LCWS08 and ILC08

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Blade-Tuner Performance

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Outline of the talk

Brief historical review

- The Superstructures Blade Tuner

The ILC Blade Tuner prototype – "Slim"(ver. 3.0.0)

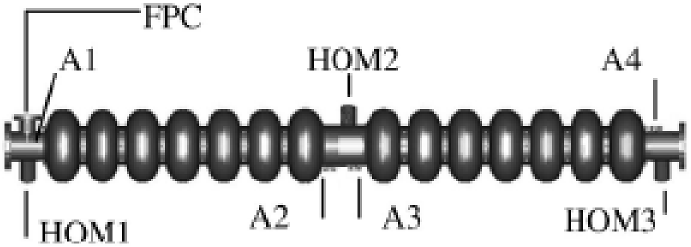
- Tuner design and tuning actions
- Cold tests of the stainless steel prototype at DESY and BESSY

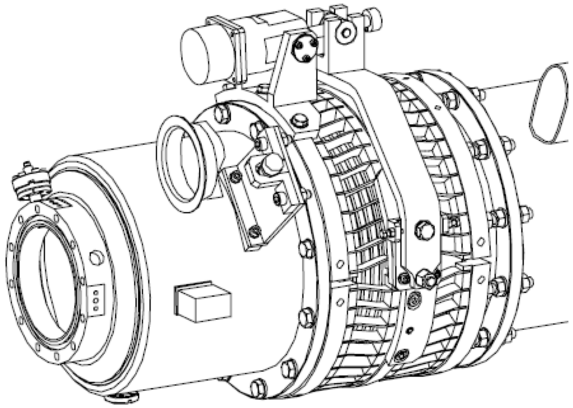
The Revised ILC Blade Tuner (ver. 3.9.4)

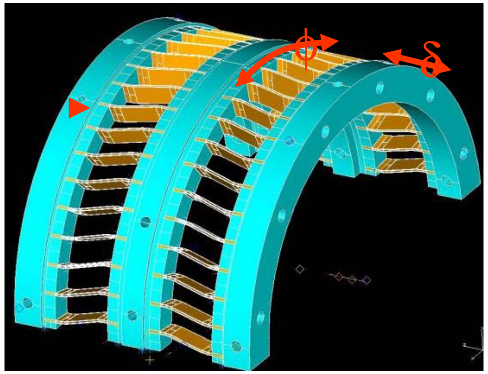
- Rationales
- Expected performances from FEM analyses: load cases and limit loads, warm tests as expected

Tuner position and plug compatibility

The Superstructure Blade Tuner







Concept: through thin “blades” transform the rotation of the 2 center ring halves in a longitudinal axial motion that changes the cavity frequency modifying its length.

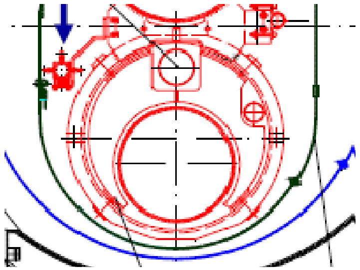
Standard motor and harmonic drive

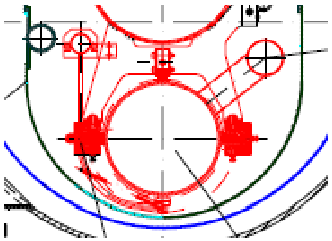
Lever arm designed by H.-B. Peters (DESY)

TTF and Superstructures

- Plug compatible experiment in the middle of the transition from Type 2 to Type 3 Cryomodule
- Special Type 2 cryomodule designed and built (MOD 7) to test superstructure in a Type 3 like environment, wile installed in a Type 2 module-string:
  - Type 2 vacuum vessel and pipe position, excluding 2-phase line
  - Type 3 sliding cavity supports
  - Use a standard Helium vessel (lateral bellow for Saclay tuner) and modify it while maintaining the standard interfaces
- After superstructure tests the “special” cryomodule became a standard Type 2 cryomodule (MOD 7*)

Type 2 cavity hanging and 2-phase pipe position

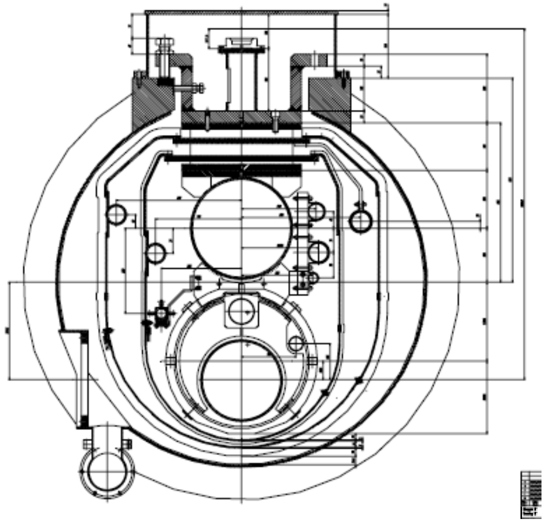


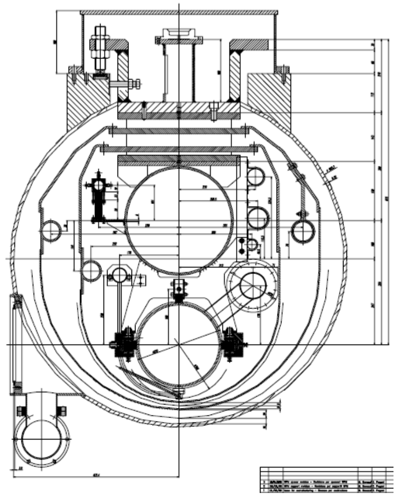


Type 3 cavity hanging and 2-phase pipe position

Type 2, Typ3 and SS Hybrid

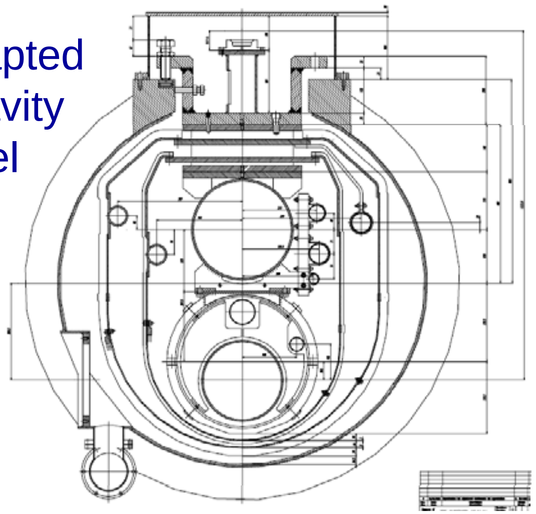
Type 2



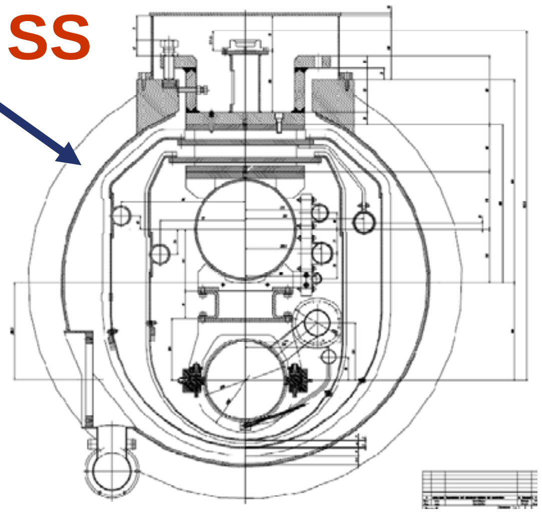


Type 3

Type SS adapted
for Type 2 cavity
Helium vessel



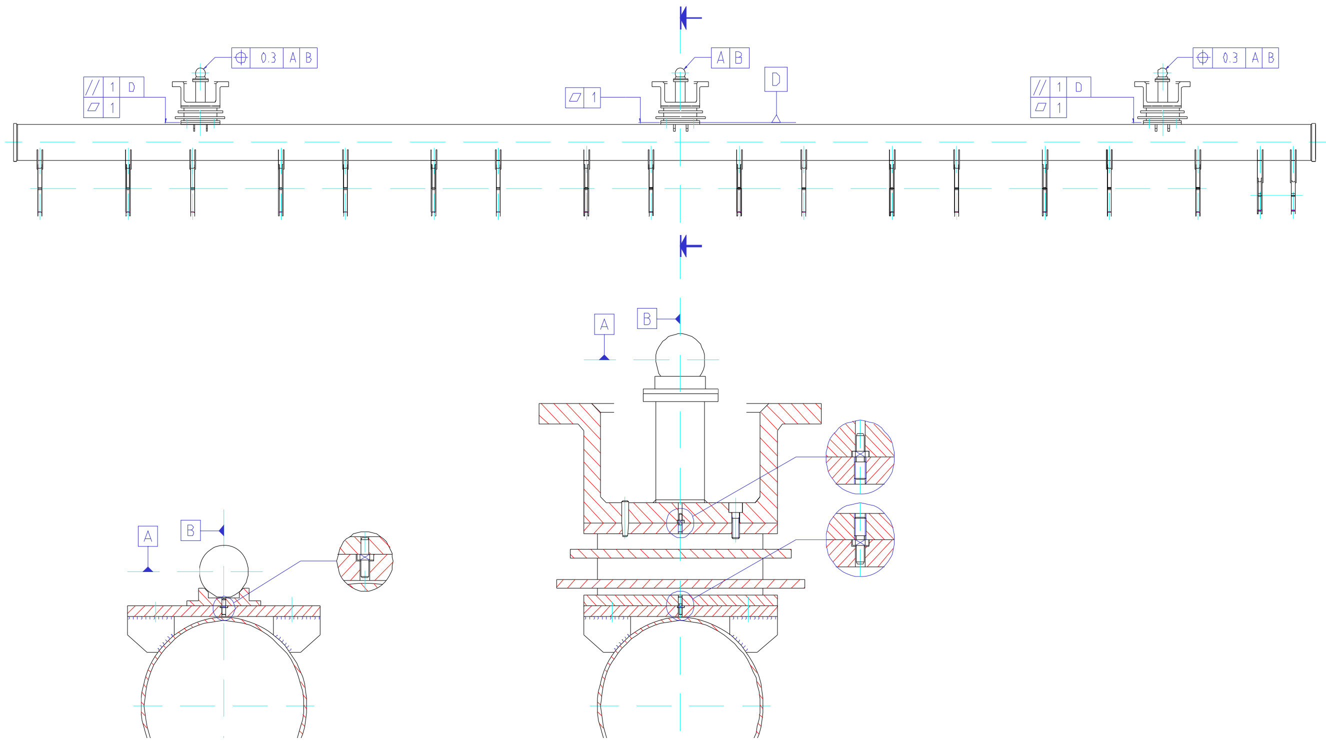
Type SS



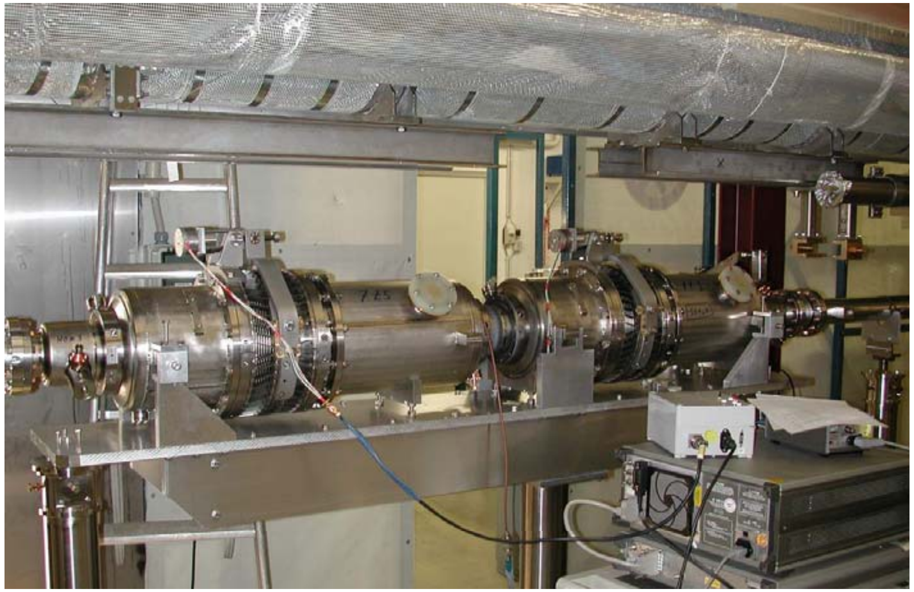
Type SS adapted
for Type 2 cavity
Helium vessel

