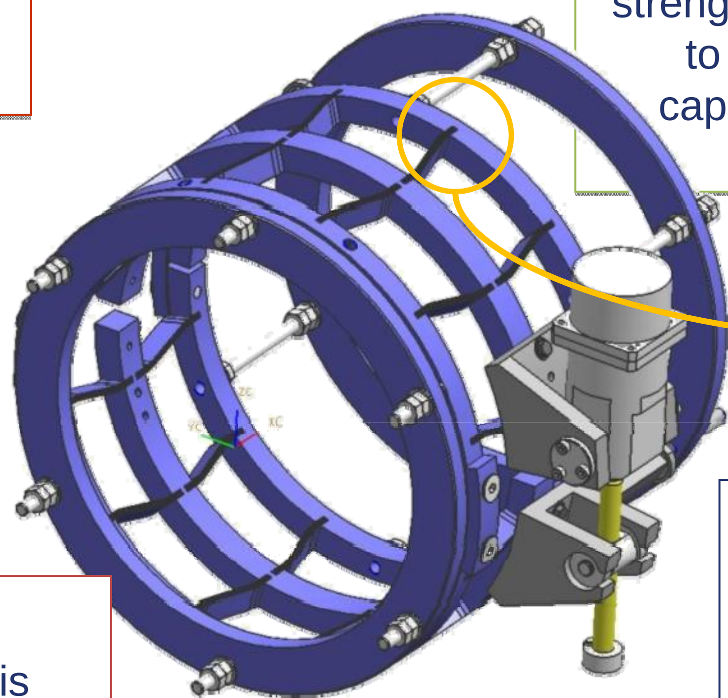
Blade Tuner prototype for the ILC

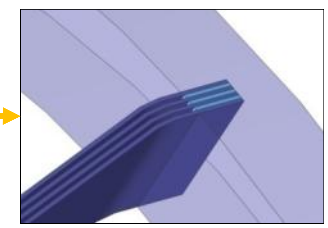
Lighter

The redesign of rings allowed an important **weight reduction** (about 40%) maintaining the full symmetry with collinear blades.

Ready for future SS tank

The tuner can be **built both with titanium or stainless steel rings**. The use of an high strength alloy for blades allows to exploit the full tuning capabilities without plastic strains.





Cheaper

The new geometry and mechanism lead to an **important reduction of costs**.

Wider tuning range

The different blade geometry adopted **improve the slow tuning capabilities** to more than 1.5mm at the cavity level.

New driving mechanism

The new driving mechanism is simpler, **cheaper and more compact**, simplifying the installation of an external **magnetic shield**.

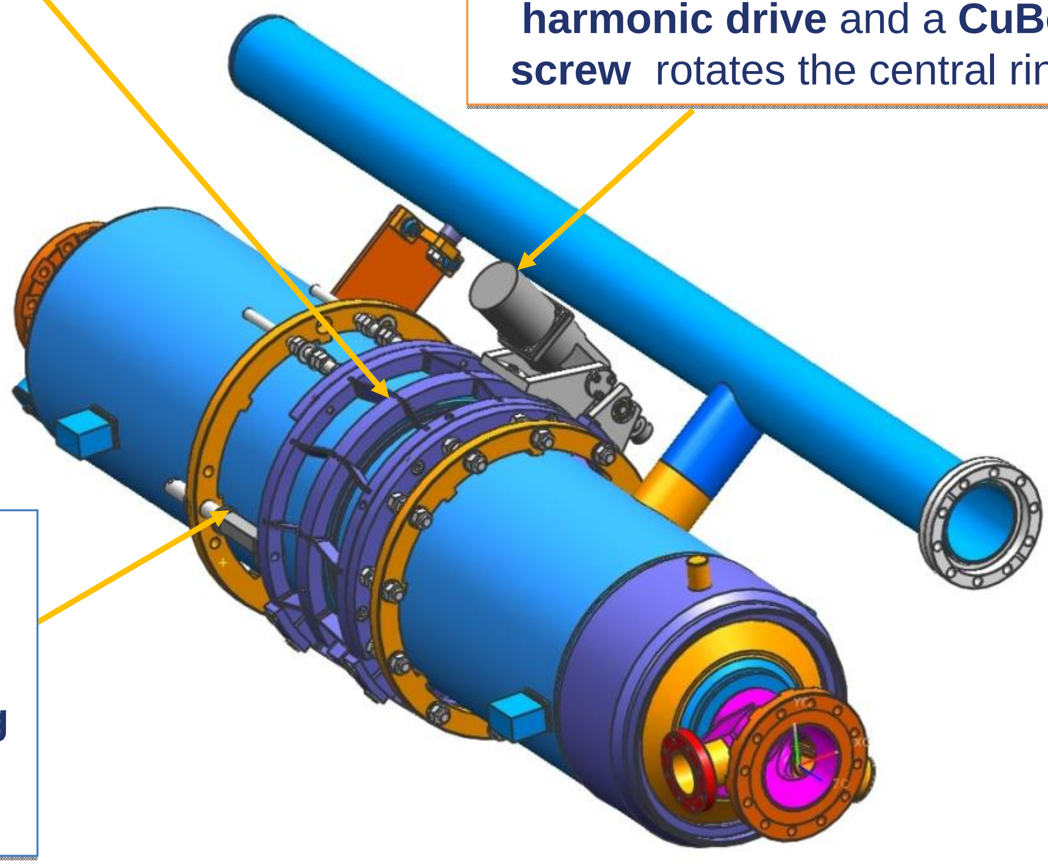
The Tuning Actions

The bending rings

The bending system consists of **three different rings**: one of the external rings is rigidly connected to the helium tank, while the central one is divided in **two halves**. The **rings are connected by thin plates, the blades**, that by means of an imposed azimuthally rotation bend and elastically change the cavity length.

The movement system

The **stepping motor**, with its **harmonic drive** and a **CuBe screw** rotates the central ring



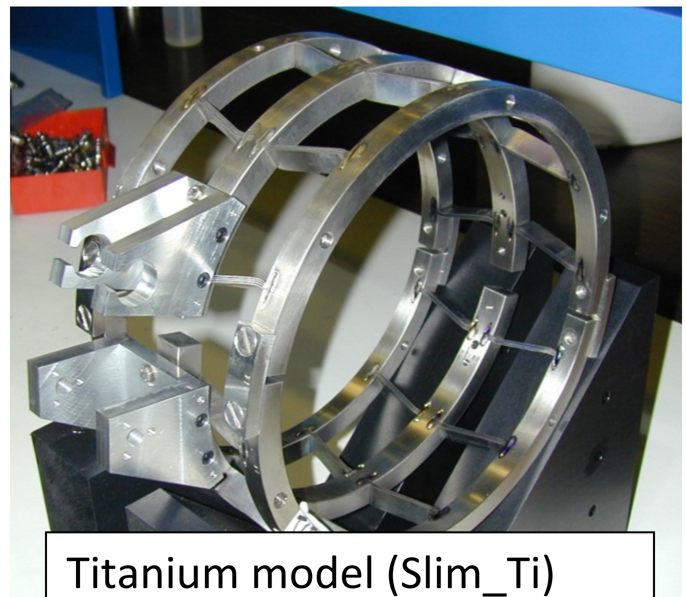
The Piezo Actuators

2 piezo actuators in parallel provide fast tuning capabilities needed for **Lorentz Force Detuning** (LFD) compensation and **microphonics** stabilization.

Blade Tuner prototype cold tests

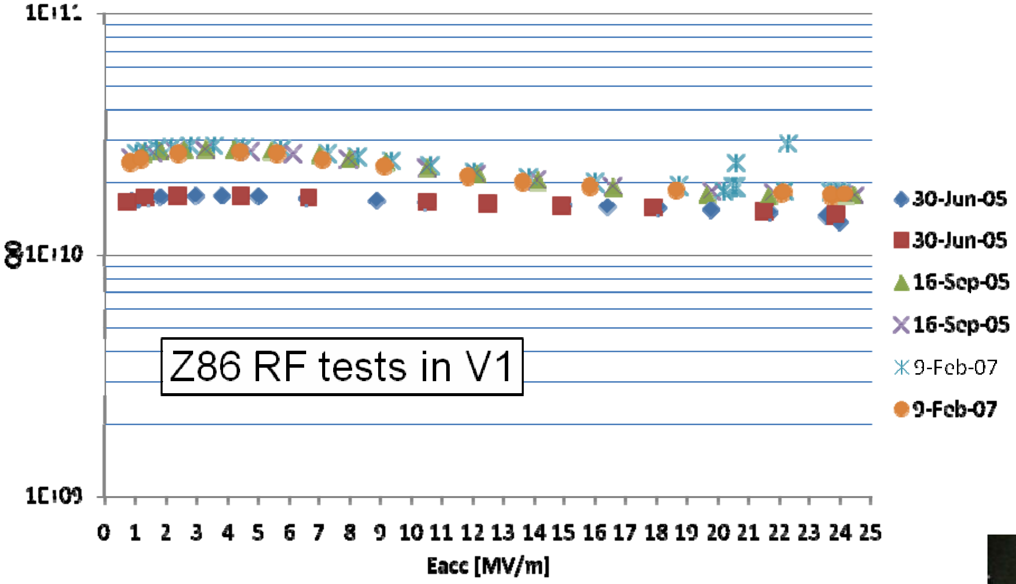
- **The Stainless Steel + INCONEL prototype has been tested at cold:**
- **Sept. 2007 in the CHECHIA** horizontal cryostat, DESY
  - Installed on the **Z86 TESLA cavity** equipped with a standard modified He vessel
  - Equipped with a standard TTF unit: **Sanyo stepper motor + HD gear**
  - **2 Noliac 40 mm** standard piezoelectric actuator installed
- **Feb. 2008 in the HoBiCaT** horizontal cryostat, BESSY
  - The same assembly but equipped with a prototype of a possible alternative driving unit: **Phytron stepper motor + Planetary Gear**

Stainless Steel + Inconel model (Slim_SS)



Titanium model (Slim_Ti)

