Blade Tuner

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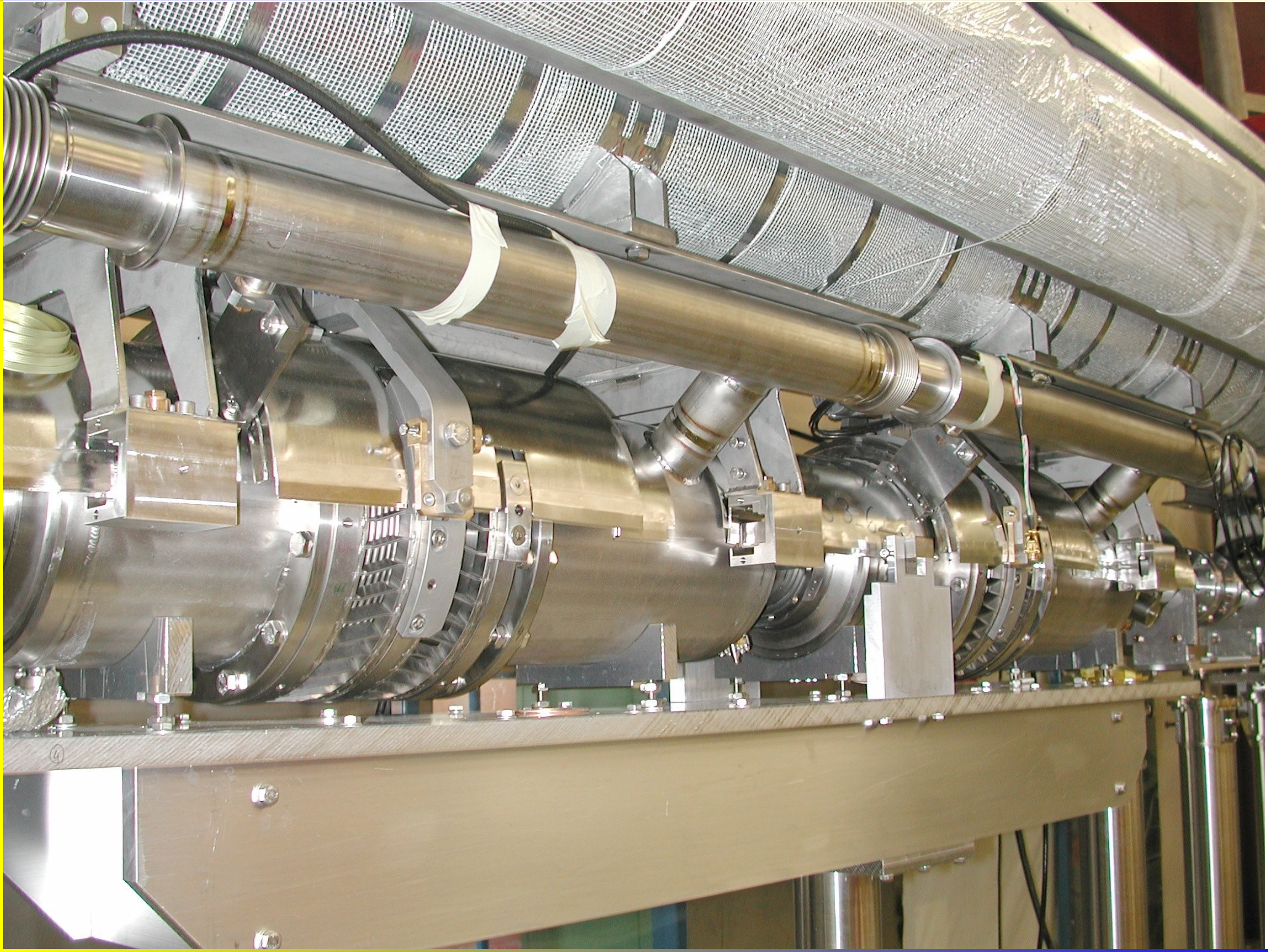
SS Tuner under installation