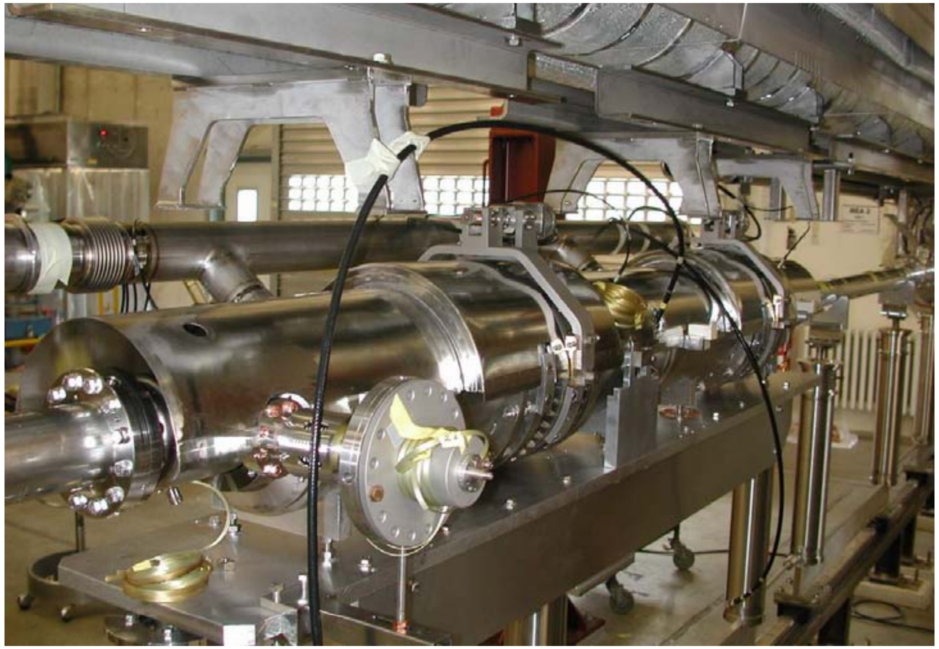
Alignment and Warm-Cold reproduc.

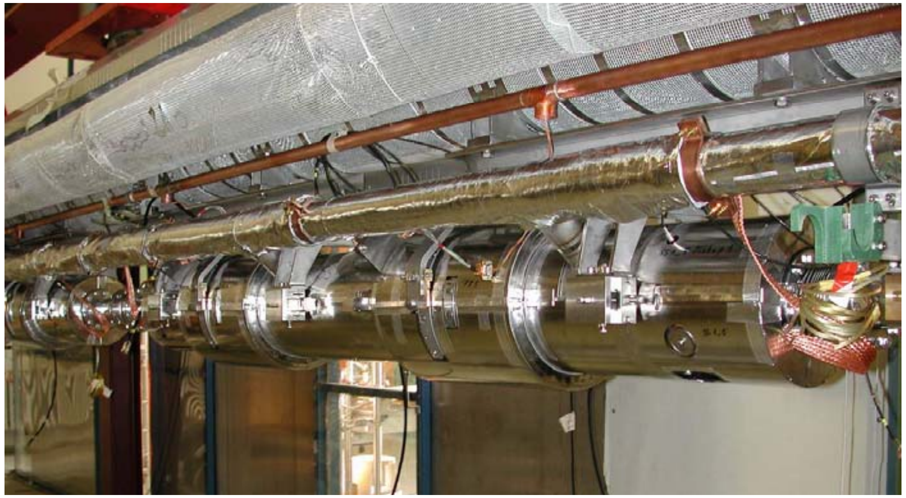
- After the poor and expensive experience of Type 1, final machining of the HeGRP is the key element of the new fabrication strategy. No welds are allowed after the axis deinition and the machining of reference planes
- Performances demonstrated by WPMs and HOMs



Superstructure string assembly







Comments and Results

- **Just slow tuning mechanism**, **no piezo-actuators installed**
- Superstructures performed very well at 15 MV/m
- Each of the four blade tuners smoothly tuned the respective cavity to the nominal frequency
- Each cavity was maintained tuned during operation
  - Correction threshold set at few degrees (few Hz)
  - Data available on TTF database
  - Each motor step produces a **0.4 Hz** frequency variation that is induced by a **1.2 nm** cavity length variation (**no irregularities observed because of rollers**)
- Each of the two cavities of a superstructure were corrected independently with the same number of steps to maintain the critical field balance of the π-0 superstructure mode

No backlash at the nanometer level

1 motor step ~ 1.4 nm pad slide ~ 0.4 Hz frequency change

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME **7**, 012002 (2004)

Test of two Nb superstructure prototypes

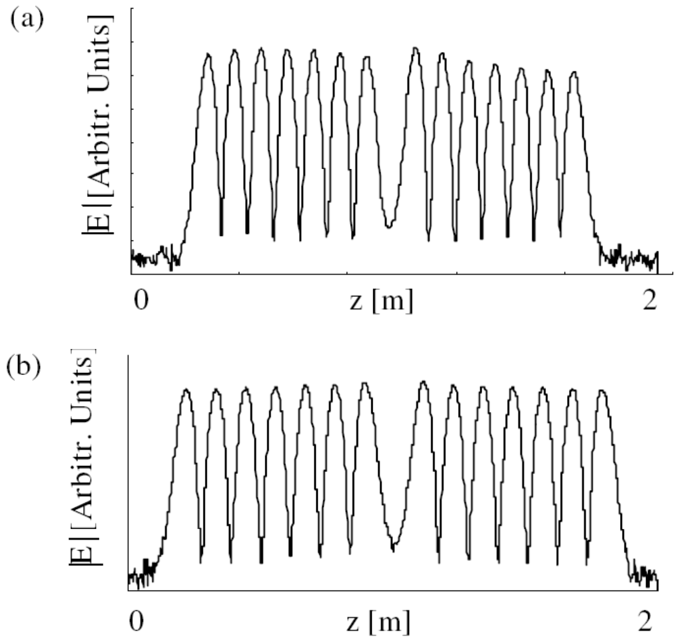
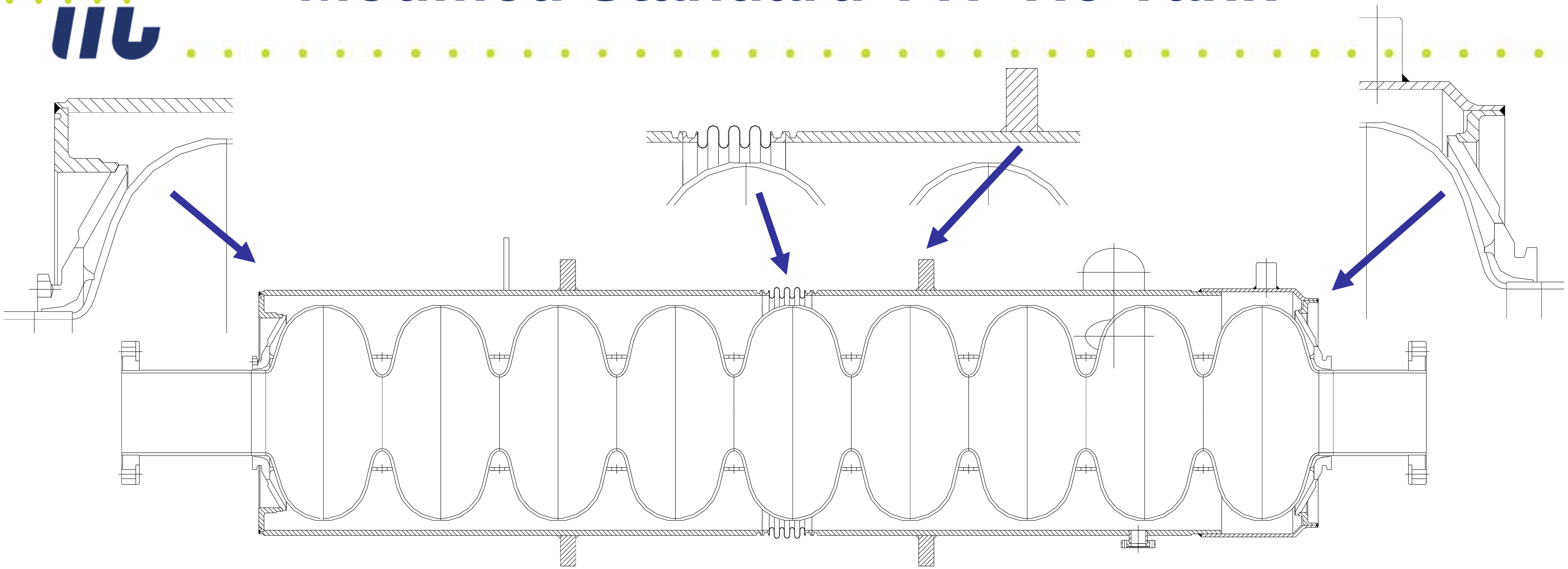
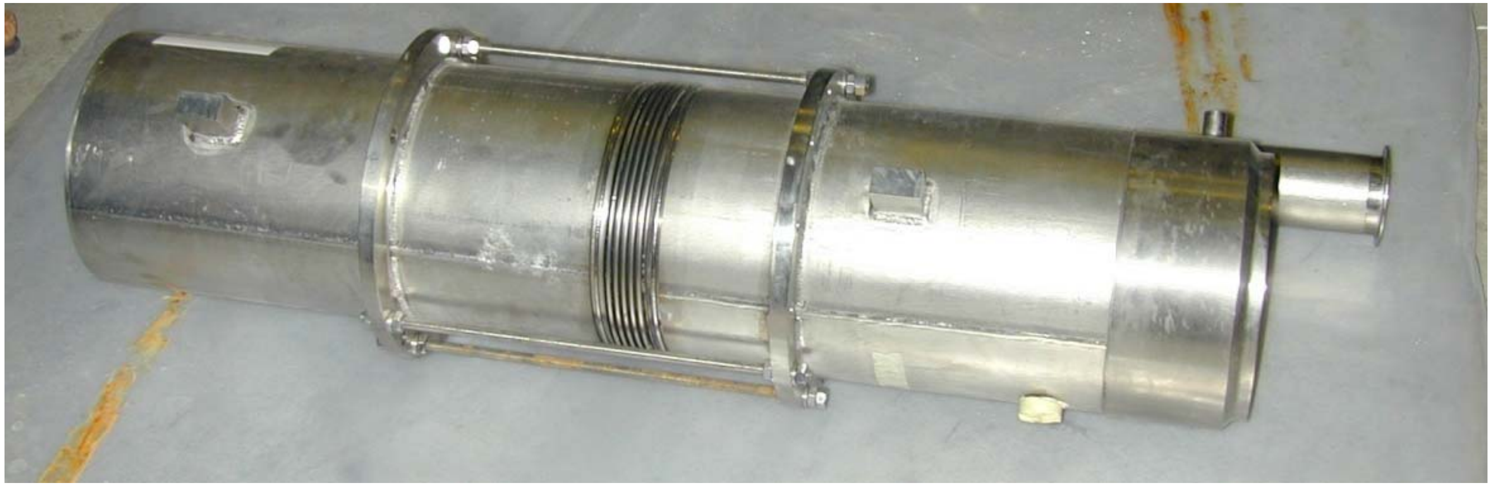


FIG. 3. Peak-to-peak field flatness. (a) P1, 92% and (b) P2, 94%.

bation causes the same frequency shift. For this, the cold tuner of each subunit was moved by 1000, 2000, and 5000 steps and for each position the frequency change Δf of the π-0 mode was measured. Then, the final positions of the tuners were chosen to maintain exact frequency equal to 1.3 GHz of the π-0 mode and simultaneously to ensure that the subunits show the same Δf when their tuners are moved by the same number of steps. The final status of the prototypes was cross-checked in the following way. We compared, for each cold prototype, the fundamental passband frequencies with the frequencies measured at room temperature when the bead-pull method showed the best achievable field profile. The

Modified Standard TTF He Tank





Motivation and consequences

Motivation

- build **2 helium vessel** to test at DESY and Fermilab 2 of the **existing superstructure** blade tuner with 2 parallel piezo-actuators:
  - in series with the tuning mechanism
  - positioned on the mid plane

Consequences

- Because of the very heavy superstructure tuning mechanism one pad couple was moved closer to the ring supporting the tuner weight.
- A special adaptation element was designed to adapt the new pad position to the standard (TTF-FLASH-XFEL) shape spacing
- A simple adaptation at the end cone region, as for superstructure, was done given that longitudinal stiffness is not so critical.