Z86 TESLA cavity



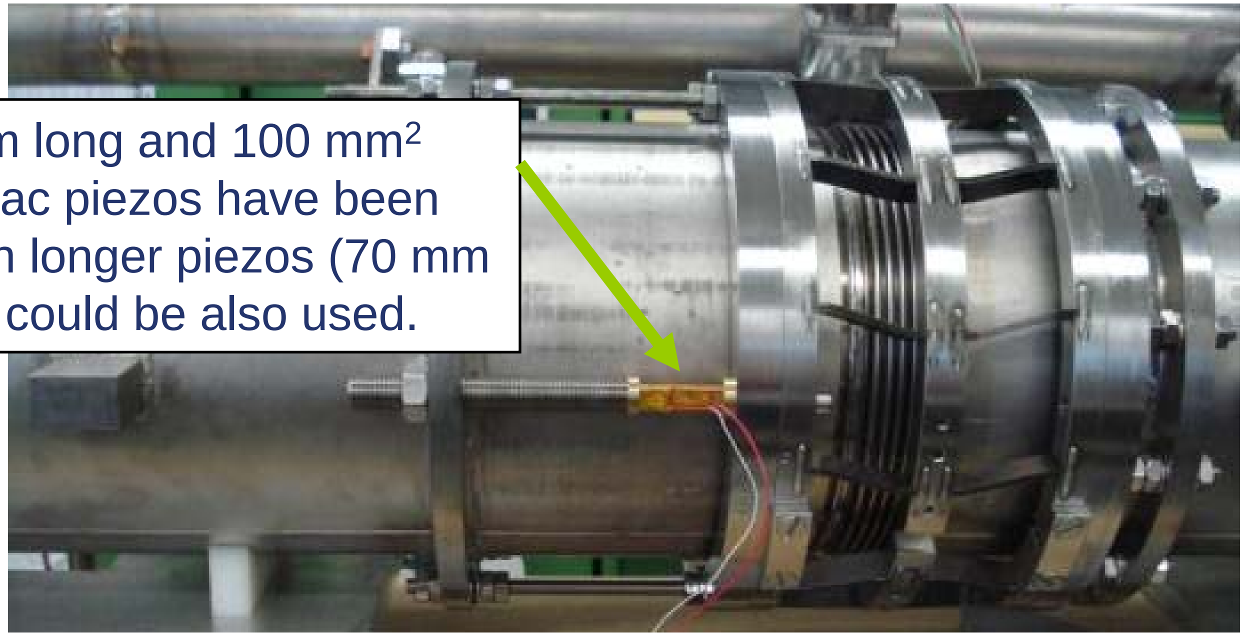
The tuner has been installed on the **Z86 TTF cavity** (24 MV/m best E_{acc}) using a "TTF standard" **modified helium tank**, with the insertion of a central bellow to allow the coaxial tuning operation

Z86 integrated in the helium tank at DESY

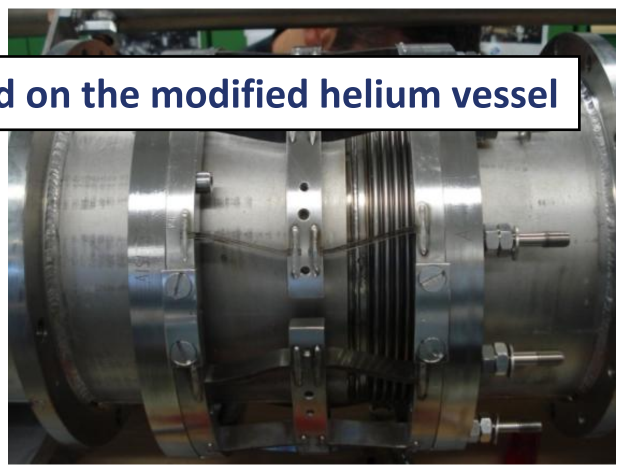
Z86 during the EB Welding at Lufthansa

Blade Tuner installation – Halle III, DESY

Two 40 mm long and 100 mm^2 section Noliac piezos have been inserted. Much longer piezos (70 mm and more) could be also used.



The tuner installed on the modified helium vessel

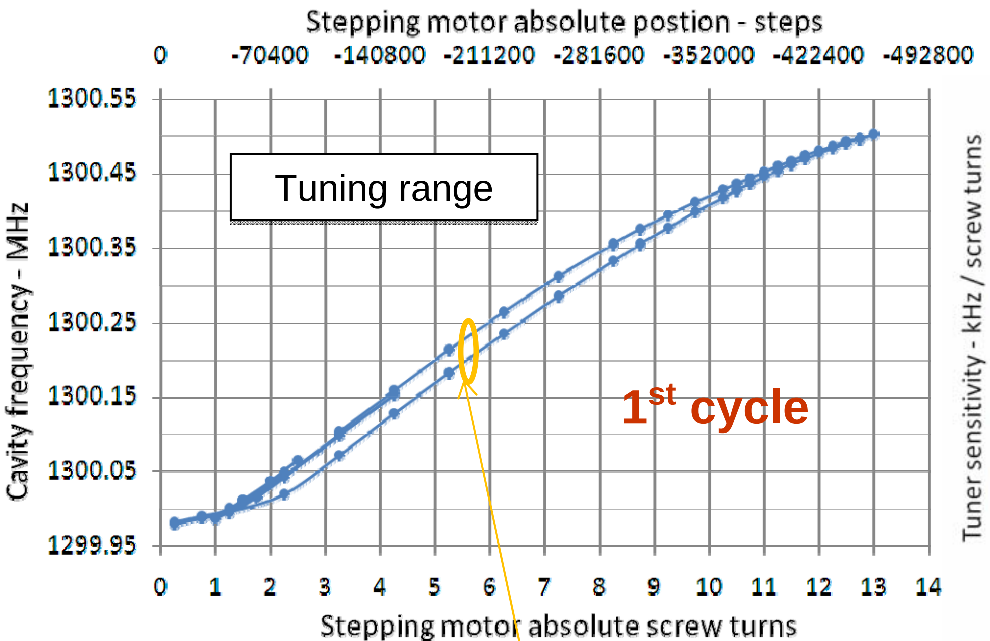


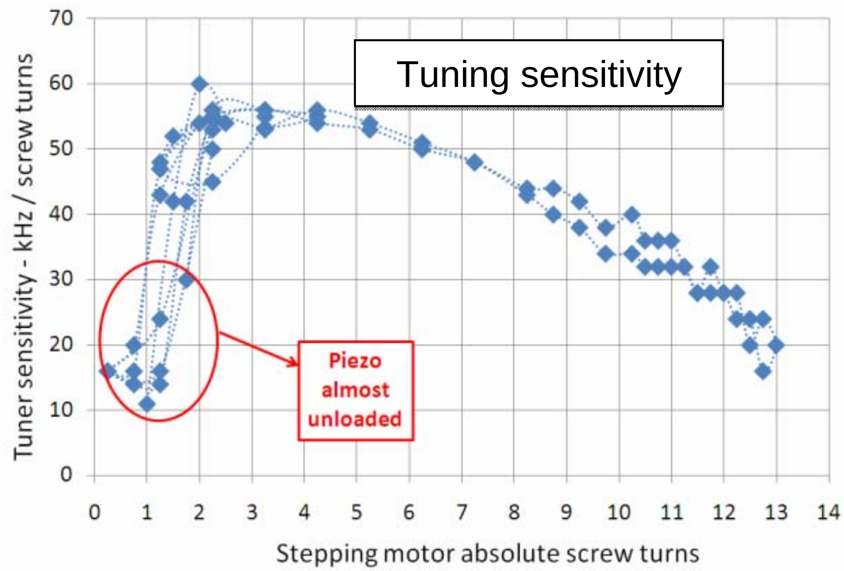
Driving motor installed

Cold test in CHECHIA – Tuning range

The measurement of the tuning range has been performed, using a Vector Network Analyzer to read the cavity resonant frequency while moving the tuner stepping motor.

The full tuning range achieved is 520 kHz



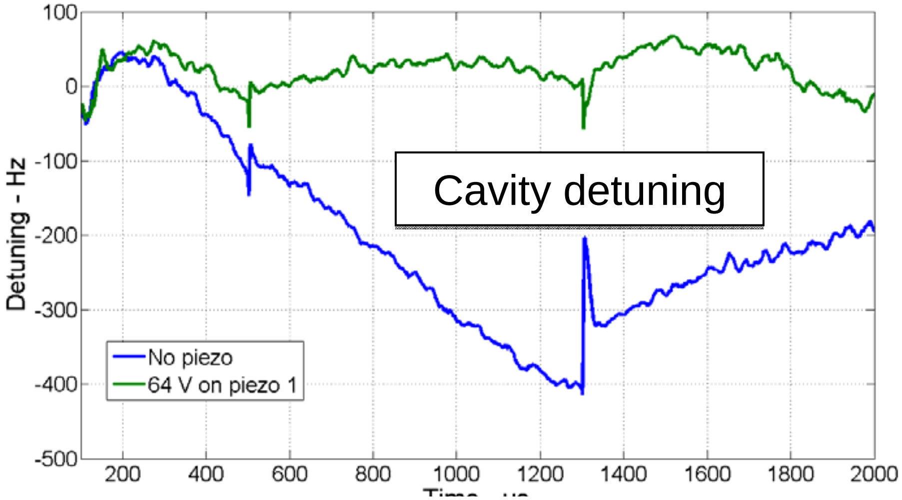


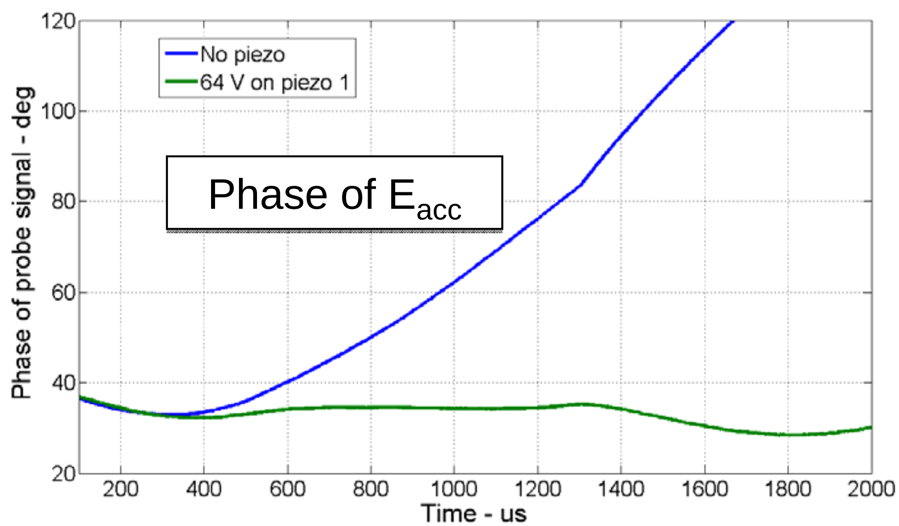
First cycle hysteresis.
Only one cycle has been performed

Two complete turns were needed from the lower end of the tuning range for both piezo actuators to be in good contact with the tuner and to allow reaching the nominal tuner sensitivity.