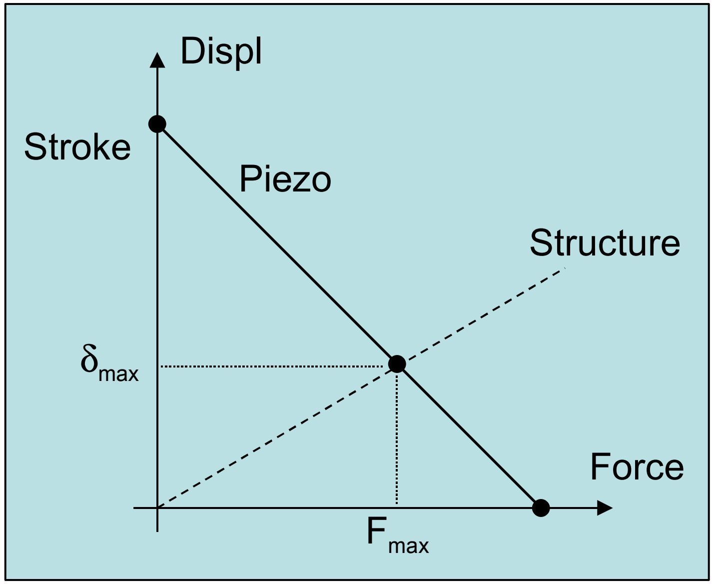


Moving to an integrated system (1)

- Piezo actuators need to be integrated in the design in order to provide the required fast tuning action for LFD compensation at high gradients ($\Delta\nu = K_L E^2$)

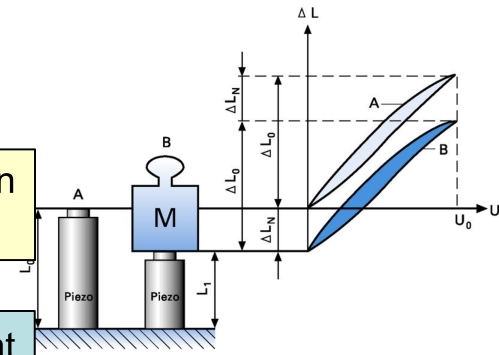
Several requirements limit the possible design configurations:

- Piezo actuators can not be subject to tension forces, while bending and shear actions have to be avoided;
- A correct preload has to be applied in order to have a longer lifetime;
- The stroke at LHe temperature is about 15% of stroke at RT;
- The generated force is always coupled with a reduction of displacement
- Uncertainties on cryogenic characteristics and piezo operation
- Expensive



Moving to an integrated system (2)

Requirements



± 1 mm fine tuning (on cavity) → ΔF on all piezo (sum) ≈ 3.5 kN

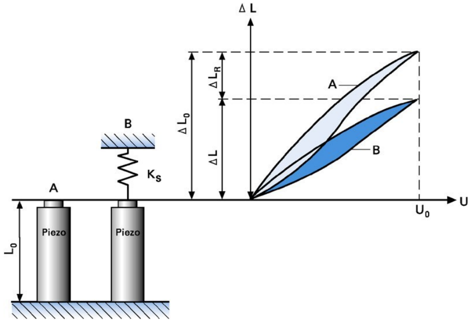
This value has to be considered as a preload variation and, if lower than the maximum characteristic force of piezo, acts as an offset

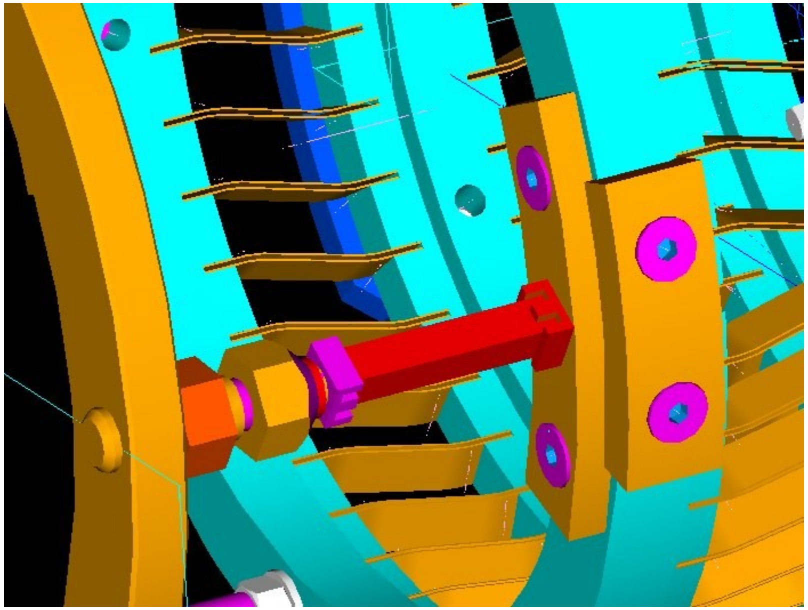
1 kHz fast tuning → ≈ 3 μm cavity displacement → ≈ 4 μm piezo displacement