Real life

- No sufficient priority on ILC and no testing slot available up to 2007 neither at DESY not at Fermilab. **New Blade Tuner**

Blade Tuner "Slim" Prototype

Lighter

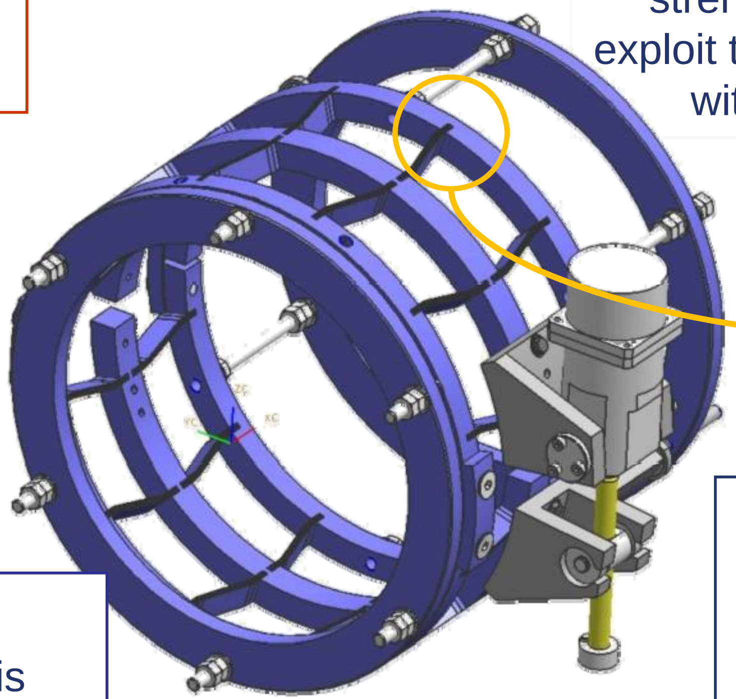
The redesign of rings allowed an important **weight reduction** (about 40%) maintaining the full symmetry with collinear blades.

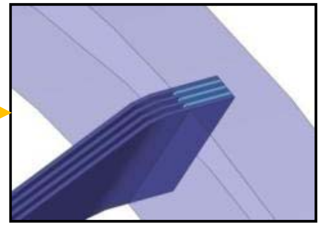
Ready for future SS tank

The tuner can be **built both with titanium or stainless steel rings**. We used a high strength alloy for blades 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**.

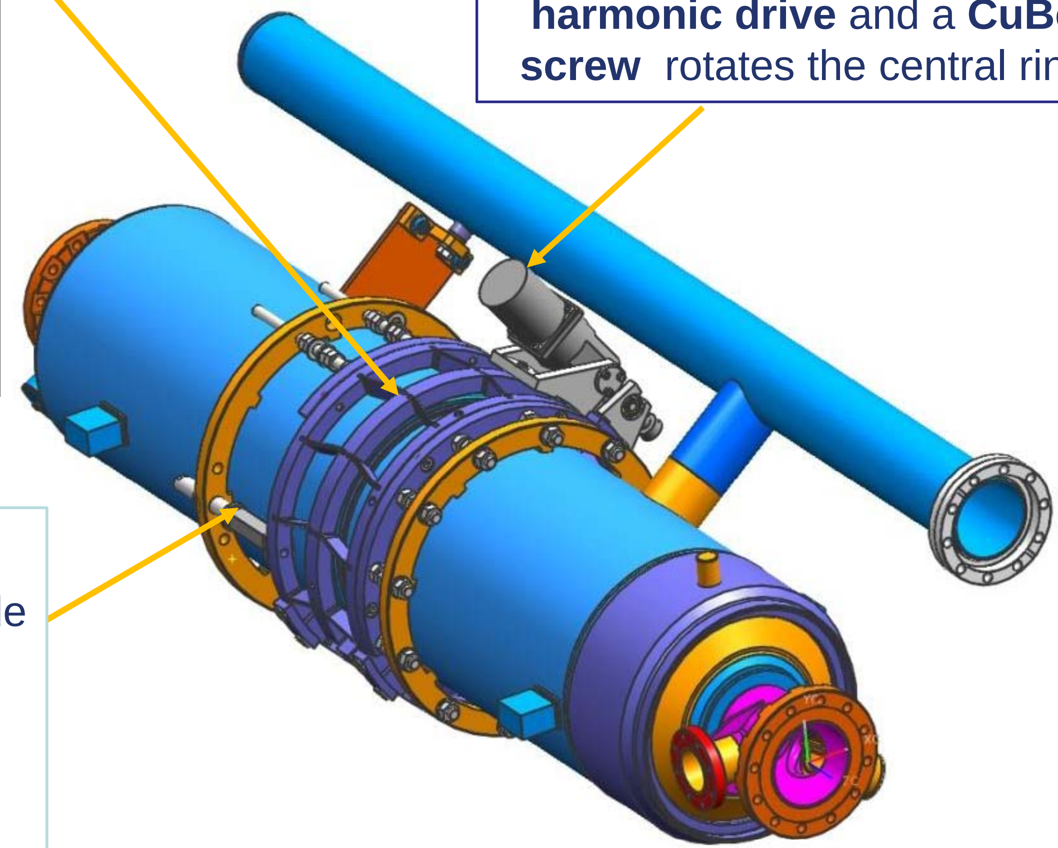
The Tuning Actions

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



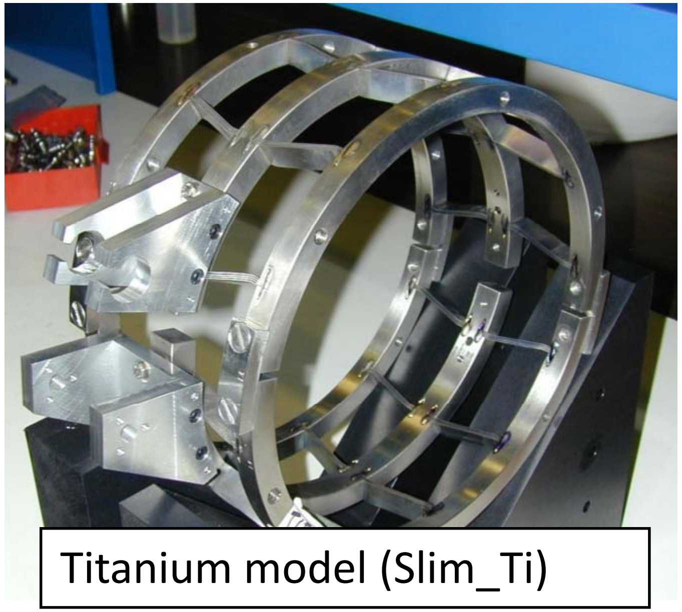
The Piezo Actuators

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

Blade Tuner prototype cold tests

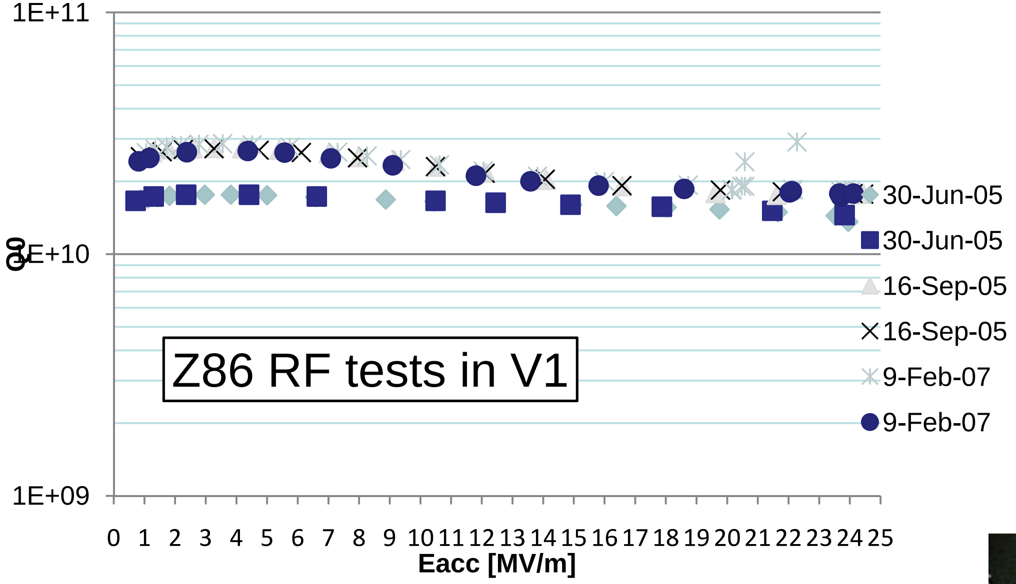
- **The Stainless Steel + INCONEL prototype has been tested at cold:**
- **Sept. 2007 in the CHECHIA** horizontal cryostat, DESY
  - Installed on the **Z86 TESLA cavity** equipped with a standard modified He vessel
  - Equipped with a standard TTF unit: **Sanyo stepper motor + Harmonic Drive gear**
  - **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)

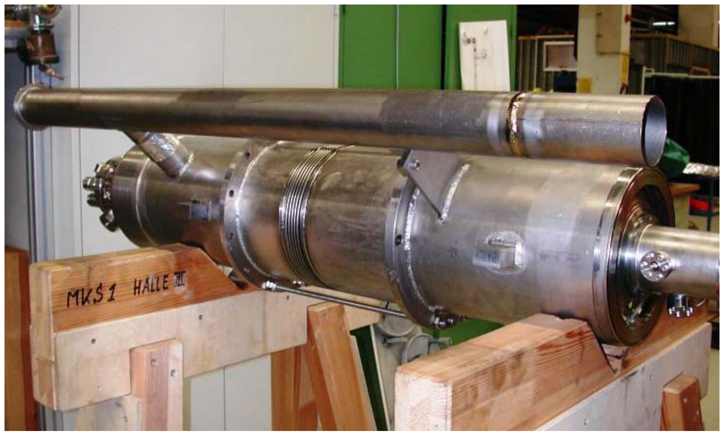


Titanium model (Slim_Ti)