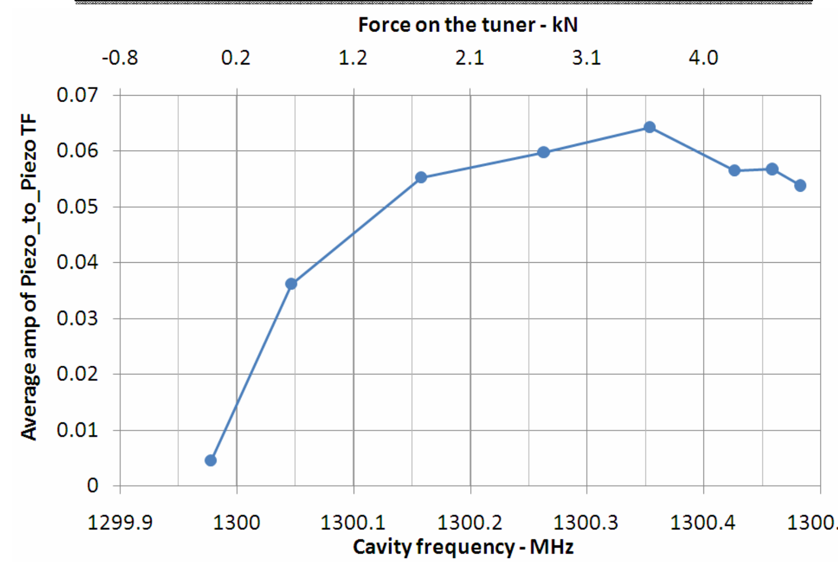
Cold test in CHECHIA – LFD compensation

single half-sine pulse, 2.5 ms long, 0.95 ms in advance with respect to RF



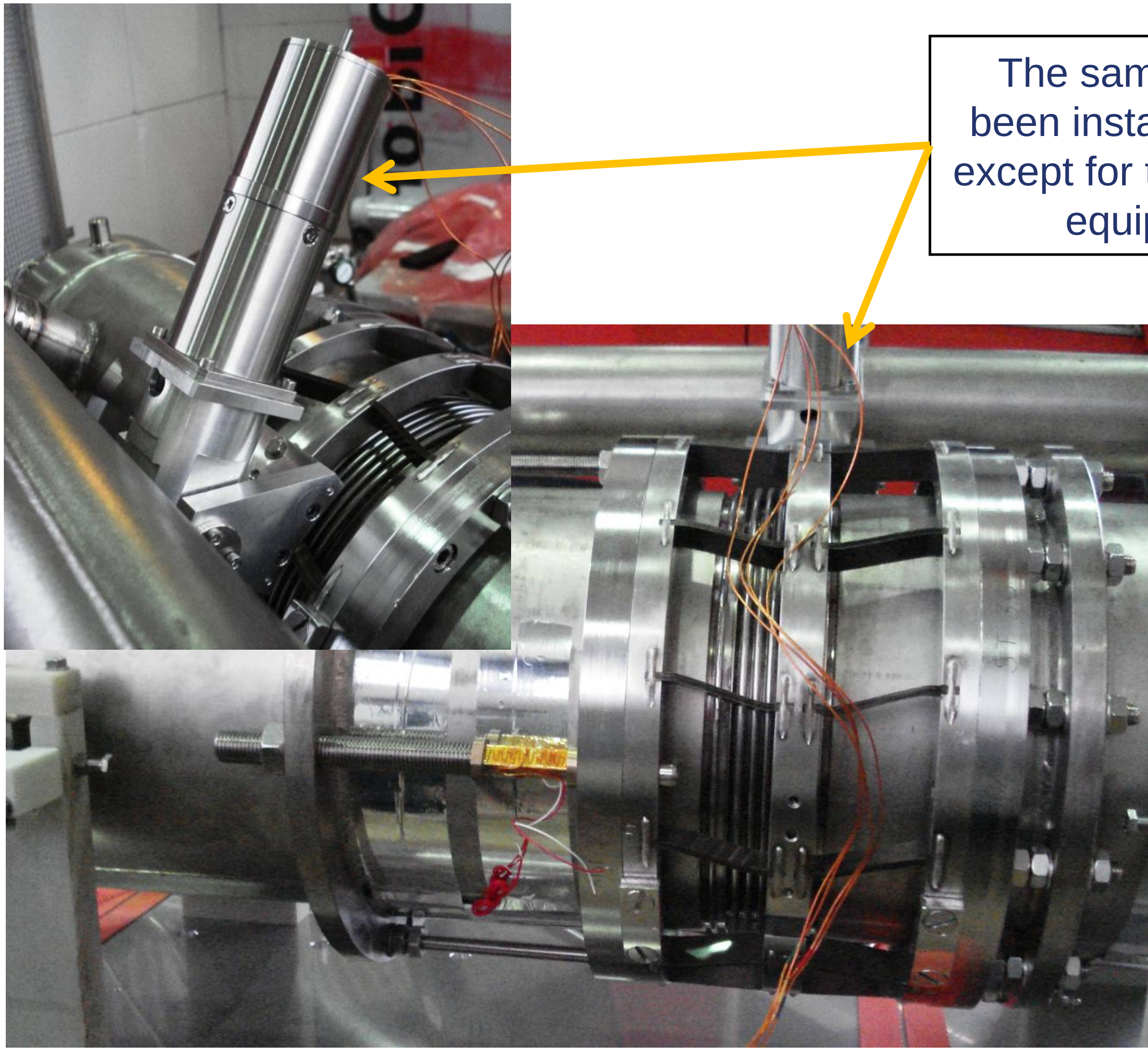


Piezo to cavity coupling strength



300 Hz of LFD, during the RF pulse flat top, have been compensated at E_{acc} = 23 MV/m, driving only one of two installed piezo actuators with 64 V, less than 1/3 of the nominal maximum driving voltage (200 V @ RT).

Blade Tuner installation in HoBiCaT, BESSY

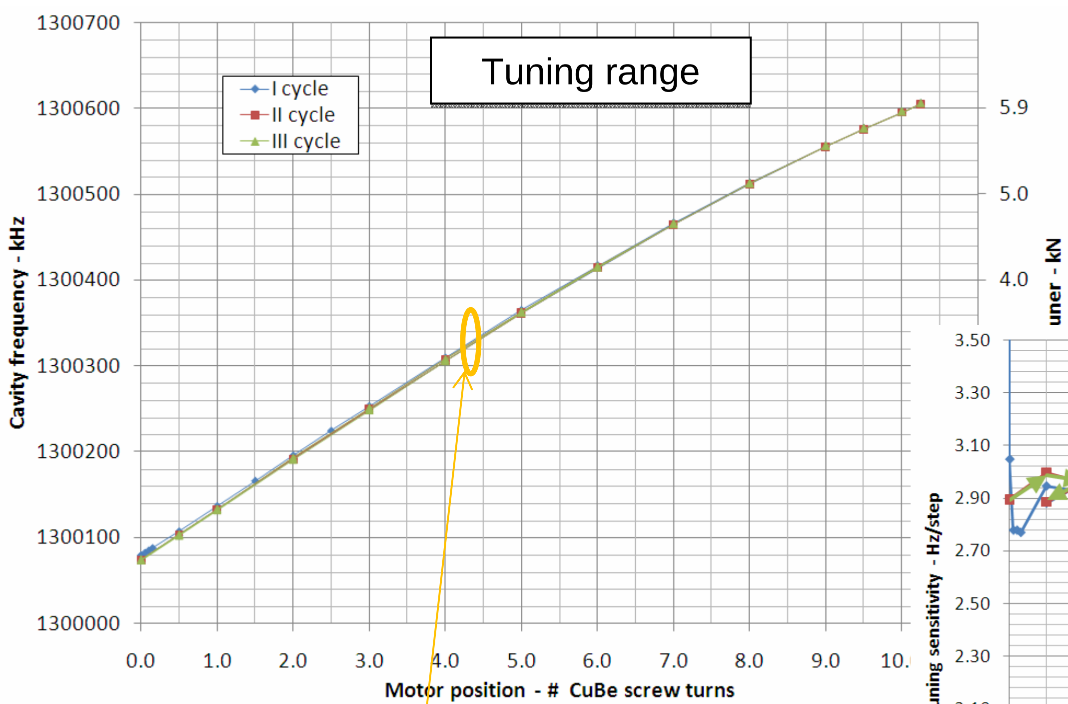


The same Blade Tuner assembly has been installed for cold testing at BESSY, except for the driving unit, a stepper motor equipped with **planetary gear**

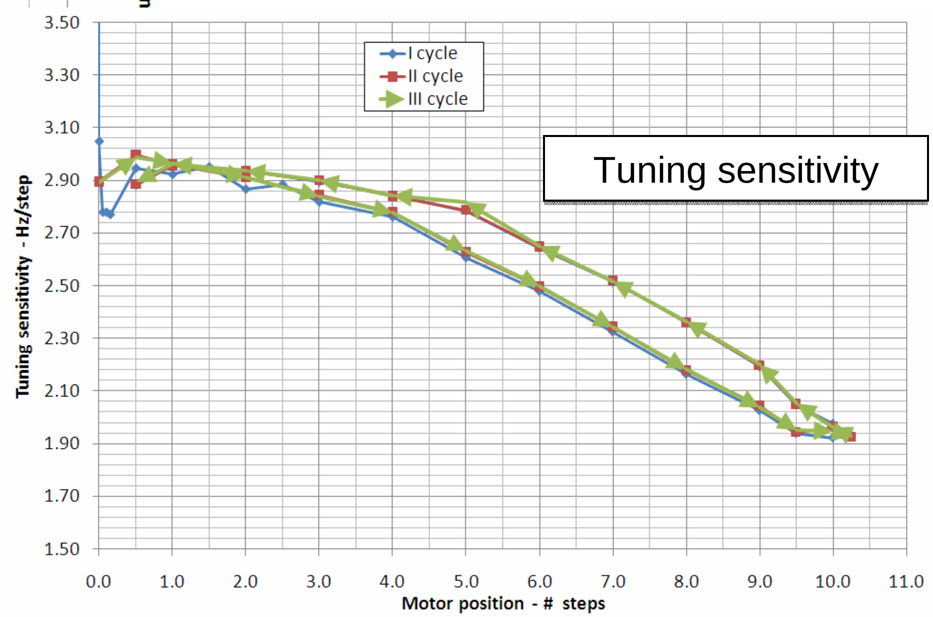
HoBiCaT at BESSY

HoBiCaT Tests – full tuning range

The tuning range of 525 kHz has been confirmed
The hysteresis has been almost cancelled.