This value has to be guaranteed at temperature lower than 4 K, we expect to need a 40 mm long piezo

4μm piezo displacement → ≈ ΔF on all piezo ≈ 11.0 N

This value has been obtained in quasi-static conditions: no dynamic forces were considered





Tuner with piezo: last version

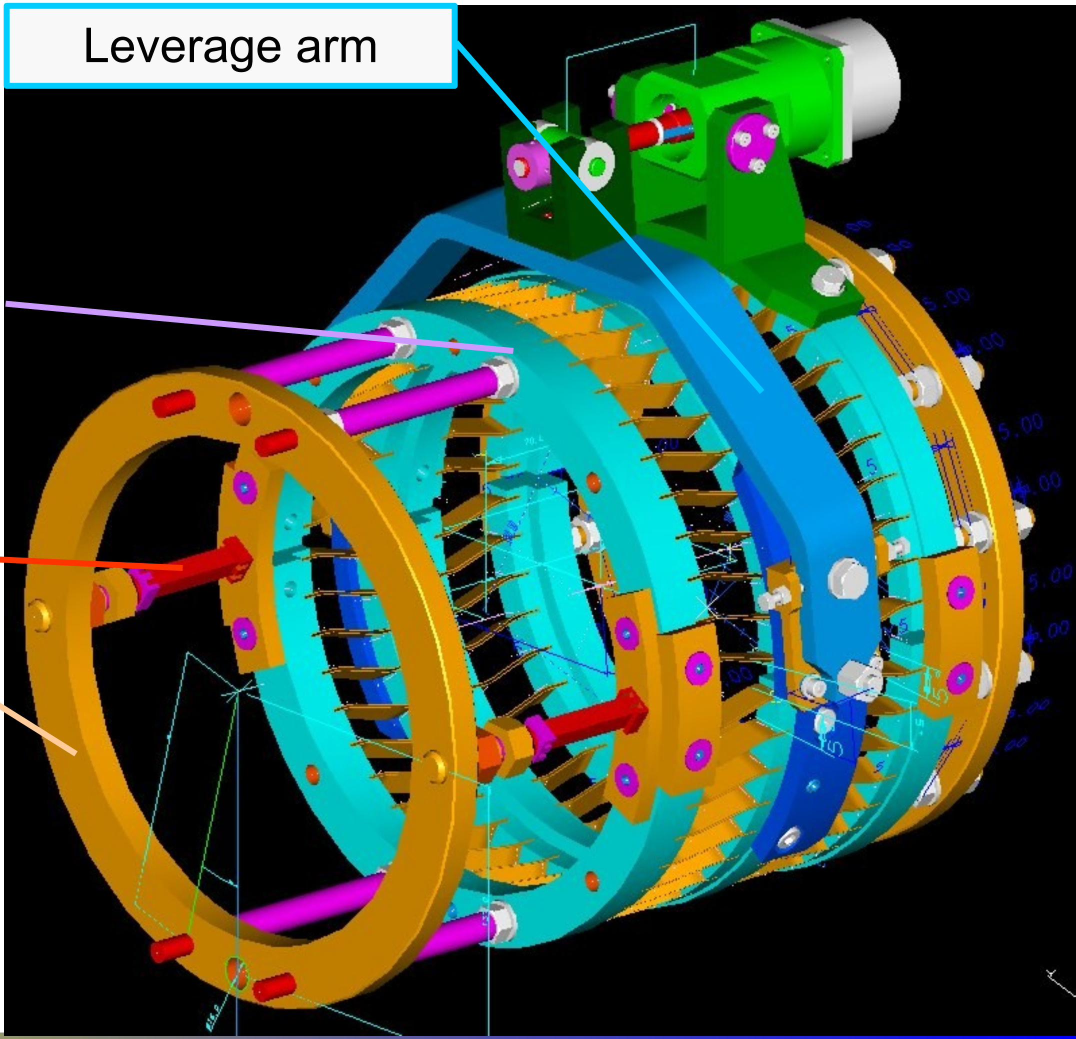
- we plan to have a test of the integrated system before end of the year
  - Requirements
    - Maximum of 2 mm slow tuner action