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

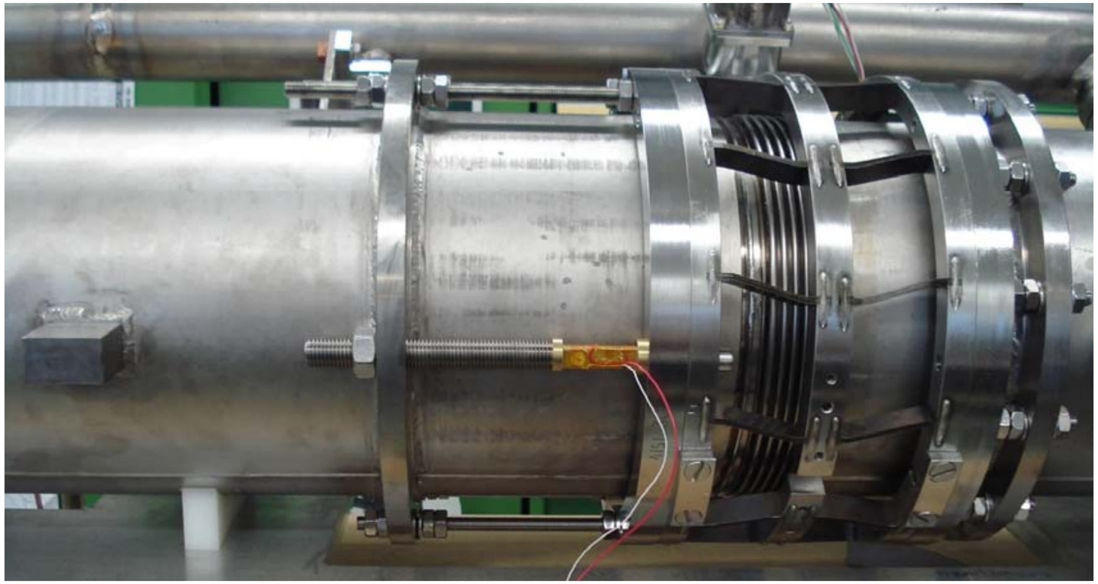


Z86 integrated in the helium tank at DESY

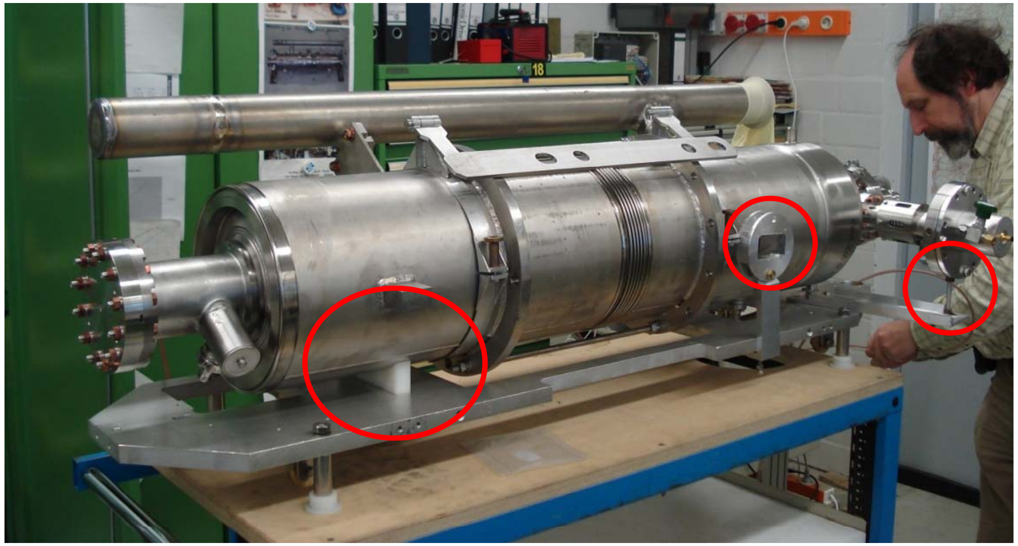
Z86 during the EB Welding at Lufthansa

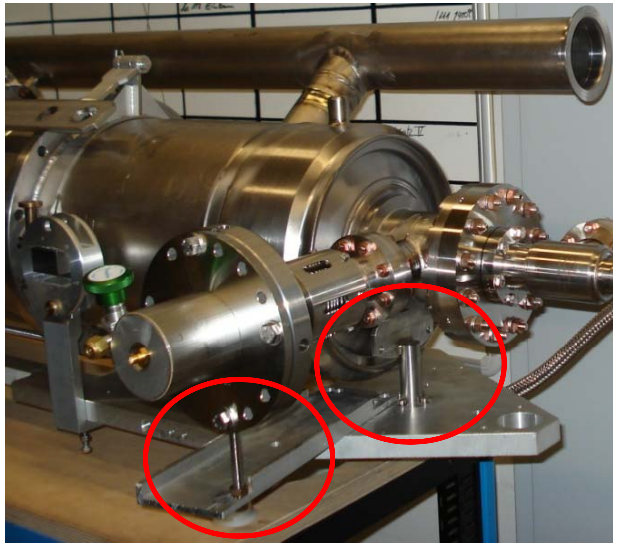
Test setup at CHECHIA - DESY

- Blade Tuner cold tests on September 2007
  - Stainless steel + Inconel Blade Tuner
  - 40 mm Noliac piezo (10 x10 mm^2)
  - Sanyo-Denki stepper motor, 200 steps/turn
  - HD drive unit, 1:88 reduction ratio
  - therefore 17600 steps each spindle turn (CuBe spindle screw, 1.5 mm/turn) **~ 10 nm/step**



Test setup at CHECHIA - DESY

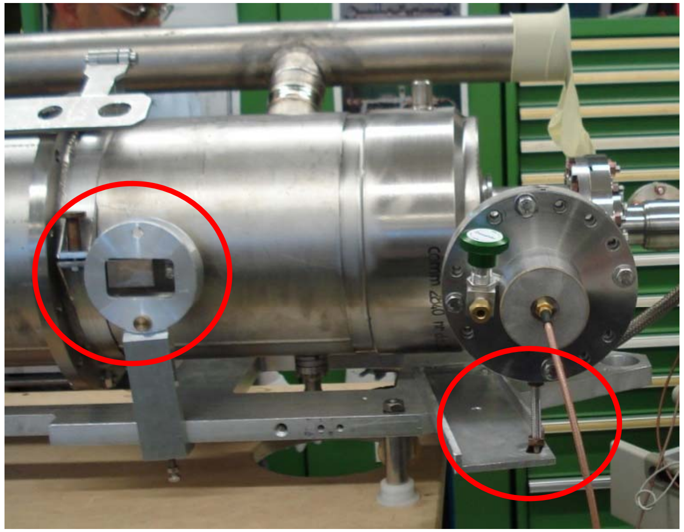




The cavity package is installed on a table

- 2 pads fixed by supporting clamps
- helium tank sliding on a Teflon support,
- beam pipe and coupler supported

The table hosting the cavity and its ancillaries is then moved into the CHECHIA cryostat

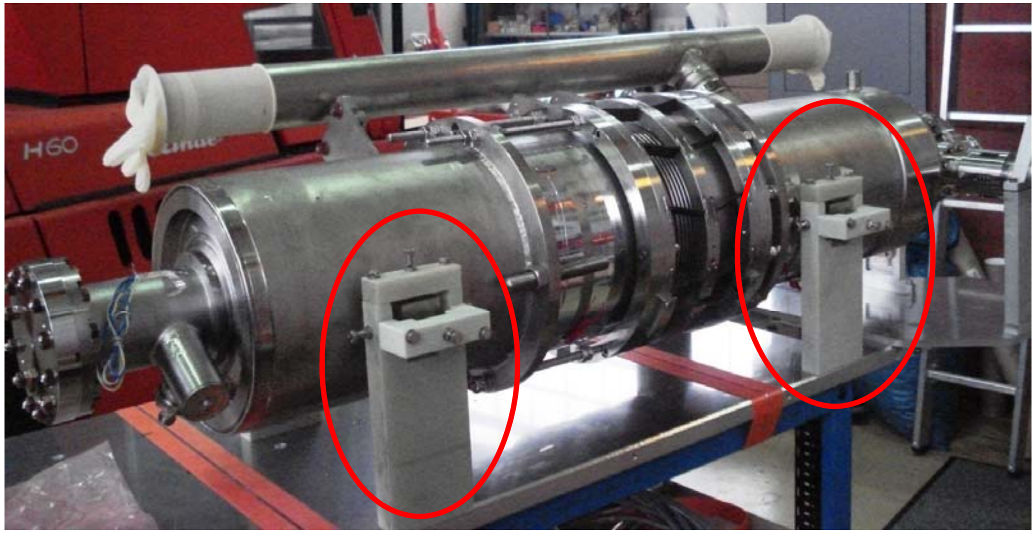


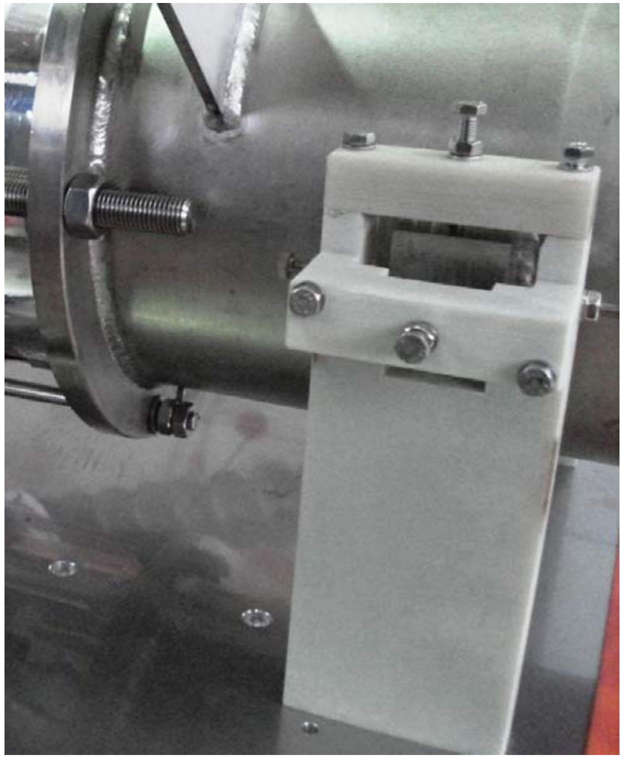
Test setup at HoBiCat - BESSY

- Blade Tuner cold tests, February and April 2008
  - Stainless steel + Inconel Blade Tuner (same as CHECHIA test)
  - 40 mm Noliac piezo (same as CHECHIA test)
  - Phytron stepper motor, 200 steps/turn
  - Phytron VGPL planetary gear, 1:100 reduction ratio
  - therefore 20000 steps each spindle turn (CuBe spindle screw, 1.5 mm/turn)

< 10 nm/step

Test setup at HoBiCat - BESSY





The cavity package is installed on a table

- Each pad is clamped in a Teflon pillar that can slide on the SS table

The table hosting the cavity and its ancillaries is then moved into the HoBiCat cryostat

Considerations about friction

Superstructure Test setup

Ti pad on rolling needles (Cry 3), 40 kg preload force, T = 77 K:

- Static friction coefficient : **0.0043**
- Dynamic friction coefficient : **0.0022**

D. Barni, M. Castelnuovo, M. Fusetti, C. Pagani and G. Varisco
FRICTION MEASUREMENTS FOR SC CAVITY SLIDING FIXTURES IN LONG CRYOSTATS
Advances in Cryogenic Engineering, **Vol. 45A**, Plenum Publishers, 2000, 905-911

CHECHIA setup

PTFE Teflon on Titanium

- Static friction coefficient : **0.17** (40 times larger than Type 3)