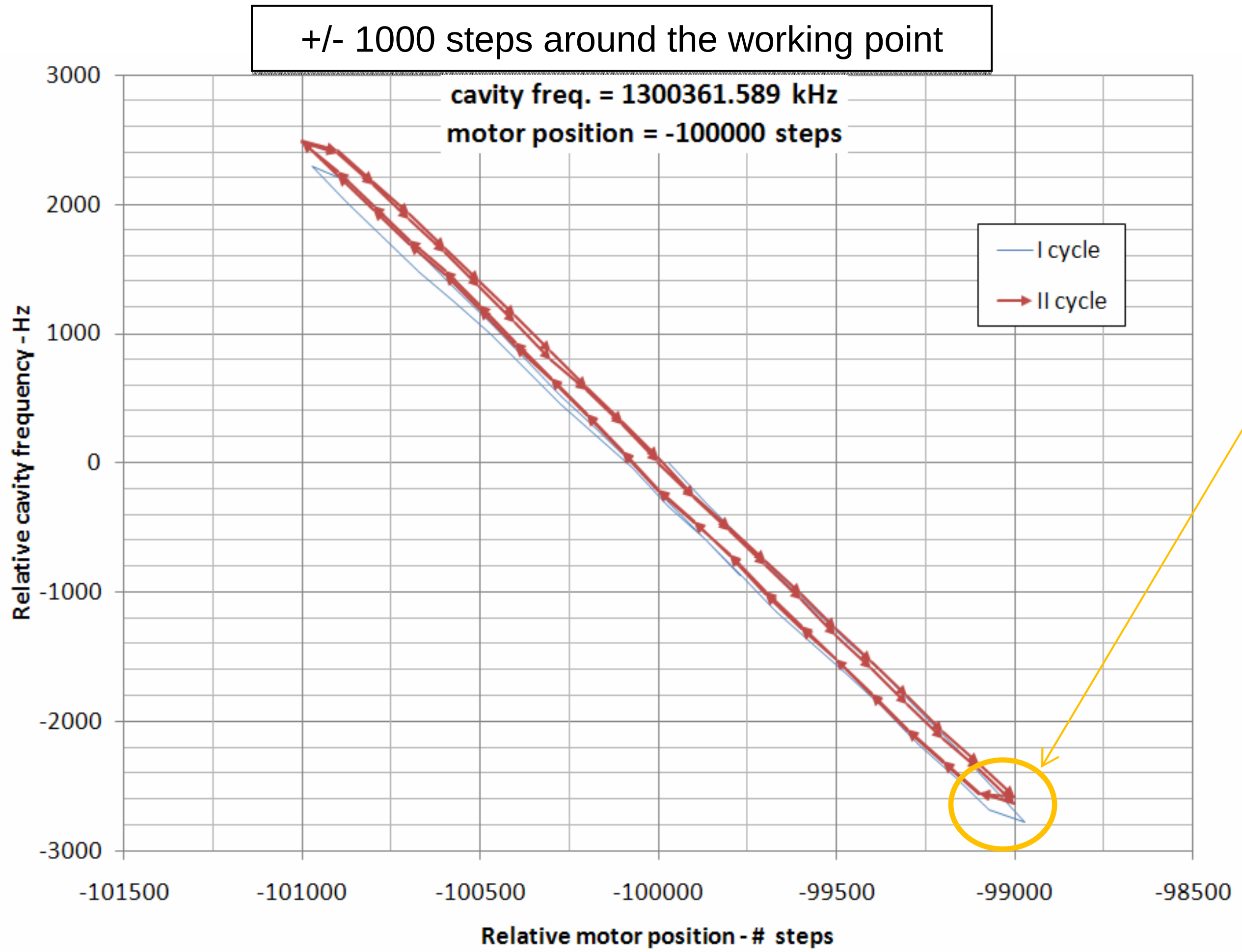
This time an **higher piezo preload** than CHECHIA test has been set. As a consequence **the piezo unloading effect is no more visible** in the sensitivity plot



Hysteresis shown in the first cycle has been almost cancelled after a few tuning range cycling

HoBiCaT Tests – close to the working point

tuning characteristics around a specific working point



The frequency positioning behavior and the amount of **backlash, about 85 steps**, is slightly higher than the one usually experienced with TTF tuner.

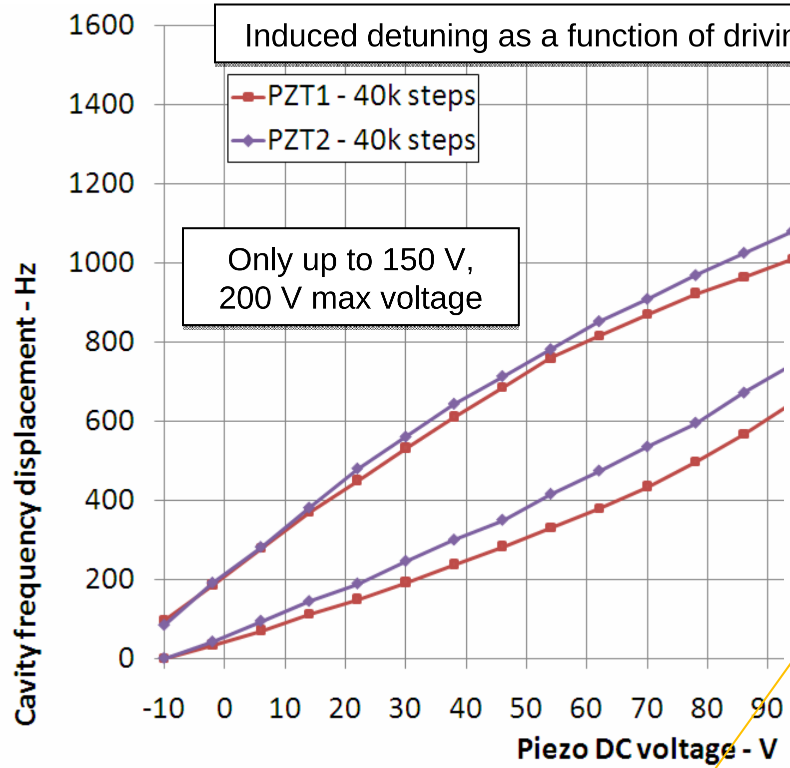
But the **planetary gear** installed, here tested for the first time, actually introduces a significantly **higher backlash if compared to HD gear, about 20 times higher**

Confirmation tests being performed this week

HoBiCaT Tests – piezo characterization

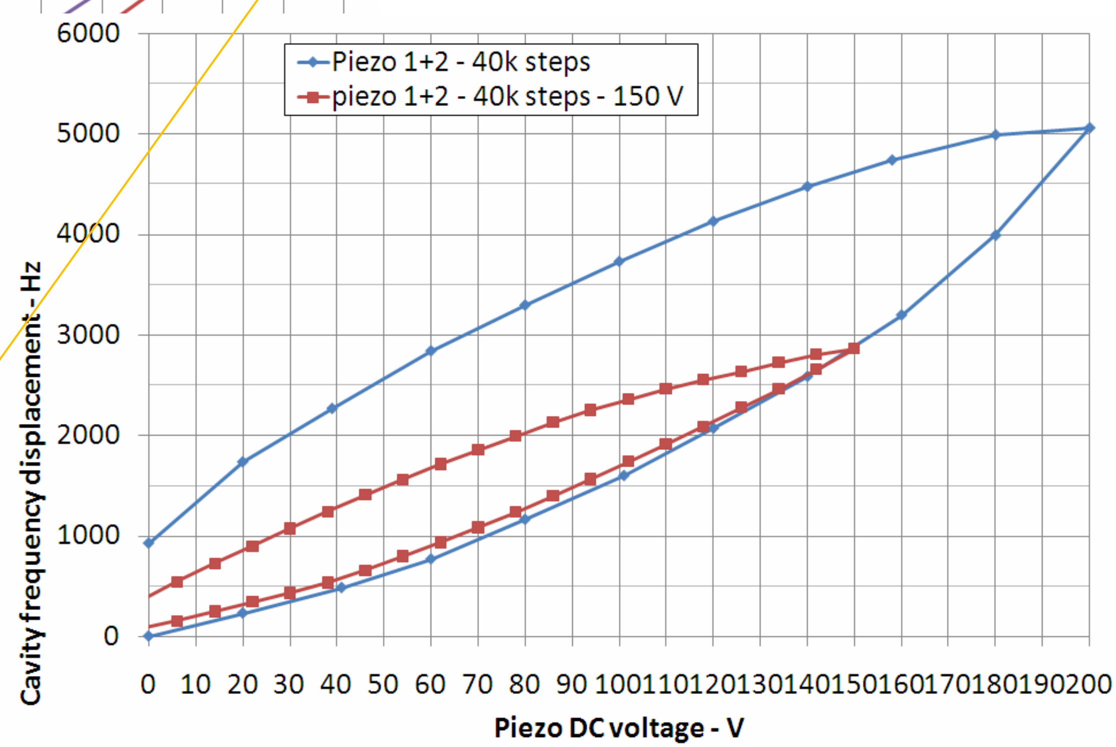
piezo fast tuning performances in terms of induced static detuning

Induced detuning as a function of driving DC voltage for each piezo



Only up to 150 V, 200 V max voltage

Induced detuning as a function of driving DC voltage for both piezo in parallel and up to the maximum voltage



Only a limited discrepancy (expected by design) has been measured for the performances of the two piezo. The difference is lower for higher loads

Blade Tuner prototype cold tests - conclusions - 1

- **The coaxial Blade Tuner prototype has been successfully cold tested.**
- **Installation, assembling and robustness**
  - The whole Blade Tuner assembly safely withstands all the cooldown, warm-up and operating procedures at DESY and BESSY.
  - A more careful positioning of the limiting bolts, needed to bear the traction force during cooldown, during installation at BESSY resulted in avoiding any potentially critical deformation of the cavity as previously seen in the DESY tests
- **Tuning range**
  - The static tuning capacity fully meets expectations and requirements.
  - A full tuning range of **525 kHz** has been measured and **600 kHz** can be achieved.
  - The observed hysteresis after the first measure has been almost cancelled after a few successive load cycles
  - The current **tuning sensitivity is of about 1.5 Hz per motor half-step**, already a reasonable value. Eventual further improvement can be easily achieved by increasing the reduction ratio of the gear.
  - Apart from the different tuning sensitivity, **the behavior for the shortest tuning range reveals a level of settling and uncertainty in the frequency positioning that is comparable to the one experienced with the TTF tuners.** Further tests will be done at BESSY starting this week. The new PL gear looks as the principal cause.