Friction Data Guide (Linden, NJ: General Magnaplate Corp., 1988

HoBiCat setup

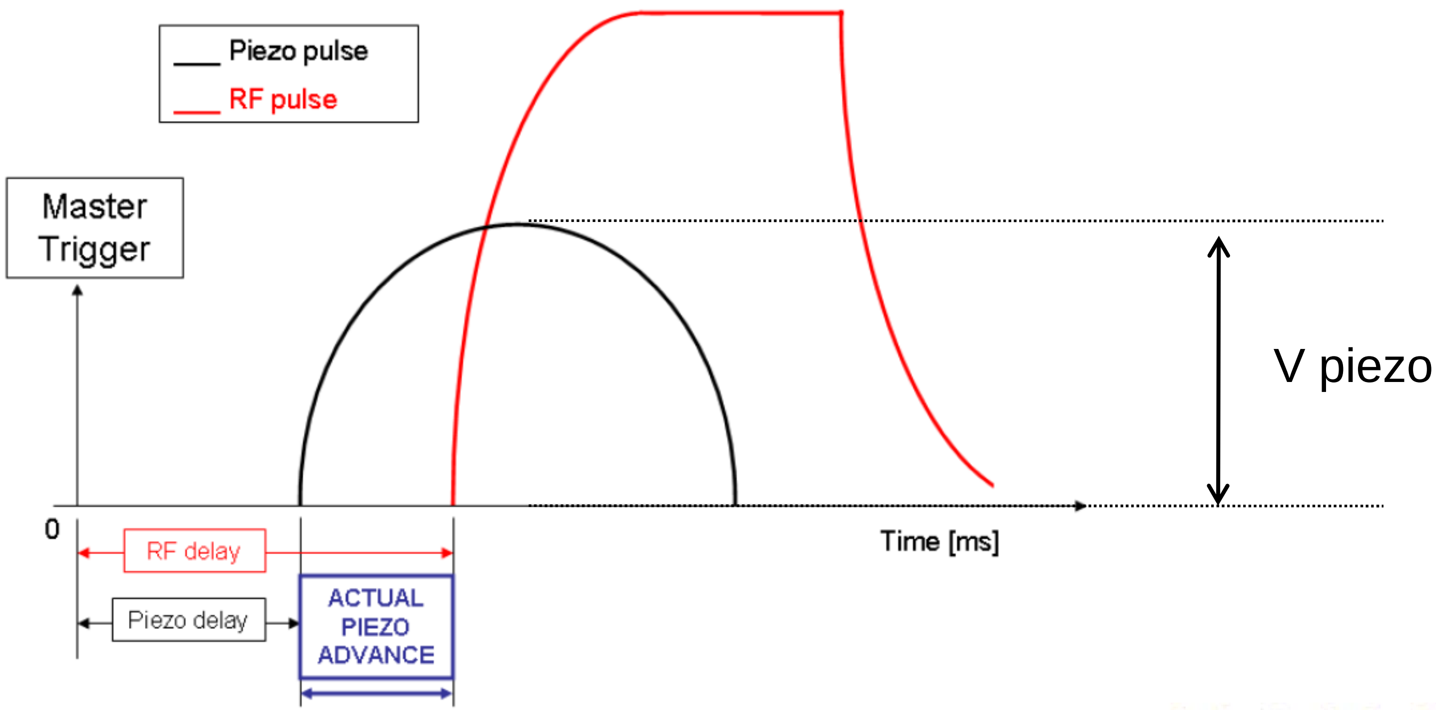
PTFE Teflon on Steel

- Static friction coefficient : **0.04** (40 times larger than Type 3)

Friction Data Guide (Linden, NJ: General Magnaplate Corp., 1988

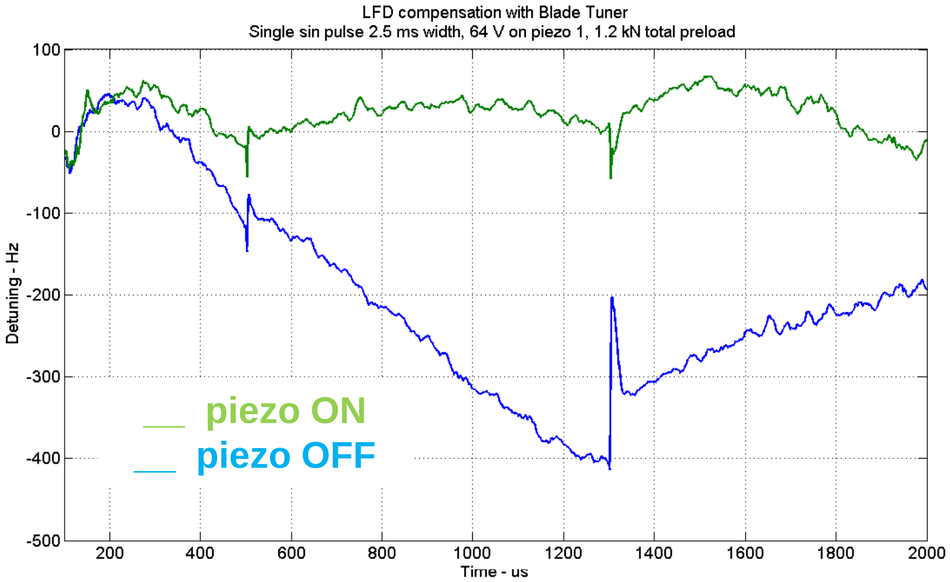
Blade Tuner tests at CHECHIA

- Frequency tuning data on a μm-scale come from mode pulsed piezo measurements:
  - pulsed piezo actuation for Lorentz Force Detuning (LFD) compensation
  - actuators are driven by a single half-sinusoidal pulse, with proper time lead toward the RF pulse

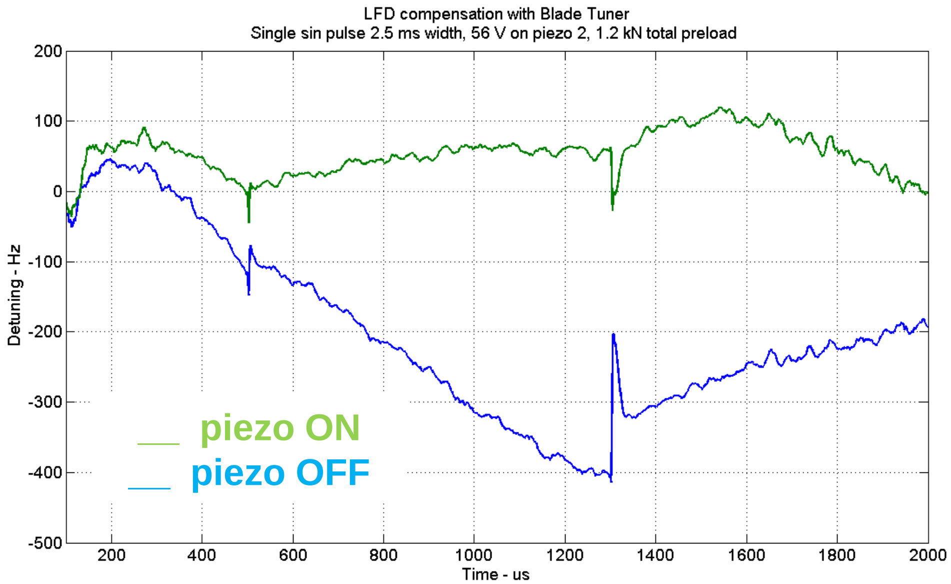


Blade Tuner tests at CHECHIA – Results

- LFD exhibited by Z86 cavity, about 300 Hz, has been compensated:
  - Actuating each piezo alone (see plots)
  - Actuating both piezo in parallel



64 V on piezo #1

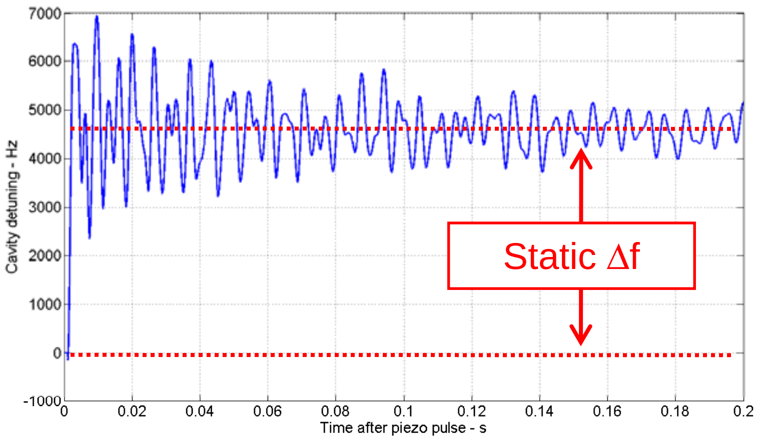


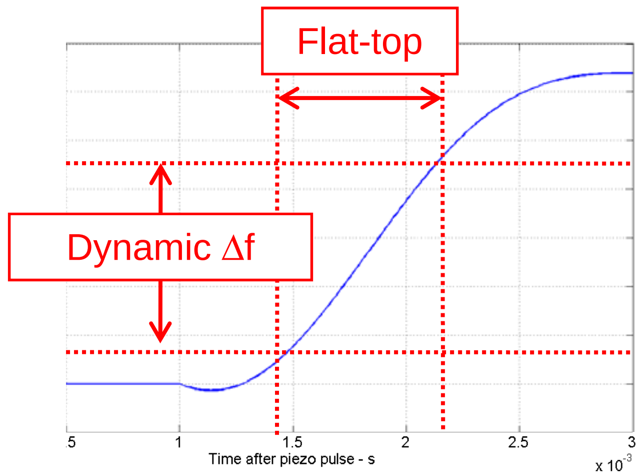
56 V on piezo #2

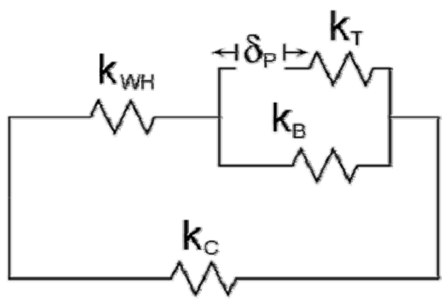
Nominal piezo pulse amplitude for this level of LFD is 60 V +/- 7%

Blade Tuner tests at CHECHIA

- Some considerations about these results. Several parameters are involved in the LFD compensation, anyway we can assume:
  - 300 Hz of dynamic compensated detuning is about 0.75 - 1 µm of induced dynamic cavity deformation. Longitudinal frequency sensitivity *df/dl* in the range 315 Hz/µm (ILC RDR) to 400 Hz/µm (experimental, FLASH).
  - Static-to-dynamic detuning ratio has been estimated through transfer function based simulations and can be assumed as about 1.2.
  - 60 V on piezo, given the 200 V maximum voltage and it's non-linearity, means about 1/5 of the maximum piezo stroke.
  - Temperature leads to a further stroke reduction: only about 13% available at T = 2 K, about 20-25 % at T = 25 K reached when piezo is operating.
  - Blade Tuner geometry efficiency has been evaluated by means of spring model of the system and it is equal to 83% when both piezo operate in parallel, therefore about 40 % when only one piezo is actuating