BESSY & DESY test conditions

	BESSY	DESY	unit
Motor	Phytron, 200 coils	Sanyo, 200 coils	
Gear	Phytron, VGPL, 100:1	HD, 88:1	
Tuning range (TR)	525	520	kHz
CuBe screw turns	10.2	13	# turns
Motor full-steps	-205000	-228800	# full-steps
Max Δf over TR	1.7 (@-100000 full-steps)	31 (@-79200 full-steps)	kHz
Δf after full TR cycle - freq. diff. at 0 turns after the cycle-	0.38	16	kHz
Max tuning sensitivity	3.0 1.5	3.1 1.55	Hz/full-step Hz/half-step
Max load on tuner during test - computed from cavity spring constant -	6	5	kN

Blade Tuner prototype cold tests - conclusions - 2

- **Piezoelectric performances**
  - The dynamic detuning compensation capabilities confirmed a large margin in terms of performances, for LFD and microphonics compensation, even in view of ILC goal gradient.
  - The entire LFD shown by the Z86 at 23 MV/m has been compensated under different load in CHECHIA.
  - 5 kHz of maximum static tuning range achieved in HoBiCaT operating the two piezo in parallel with only 1 kN preload each and 200 V maximum voltage. According to TTF experience, this would lead to about **2.5 kHz dynamic detuning** compensation range with TTF pulses
  - The Blade Tuner assembly reveled an higher dynamic Lorentz coefficient, as expected, if compared to average TTF tuner experiences. This has been anyway easily compensated by the higher fast tuning efficiency and it is fully explained by the adapted Helium tank and the provisional assembly for this test.
  - Limited discrepancies have been also observed in the performances of the two installed actuators, this difference gets lower when increasing the load. A slightly stiffer tuner its not required but preferred.
  - Tests confirmed that the operating temperature of piezo is between **20 K and 30 K**,

Motor position / total load [# steps] / [kN]	**Voltage range** [V]	**Cavity Δf Piezo 1** (motor side) [kHz]	**Cavity Δf Piezo 2** [kHz]	**Cavity Δf Piezo 1+2** [kHz]	**Piezo 1 to total** [%]
0 / 1	0 – 150	0.79	1.11		42
- 40000 / 2	0 – 150	1.27	1.41	2.86	47
- 40000 / 2	0 – 200			5.06	

Blade Tuner prototype cold tests - conclusions - 3

- **Stepper motor considerations**
  - The Blade tuner correctly operated with both standard TTF drive unit and proposal unit equipped with VGPL gear, both of them anyway dimensioned for TTF I tuner
  - Blade Tuner requires an higher torque to the motor, anyway safely within capabilities of the driving units in use for TTF/XFEL
  - The possibility of a dedicated driving unit for the Blade Tuner can be considered. A VGPL planetary gear with 1:200 reduction ratio would grant lower torque and higher tuning sensitivity

Formula used to estimate the real torque required to operate the tuner with friction

$$M_{motor} = \frac{F_{axial} \cdot p_{screw}}{2\pi \cdot 1000 \cdot \eta}$$

$\eta = 0.159$ for TTF CuBe screw

$\eta = 1$ if no friction

	Motor	Gear	F_{tuner} axial kN	F_{screw} axial N	M_{max} ideal Nm	M_{max} real Nm	M_{max} motor + gear 1 A drive half-step Nm	Max. freq. sens. half-step Hz/half-step
TTF I	Sanyo 200 steps	HD 1:88	3	200	0.05	0.3	11.7	0.75
Slim SS	Sanyo 200 steps	HD 1:88	6.5	800	0.2	1.2	11.7	1.56
	Phytron 200.2,5	VGPL 1:100	6.5	800	0.2	1.2	6.5	1.50
Slim Ti Rev	Phytron 200.2,5	VGPL 1:100	9	1600	0.4	2.4	6.5	1.50
	Phytron 200.1,2	VGPL 1:200	9	1600	0.4	2.4	25	0.75

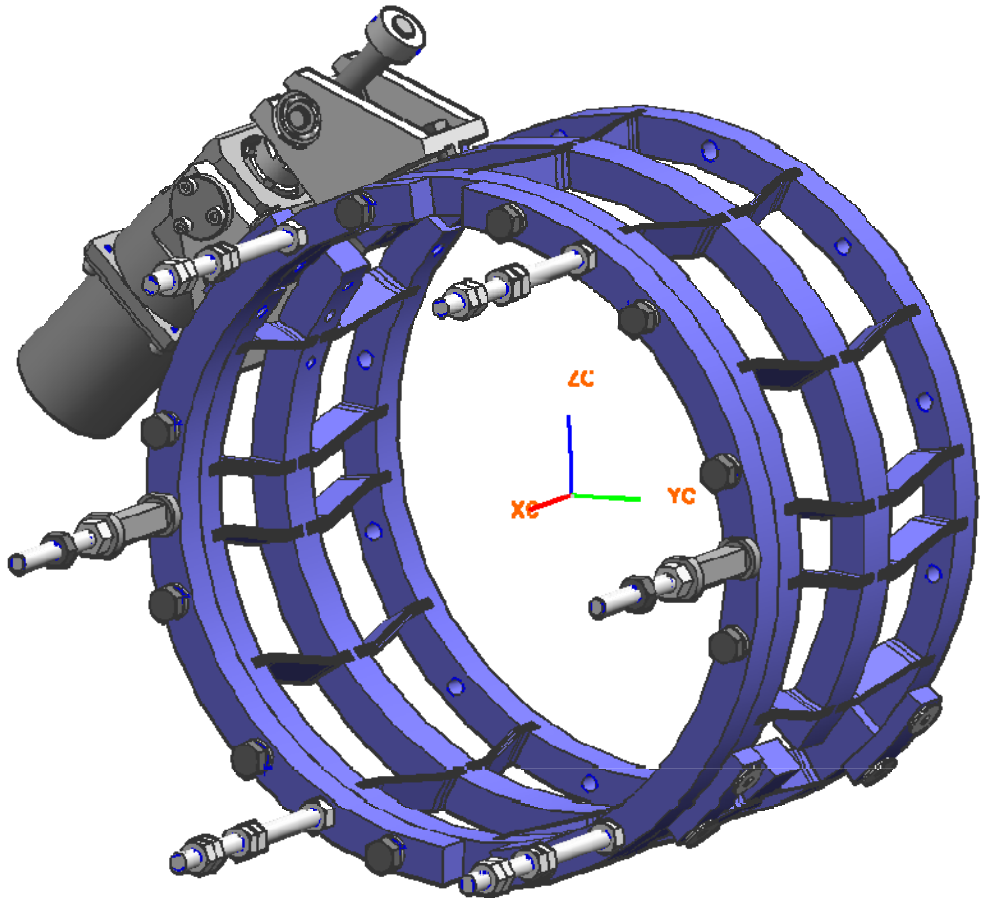
M_{max} ideal means no friction considered, **M_{max} real** takes into account screw actual friction

The ILC Blade Tuner

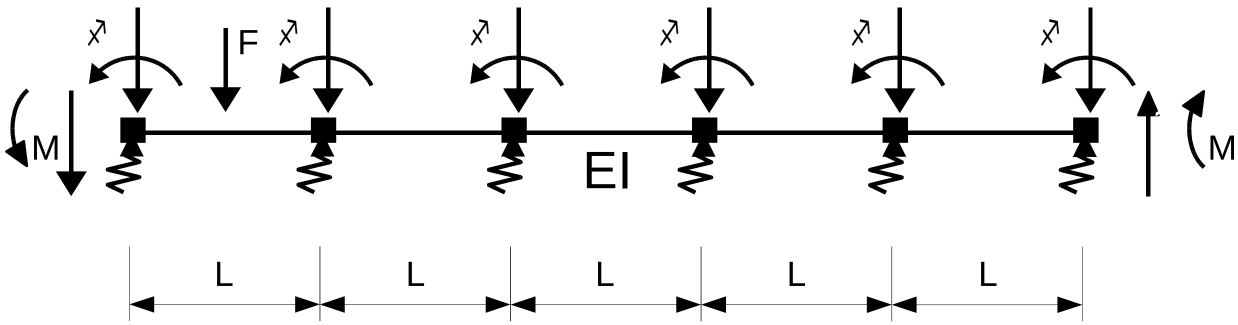
On the basis of the test results here presented the ILC Blade Tuner prototype is already close to fulfill all the XFEL and ILC specifications.

The experience gained with the cold tests on the so called 3.0.0 prototype has been used for the final revision of the Blade Tuner, currently under construction.

The first 8 units are expected by May 2008, and the will be delivered to Fermilab for the second ILCTA cryomodule.



Force distribution on tested tuner 3.0.0



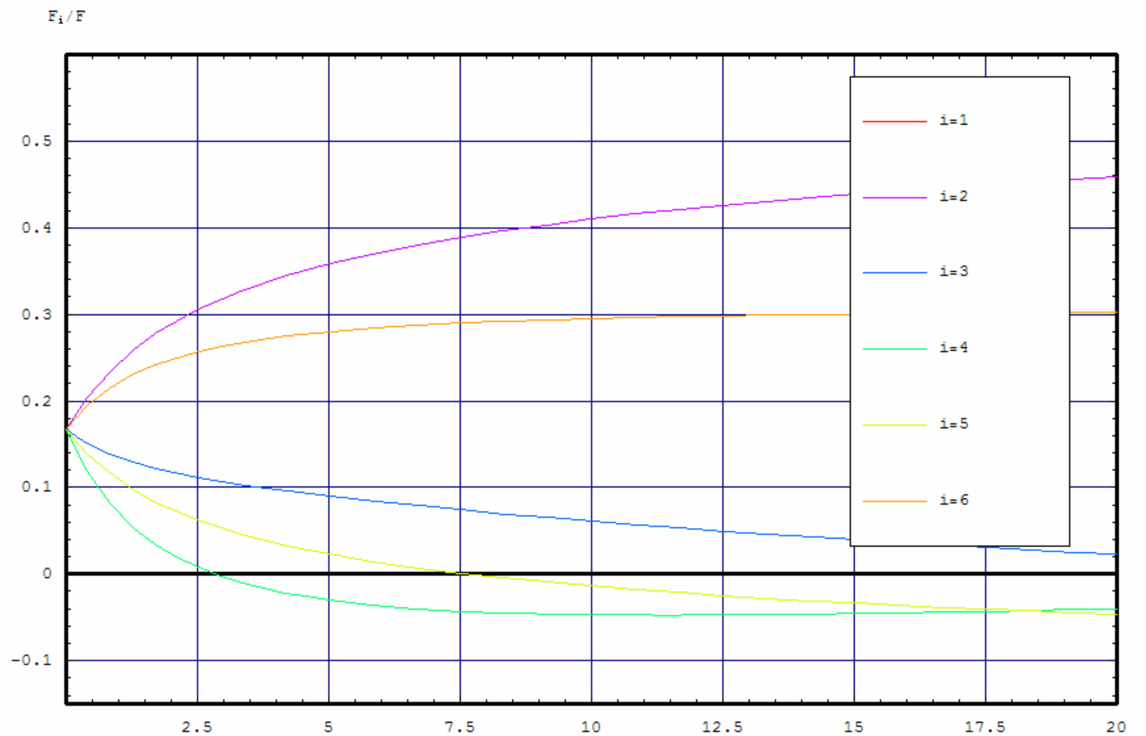
Simple analytical model used to study the force distribution among the blades pack in the tested Blade Tuner prototype

Results:

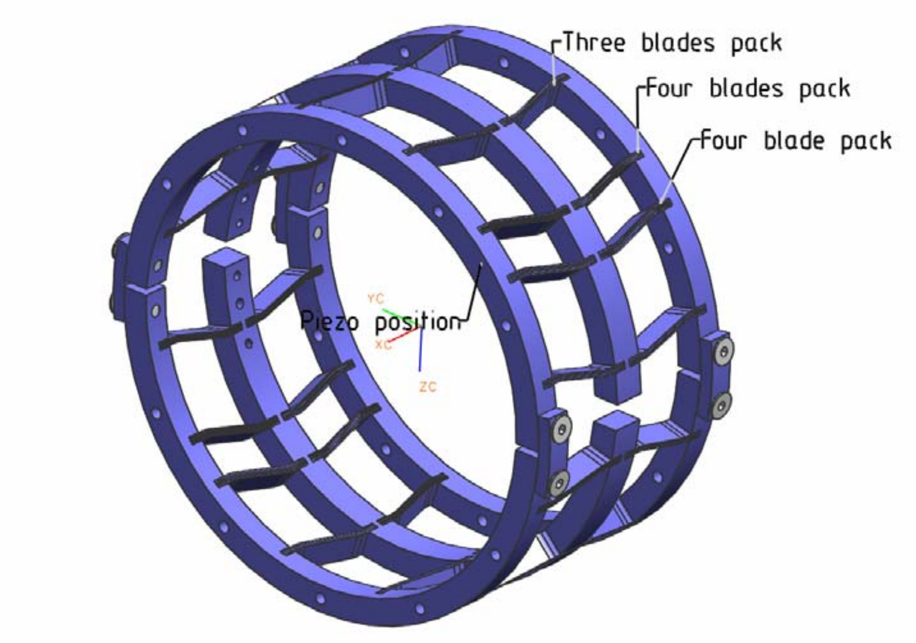
35% of the piezo load goes on the blade pack n. 1 and 2 and a 28% goes on blade pack n. 6.

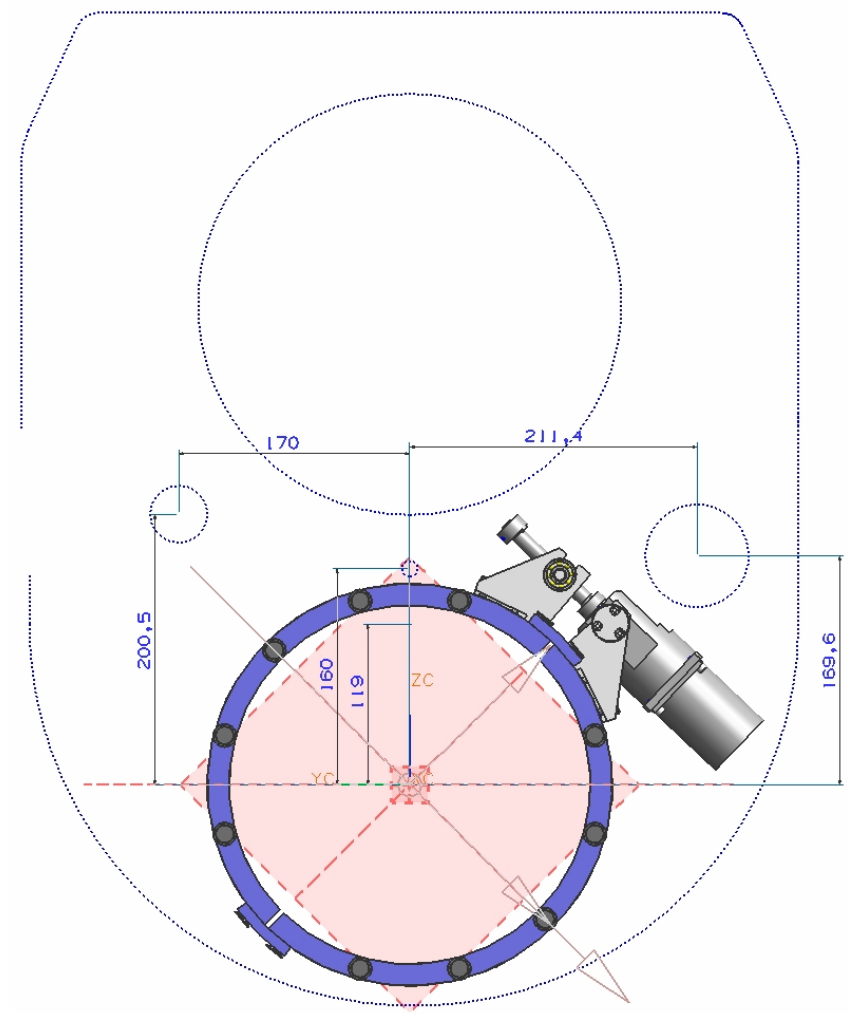
Solution:

Double the blades pack in the region corresponding to the piezo position and reduce other packs so to keep the about the same blade total number



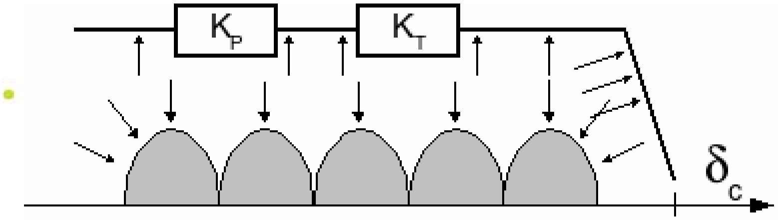
Geometry of the revised tuner 3.9.4





the piezo positions correspond to the double blade packs: as seen these packs withstand an higher load and therefore they were doubled.

Load cases



operating conditions

Condition	Pressure			Temp.	Max load[1]
	Beam pipe	He tank	isovac	cavity	tuner
	mbar	mbar	mbar	K	N
Start	1000 - Ar	1000	1000	300	0
Piezo preloaded	1000 - Ar	1000	1000	300	-2200
Ready to cool down	0	1000	1000	300	-3116
Cool down	0	2000	0	300 to 4	+4815
Stable 1.9 K	0	20	0	1.9	-2150

ASME / PED check

For PED to be multiplied by 1.43

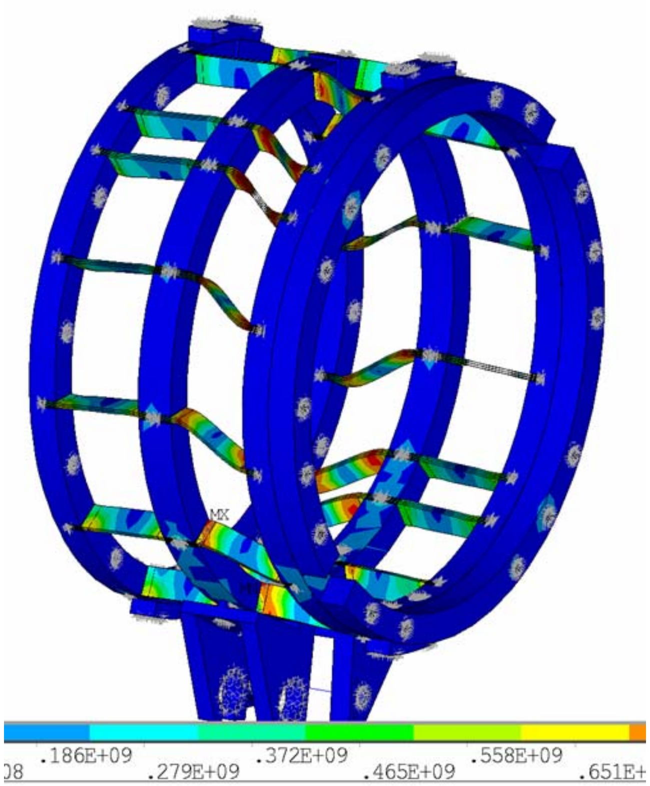
Condition	Pressure			Temp.	Max load
	Beam pipe	He tank	isovac	cavity	Tuner
	mbar	mbar	mbar	K	N
Emergency	0	4000	0	300	+9630
Leak test	0	0	1000	300	-2840