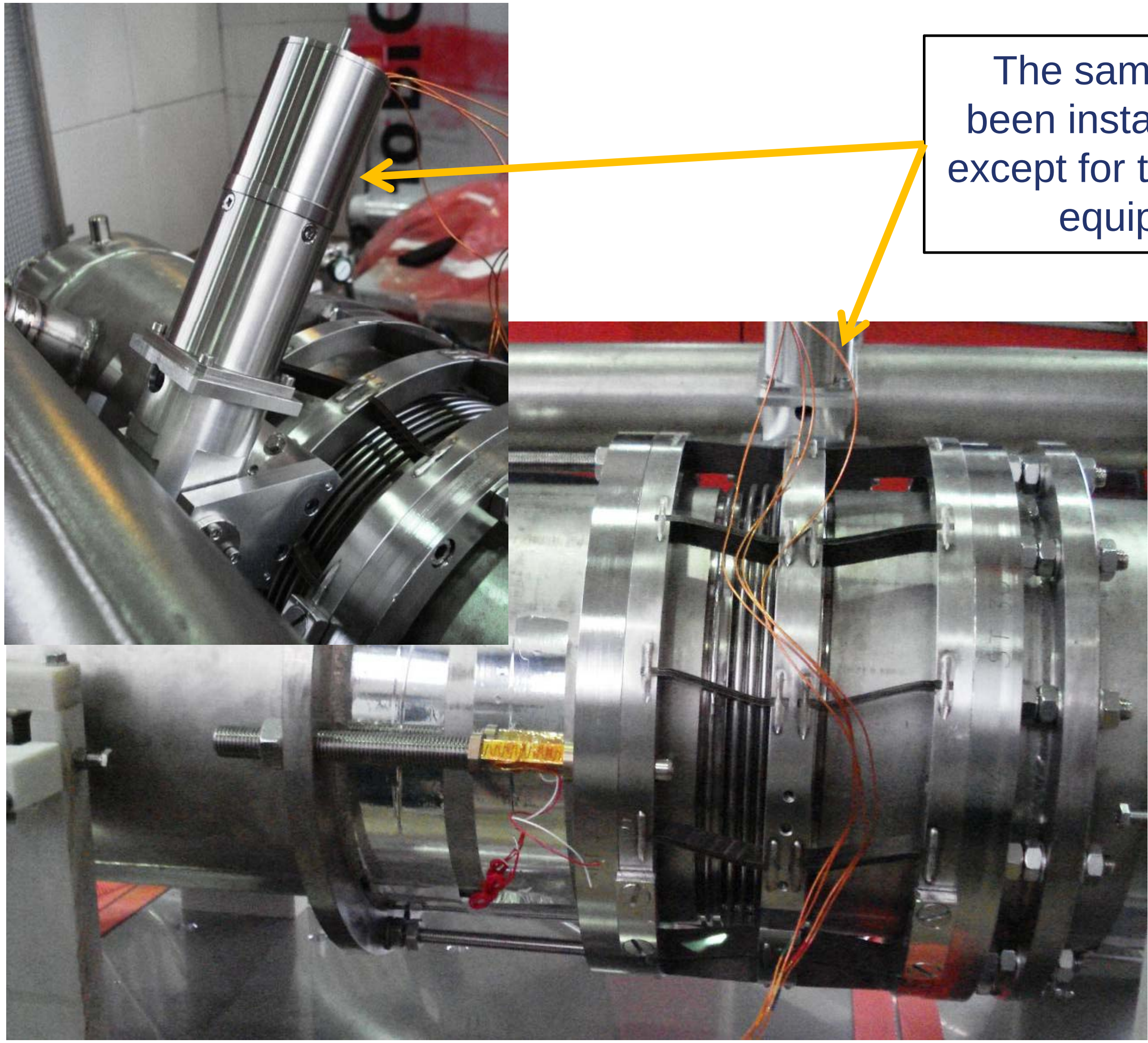
Blade Tuner tests at CHECHIA

The piezo assisted blade tuner performed as expected

Simulations are confirmed by experimental data

	Only one piezo acting
Nominal RF stroke at 200 V (max voltage)	60 μm
Stroke at 60 V	12 μm
Residual stroke at 25 K	3 μm
Blade Tuner efficiency	40 % +/-10%
Static-to-Dynamic ratio	1.2
Resulting stroke at the cavity	1 μm +/- 10%
Expected resulting dynamic cavity frequency variation	280 - 350 Hz
Measured resulting dynamic cavity frequency variation	300 Hz

Blade Tuner installation in HoBiCaT, BESSY



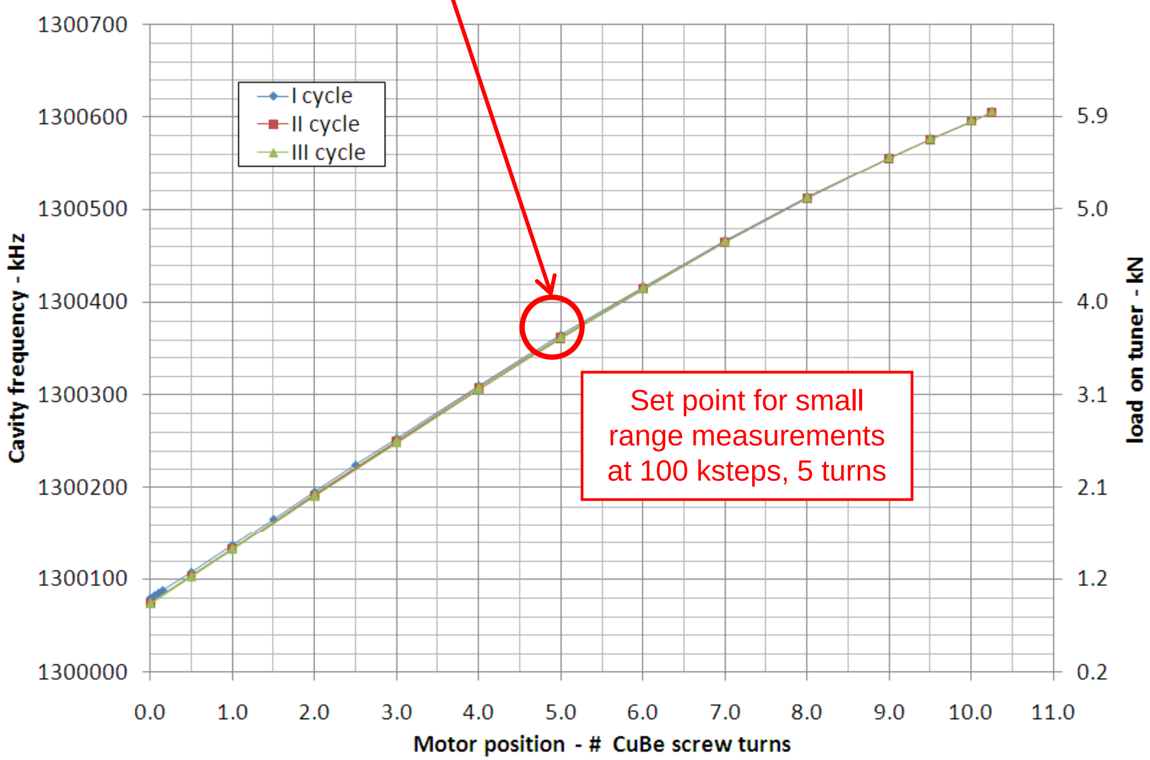
The same Blade Tuner assembly has been installed for cold testing at BESSY, except for the driving unit, a stepper motor equipped with **planetary gear**

HoBiCaT at BESSY

Blade Tuner tests at HoBiCaT

Data about frequency tuning on a μm-scale come from:

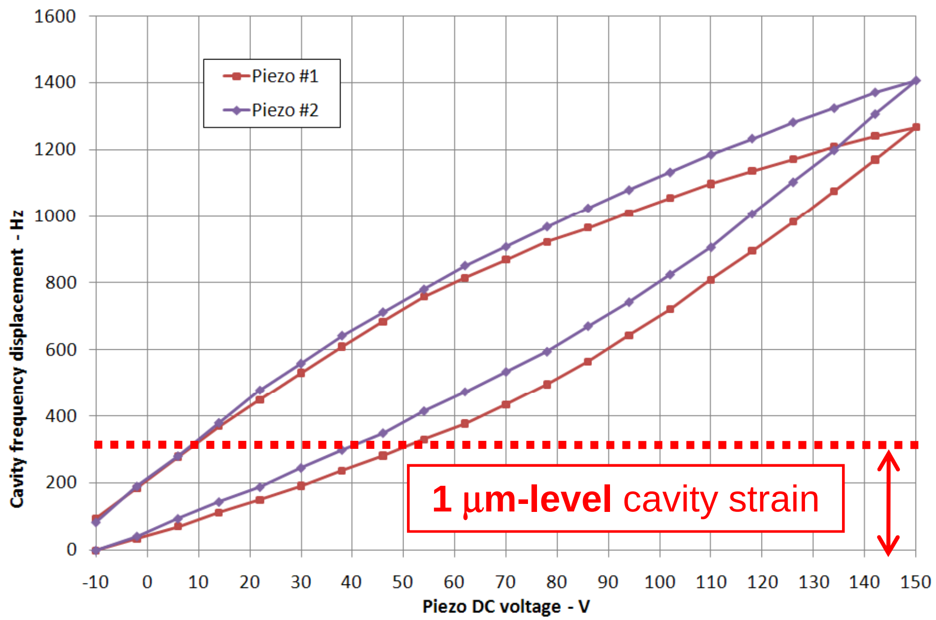
- Piezo actuators static tuning range measurements. Piezo are driven with DC voltage
- Drive unit small range measurements. Stepper motor is driven in a small range around a working point



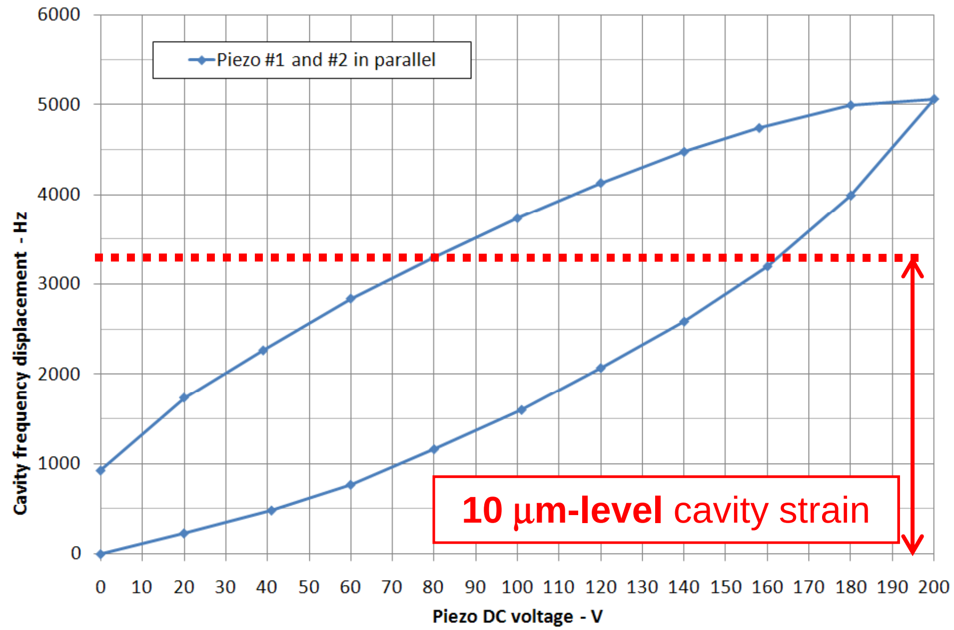
Blade Tuner tests at HoBiCaT

- Each piezo actuator alone and also both in parallel have been driven with a DC voltage, the cavity frequency is locked by a PLL and measured.
- No deviation observed from the hysteresis curves expected from piezoelectric properties: no obstacles to the movement of piezo.
- Looking at plots a sub-micron resolution can be observed: 10 V step in piezo driving voltage corresponds to about 0.1 µm at low absolute voltage (where slope is lower)