[1] Positive forces are in traction direction

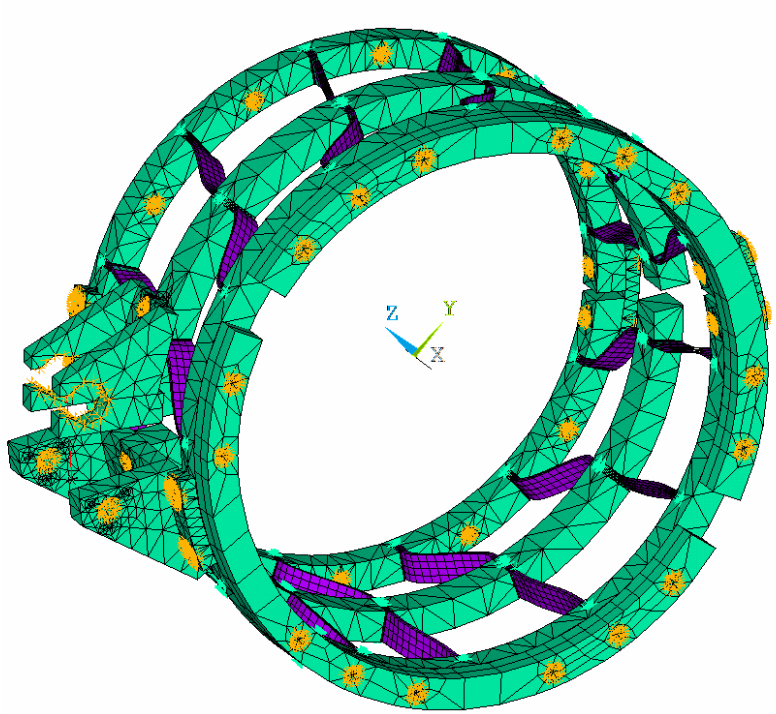
Design analysis – whole tuner

Possible failure modes for the revised Blade Tuner have been studied through a complete 3D FE model in order to evaluate its limit loads
In these analyses the tuner is at 0 screw turn position

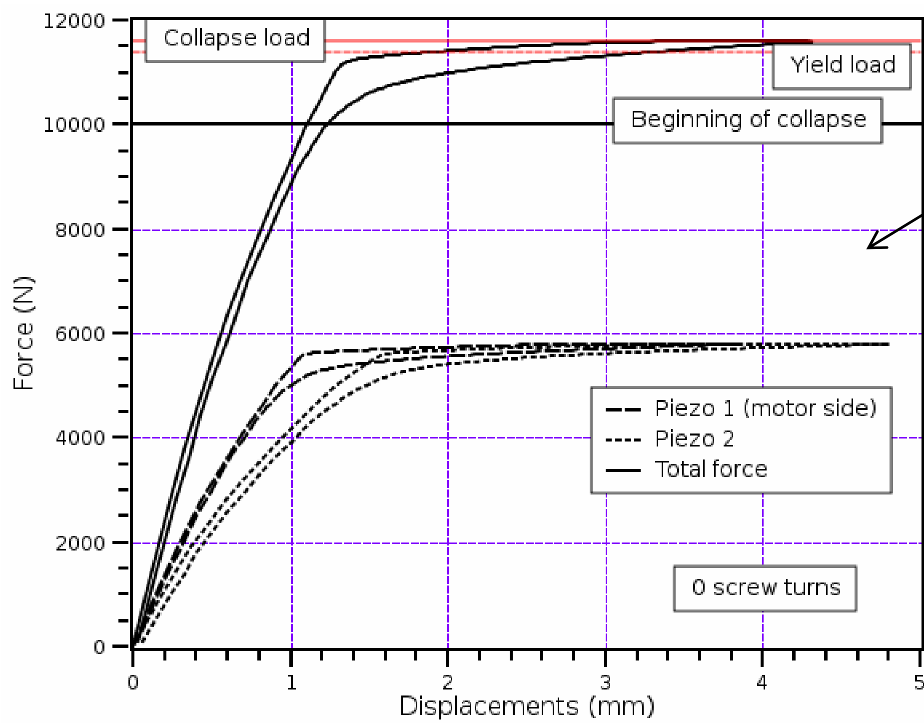
Collapse at 11.6 kN



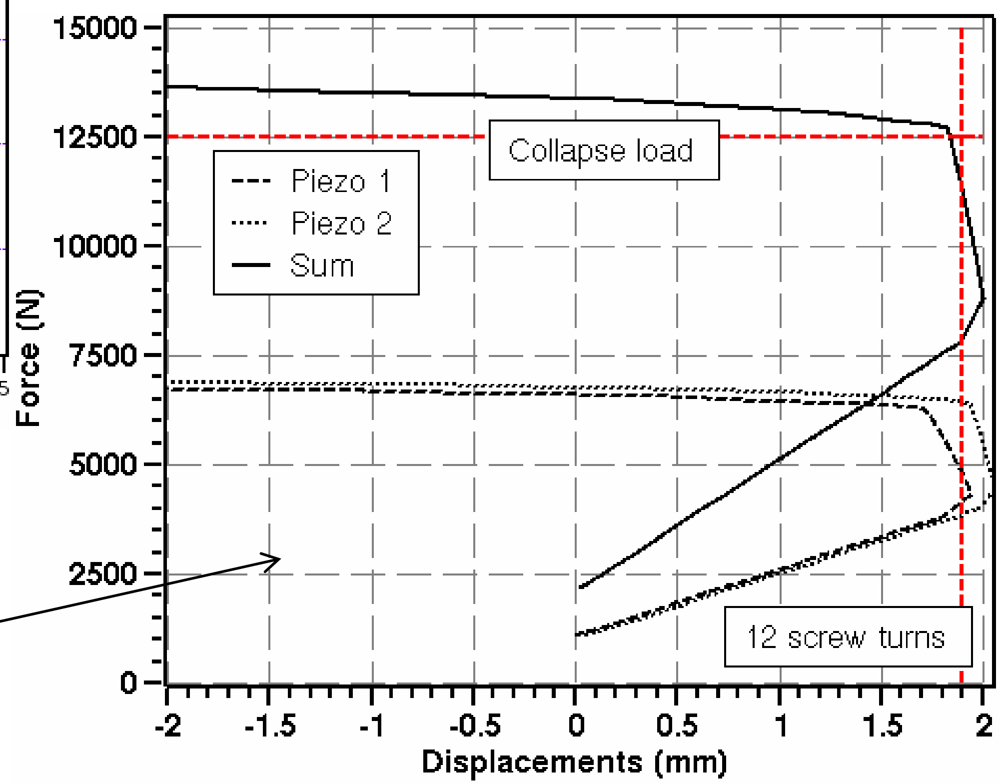
Buckling at 17.6 kN



Design analysis – collapse loads



Displacements and force distribution at the piezo positions with the tuner at the **0 screw** turns position

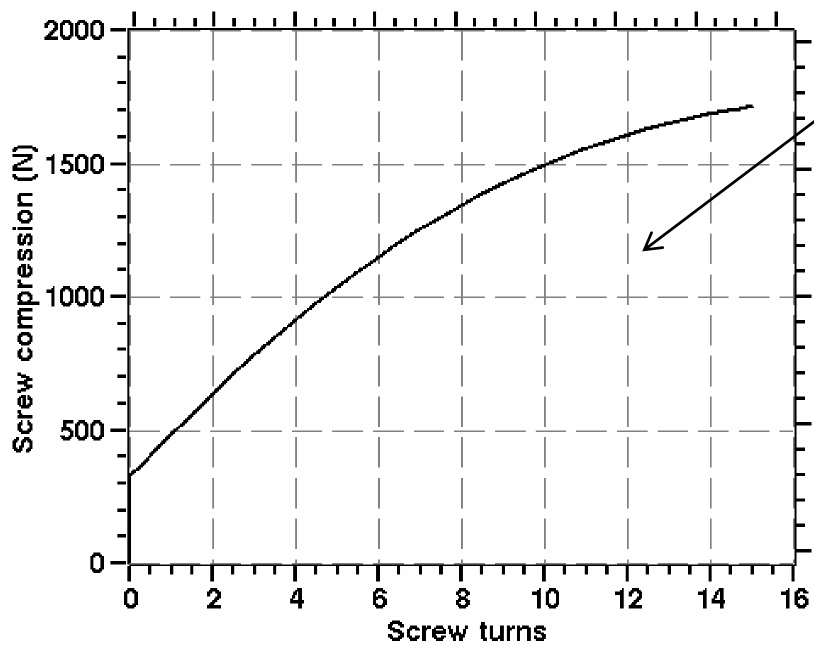


Displacements and force distribution at the piezo positions with the tuner at the **12 screw** turns position, the nominal maximum extension
(max sustainable is 14 turns)

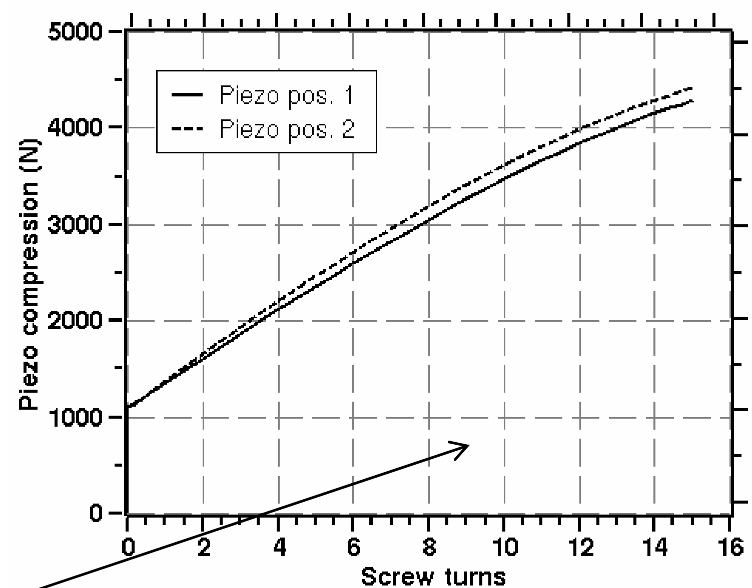
Design analyses – CuBe motor screw

The full 3D FEM analysis allowed to determine the axial force on the CuBe screw of the driving unit and on the two installed actuators for the entire range of operation of the tuner, from the minimum to the maximum sustainable extension corresponding to 14 screw turns.

A piezo preload of 1.1 kN each stack is assumed,



Axial force acting on the CuBe screw

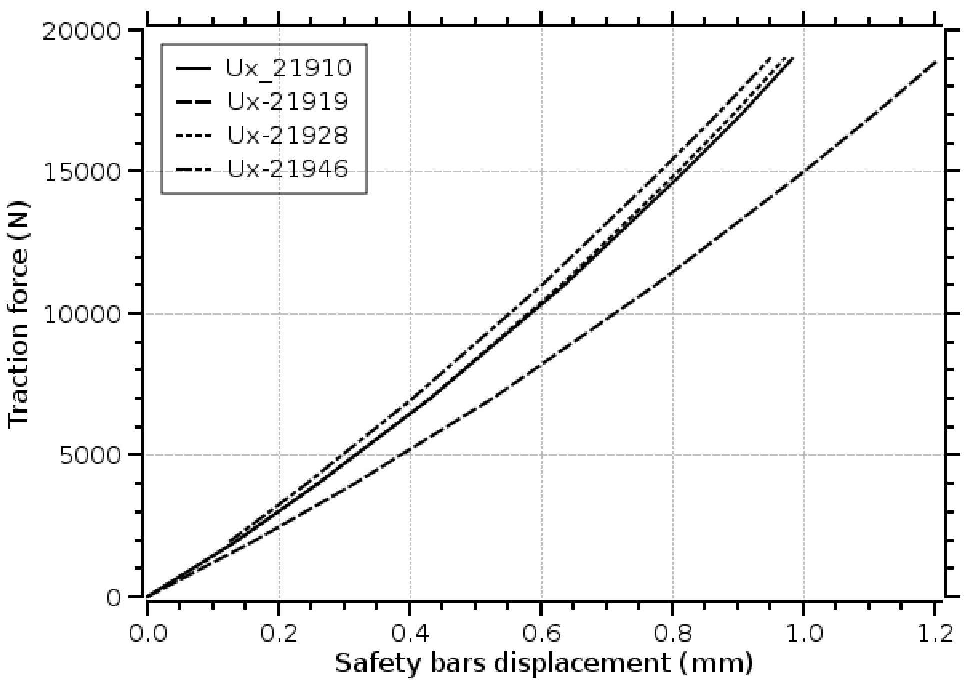


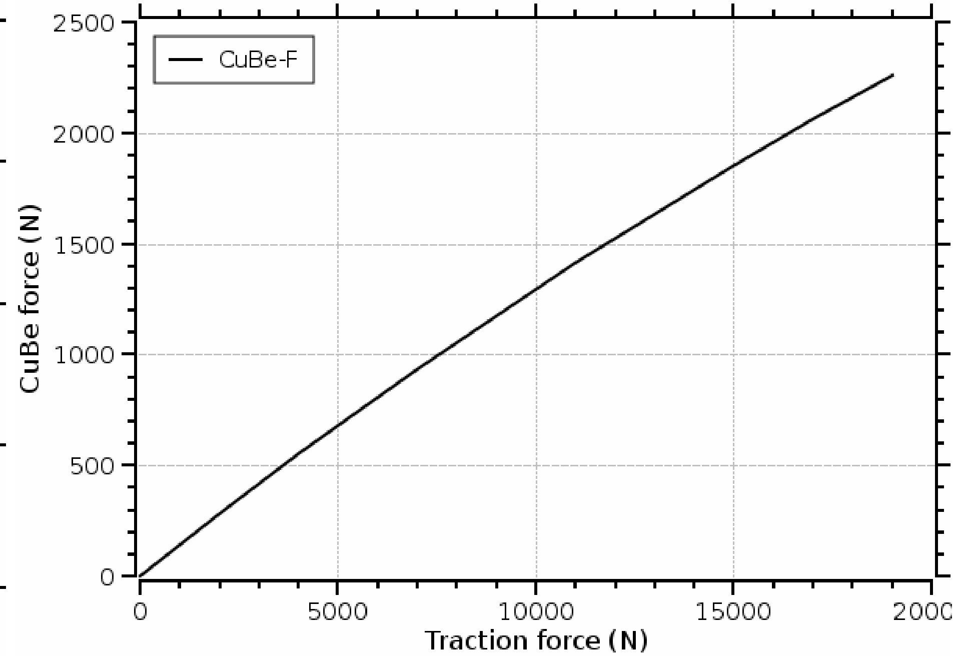
With the new Tuner design the sensitivity of the two piezo actuators is well balanced.

Design analysis – tensile strength

During cool-down phase the Blade Tuner is subjected to an intense tensile force.

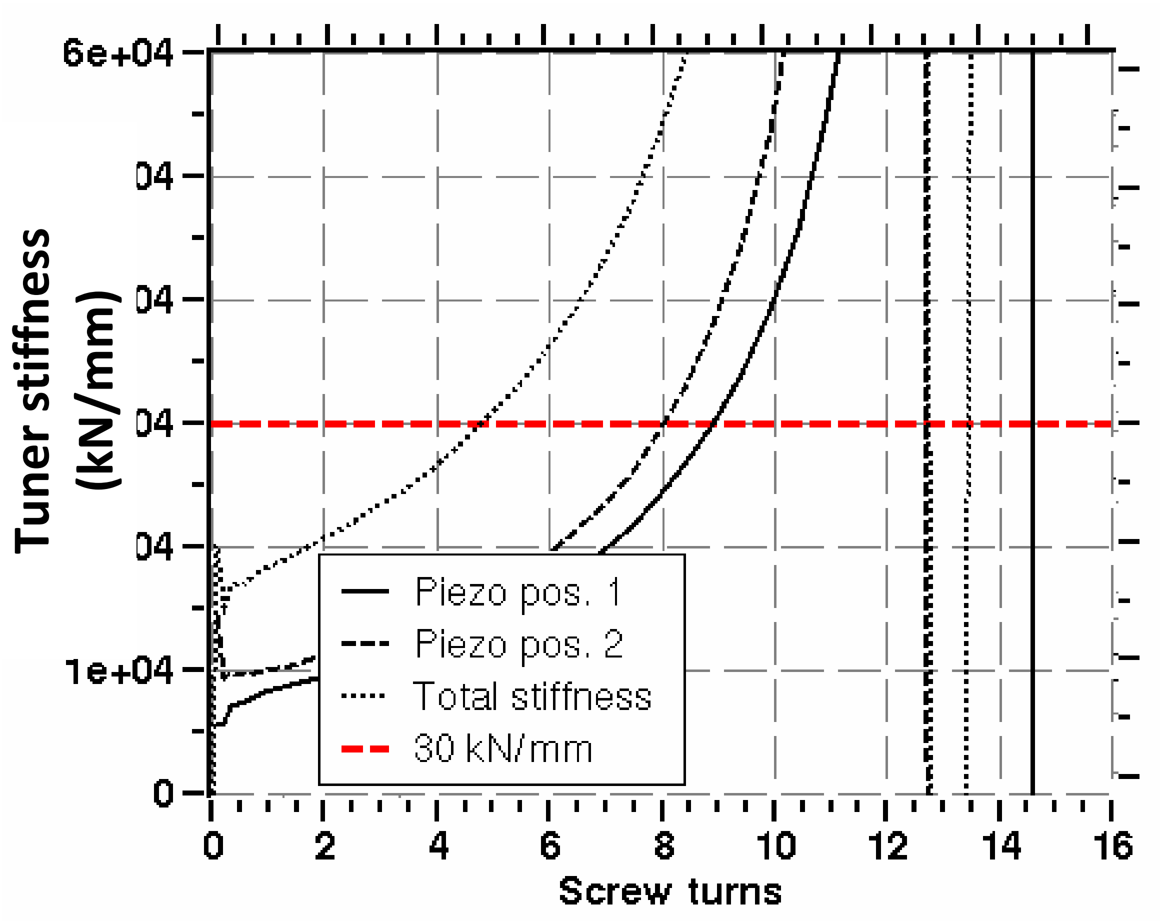
Analysis shows the displacements at the safety bars position and the compression force on the CuBe driving screw





Design analysis – tuner stiffness

Estimated stiffness as a function of the tuner extension in terms of screw turns



The revised geometry of the Blade Tuner grants a significant margin in terms of mechanical stiffness when operated in the designed region:

About **35 kN/mm** at 6 screw turns position, middle of the nominal tuning range

Revised Blade Tuner - conclusions

Tuner under construction (3.9.4)	Tuner characteristics	Required value	Margin factor
Tuning range - nominal (no hysteresis)	0 – 500 kHz		
Tuning range – max. (some hysteresis[1])	0 – 600 kHz		
Max compression strength[2]	7800 + 3100 N	7800 + 1.1 * 2840 N	1.0
Max traction strength	16000 N	13771 N	1.16
Compression stiffness	15 – 100 kN/mm		
Mean freq. sensitivity	1.5 Hz/half-step - XFEL standard drive unit -	~ 0.75 Hz/half-step - actual TTF I tuner sensitivity -	
	0.75 Hz/half-step - devoted 1:200 gear -		
Max. torque at the CuBe screw	12.5 Nm - XFEL standard drive unit -	2.4 Nm	5.2
	25 Nm - devoted 1:200 gear -		10.4

1 With plastic deformations limited to the blade packs near the motor
2 This is composed of the fixed part due to the cavity deformation and a variable part due to external pressure