Each piezo alone up to 150 V:
1.3 kHz +/- 10 % tuning range



Both piezo together up to 200 V:
5 kHz tuning range



Blade Tuner tests at HoBiCaT

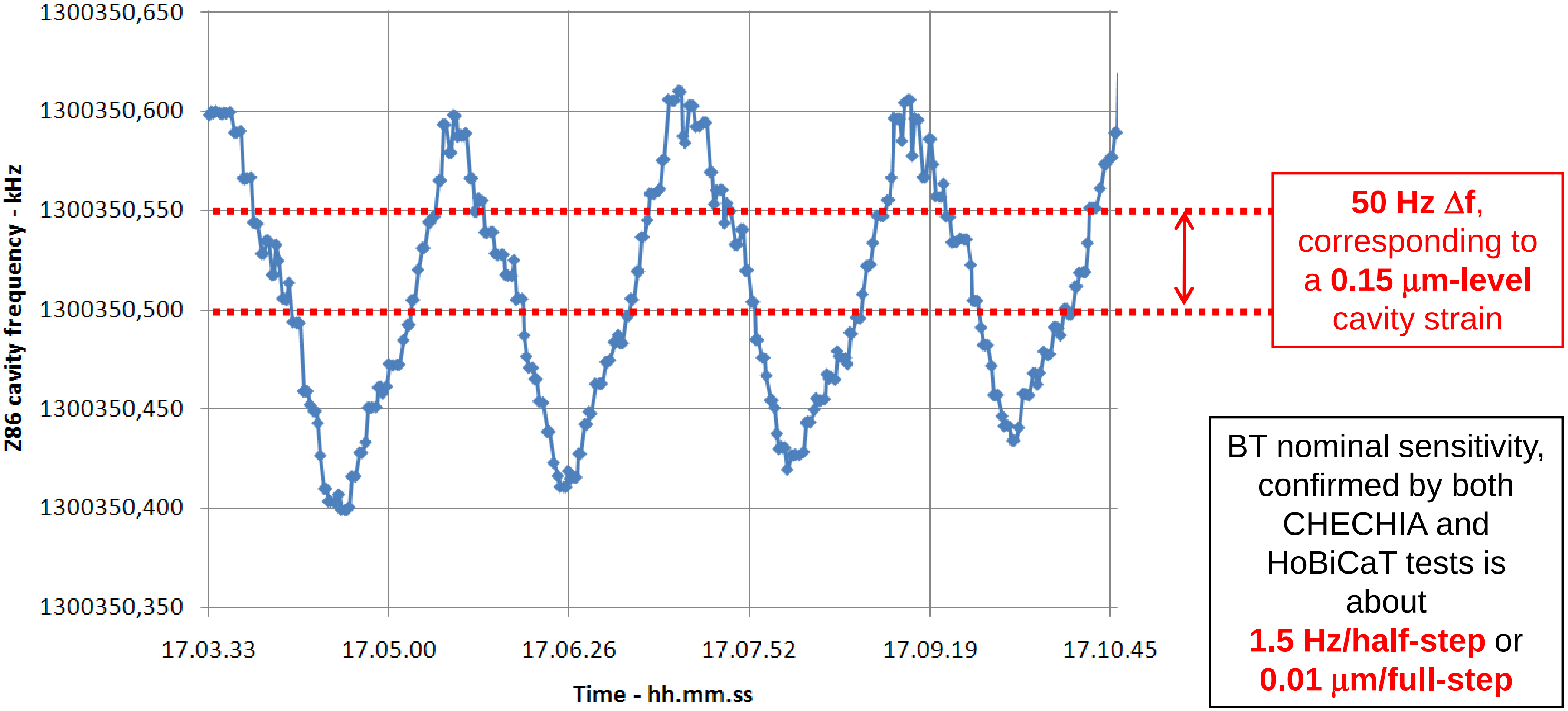
The HoBiCaT piezo tests confirm that the entire stroke expected to be transmitted to the cavity by piezo actuators is achieved:

Consider for example the test with both piezo operated in parallel up to 200 V (table):

	Both piezo acting
Nominal RT stroke at 200 V (max voltage)	60 μm
Residual stroke at working T (25%)	15 μm
Blade Tuner efficiency	83 %
Resulting stroke at the cavity	**13 μm**
Expected resulting static cavity frequency variation	4.1 – 5.2 kHz
Measured static cavity frequency variation	**5 kHz**

Some backlash from Gear Box

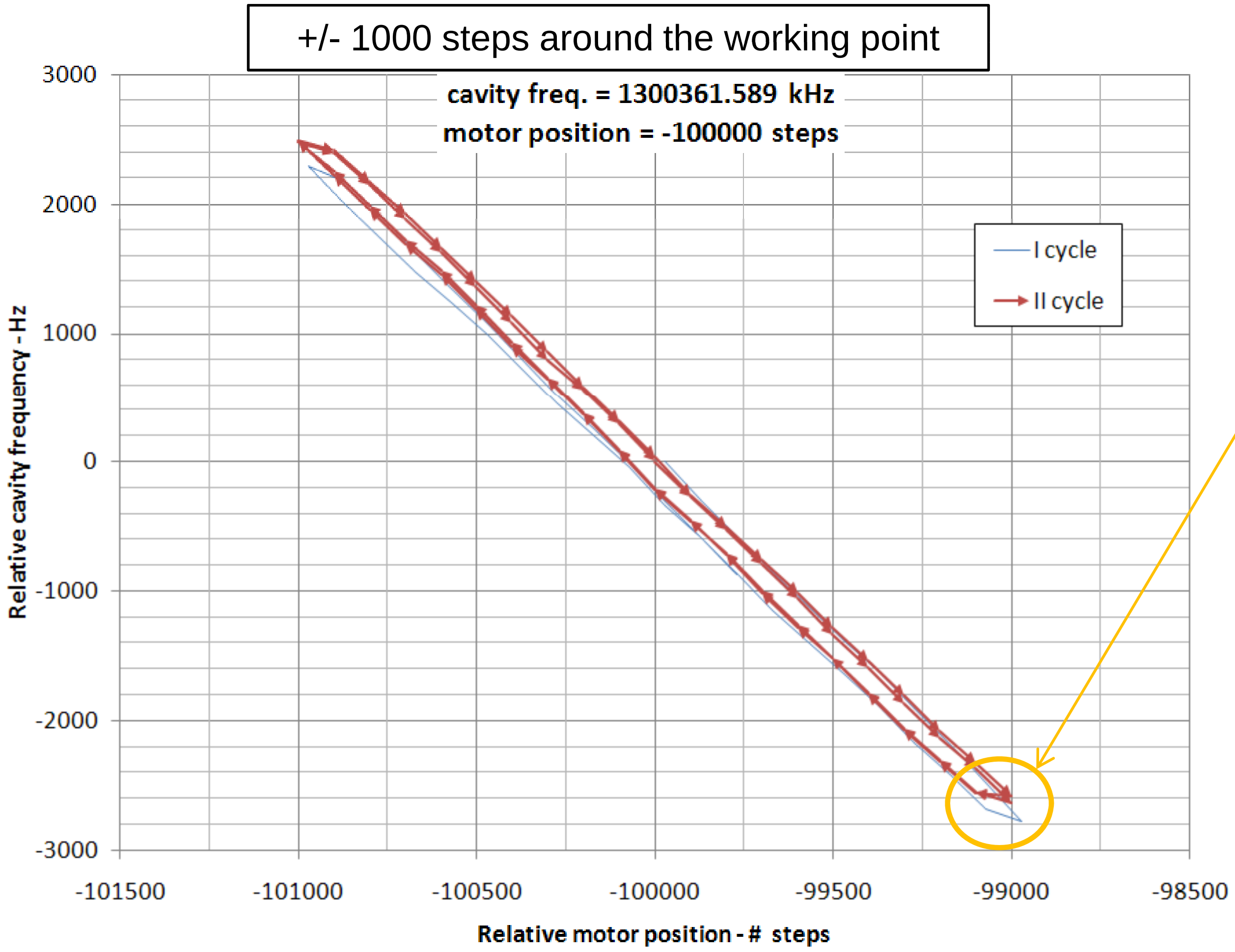
- Drive unit small range tests: the stepper motor has been driven iteratively in the range +/- 60 steps around the working point, by steps of 6 motor steps.
- The tuning effect on cavity of a single bunch of 6 motor steps, about 60 nm or 6/20000 of a spindle turn, is visible.
- As expected some backlash noise from gear box is visible



BT nominal sensitivity, confirmed by both CHECHIA and HoBiCaT tests is about **1.5 Hz/half-step** or **0.01 μm/full-step**

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.

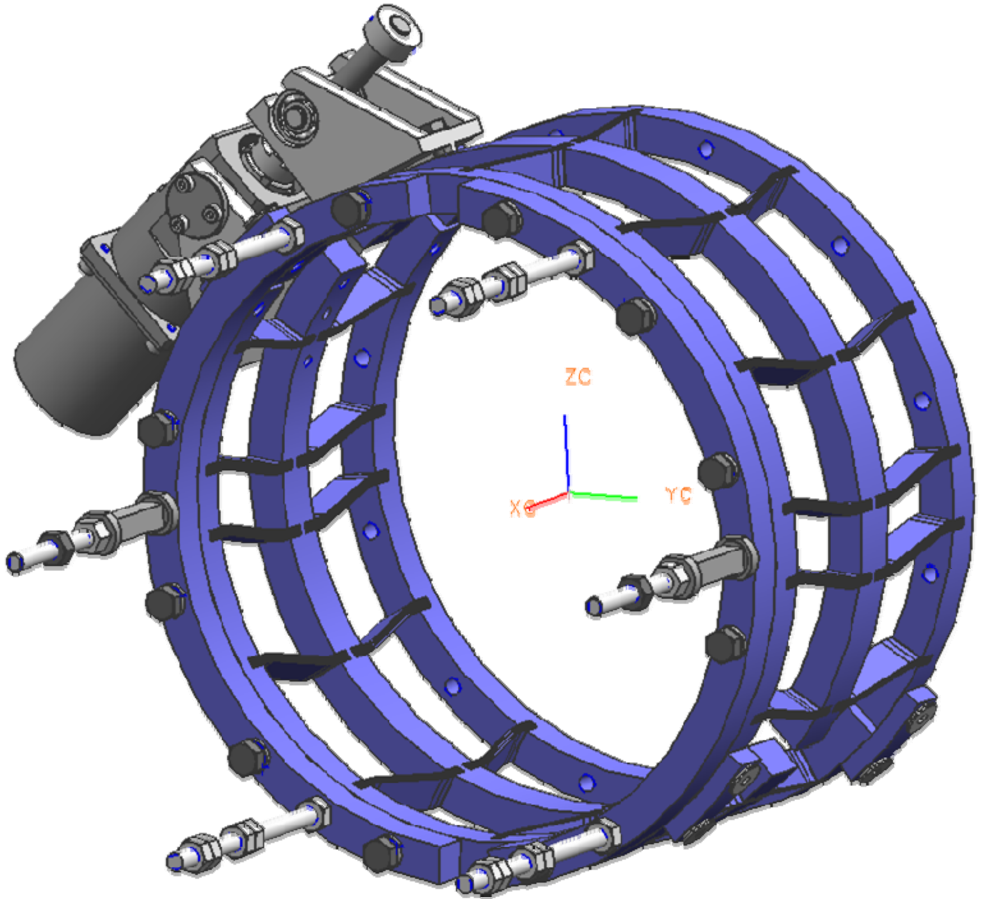
But the planetary gear installed, here tested for the first time, actually introduces a significantly **higher backlash if compared to HD gear, about 20 times higher**

The ILC Blade Tuner

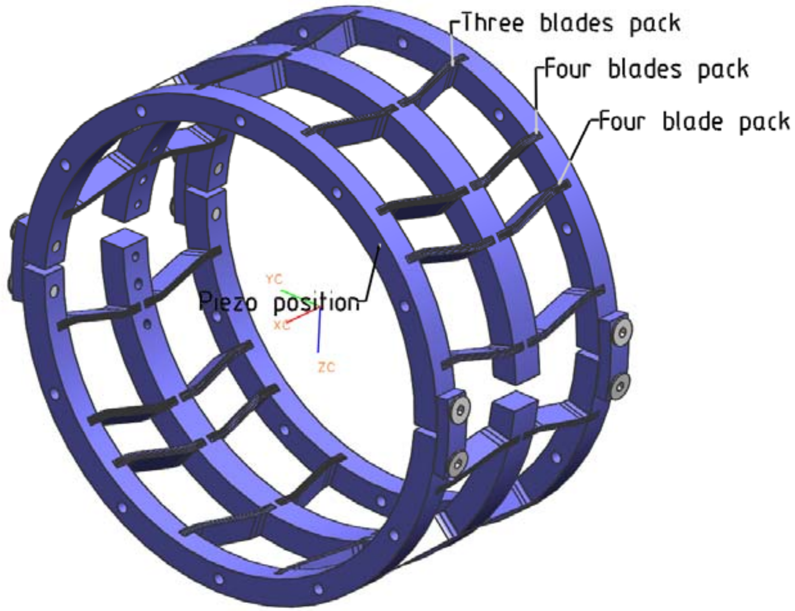
On the basis of the test results here presented the ILC Blade Tuner prototype is already close to fulfill all the XFEL and ILC specifications.

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.

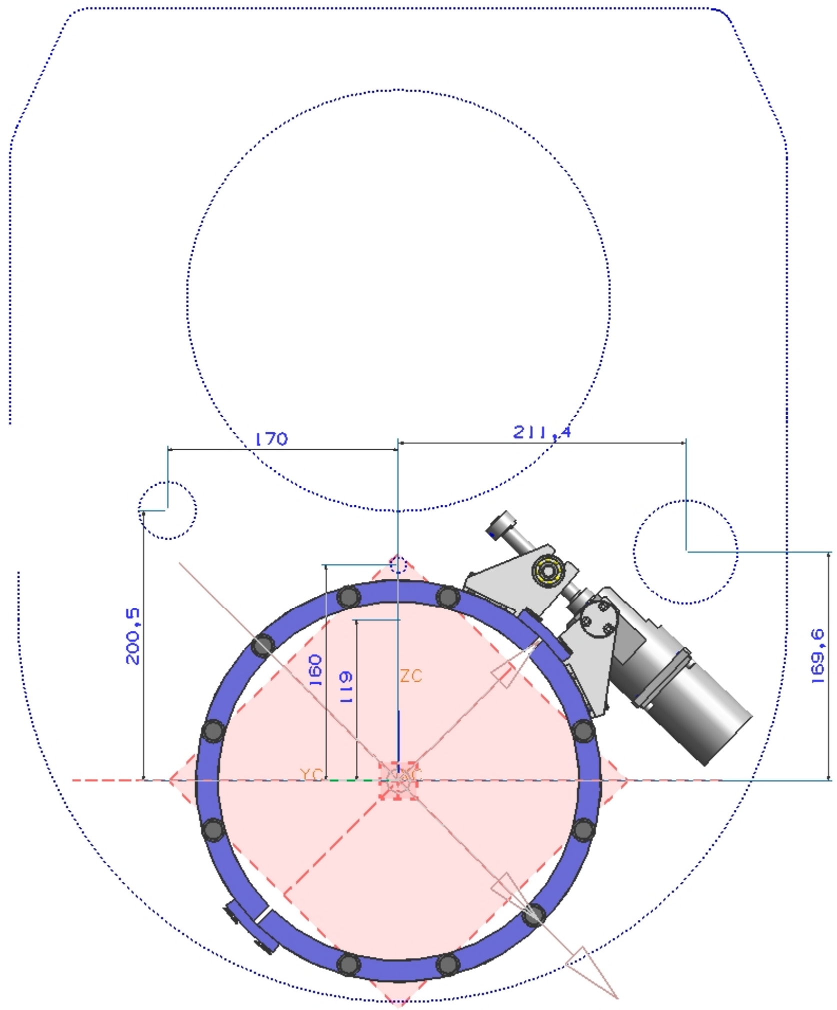
The first 8 units for Fermilab have been produced and 2 more are under construction.



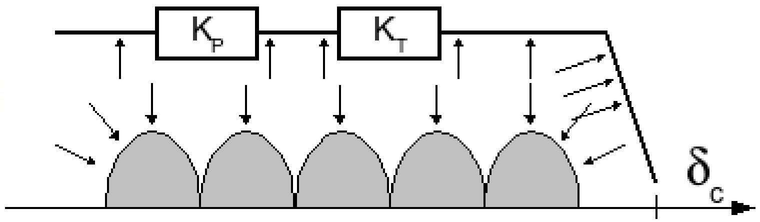
Geometry of the revised tuner 3.9.4



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

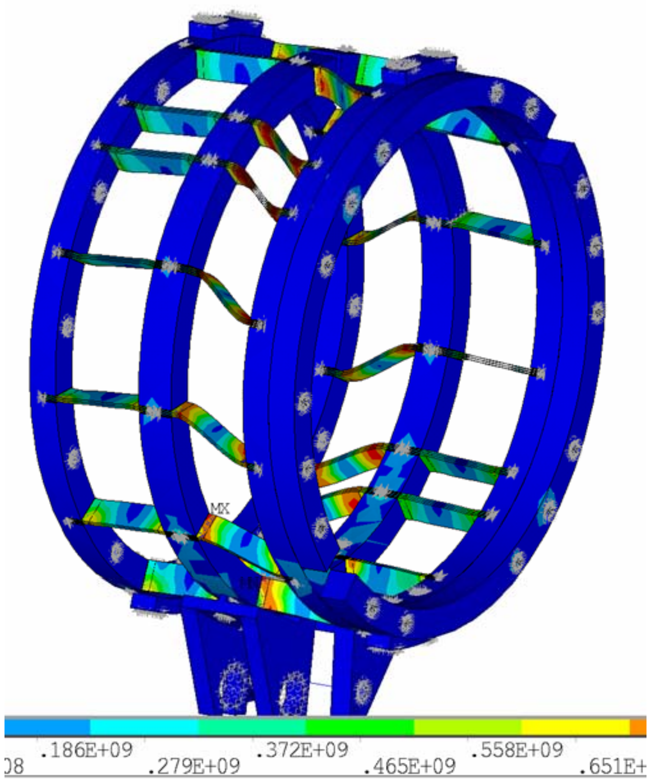
Condition	Pressure			Temp.	Max load
	Beam pipe	He tank	isovac	cavity	Tuner
	mbar	mbar	mbar	K	N
Emergency	0	4000	0	300	+9630
Leak test	0	0	1000	300	-2840

1 Positive forces are in traction direction

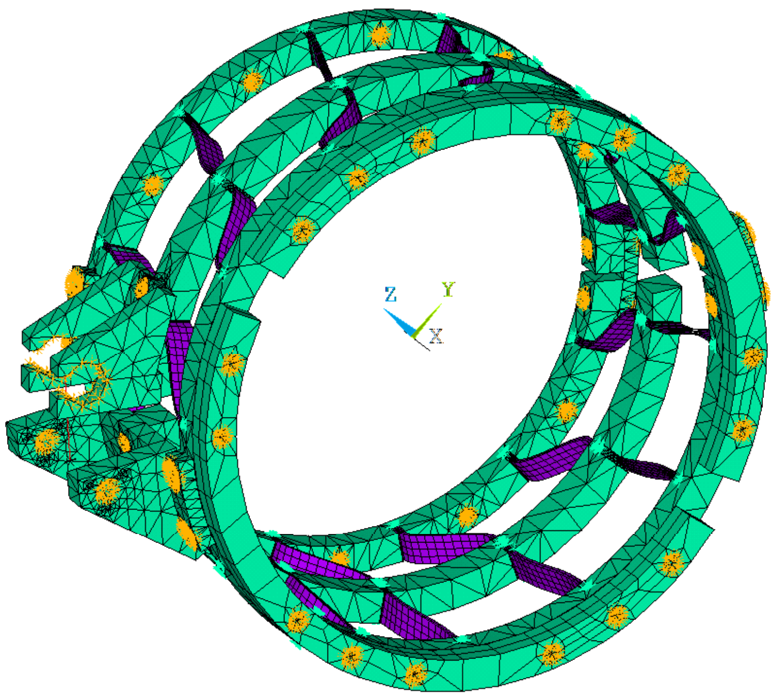
Design analysis – whole tuner

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



Revised Blade Tuner - conclusions

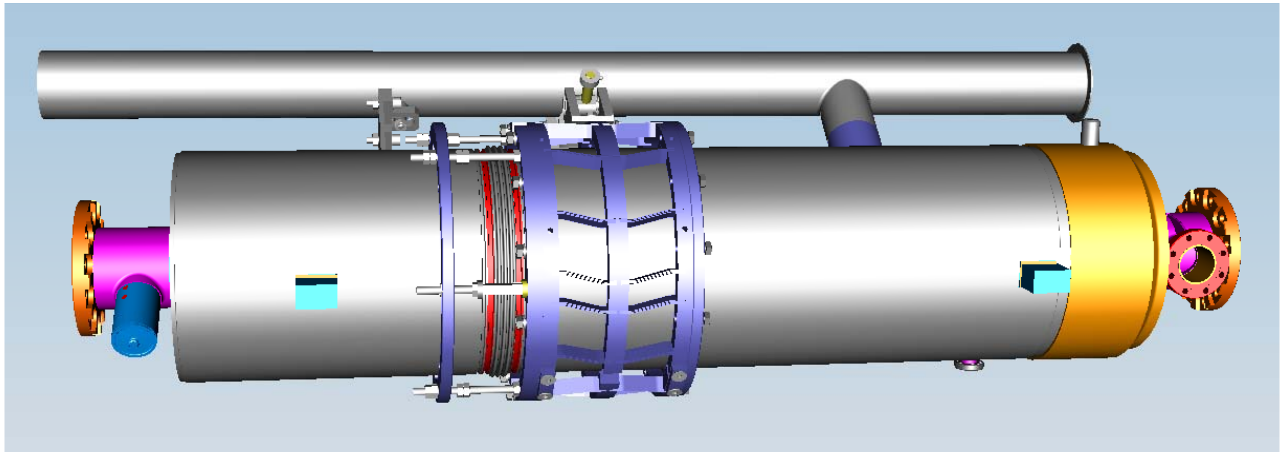
<table>
<tr><th>Tuner under construction (3.9.4)</th><th>Tuner characteristics</th><th>Required value</th><th>Margin factor</th></tr>
<tr><td>Tuning range - nominal
(no hysteresis)</td><td>0 – 500 kHz</td><td></td><td></td></tr>
<tr><td>Tuning range – max.
(some hysteresis[1])</td><td>0 – 600 kHz</td>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

1 With some plastic deformations at worm, 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

Tuner position

- The INFN proposed position is fine
  - Maintain the plug compatibility with FHASH-XFEL cavities
  - Produce a negligible static deformation of 0.13 mm
  - No backlash on the rollers (superstructure data)
  - Easy and proven assembly procedure



  - Moving the bellow at the tuner center the sag increases to 0.16 mm
  - No need to move the tuner outside the pads. It just add complexity and cost (end group-He Tank connections, cantilever effect, etc.)

He Tank sag and bellow position

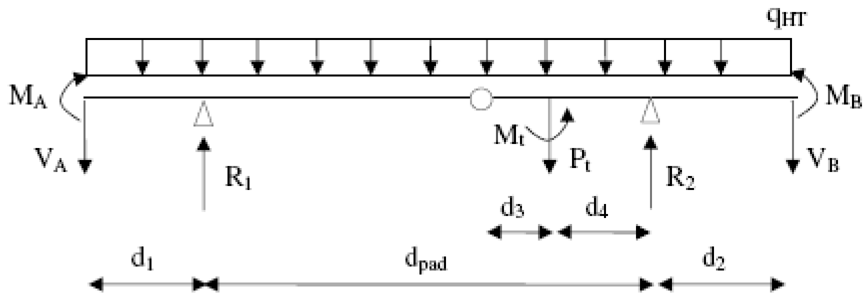


Fig. 1: helium tank static model

Pad distance = 750 mm

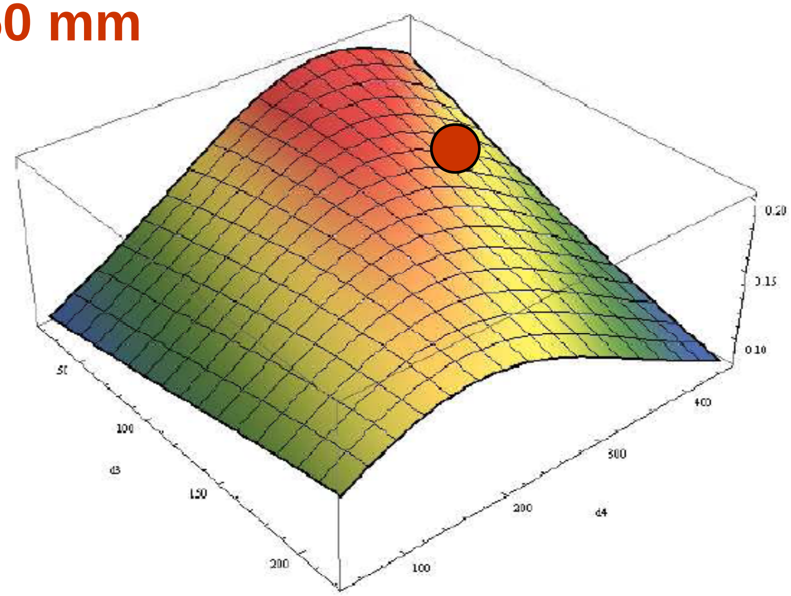


Fig. 3: maximum cavity displacement vs d_3 and d_4