Stiffeners bars
Could be used in working cond.?
Probably as safety devices.

piezo

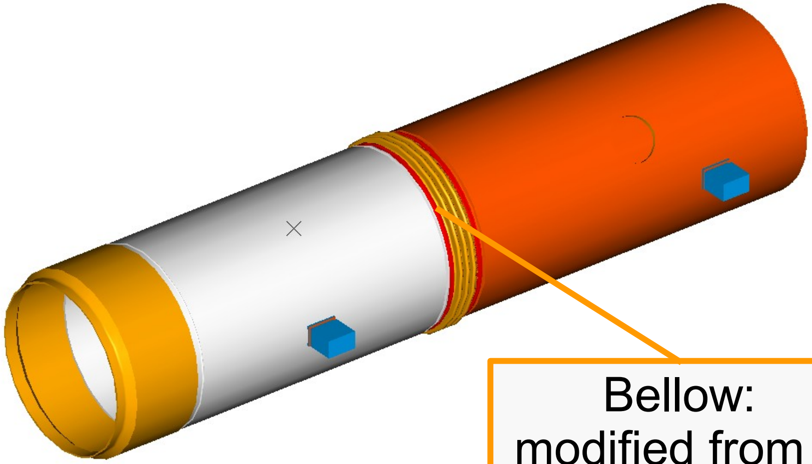
Ti ring welded on the tank

  - Need modifications to standard He tank

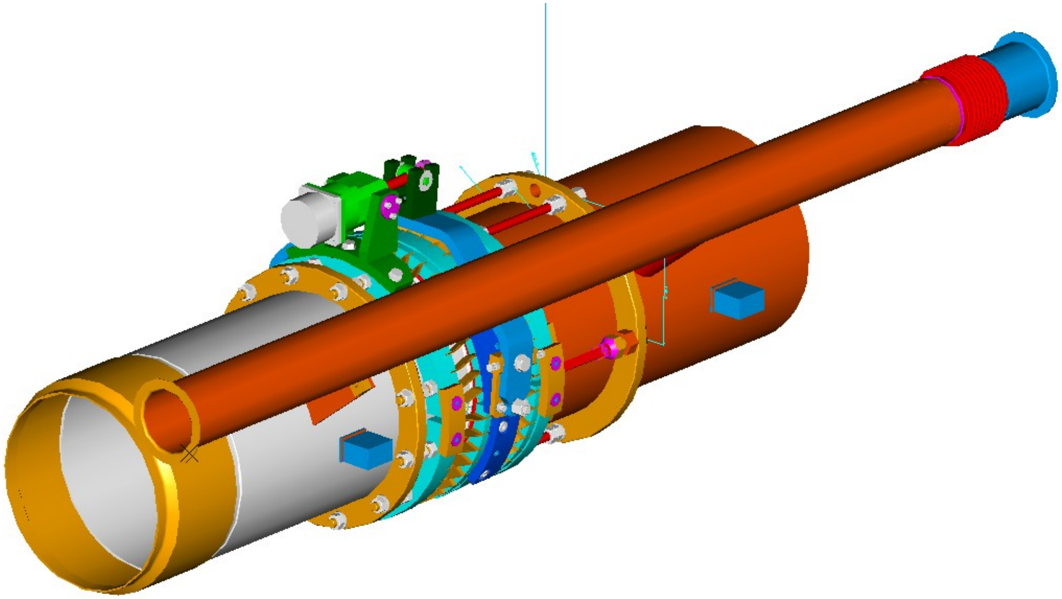


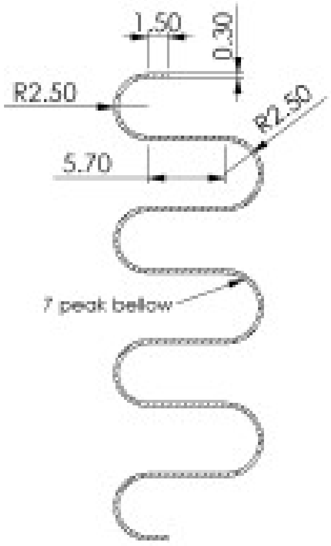
Revised He Tank

- Now the He tank needs to be split in two parts, with a bellow in between to allow the cavity elongation
- Magnetic shield assembly should probably be improved



Bellow: modified from 4 to 7 peaks





Status of tuner activities

Completed…

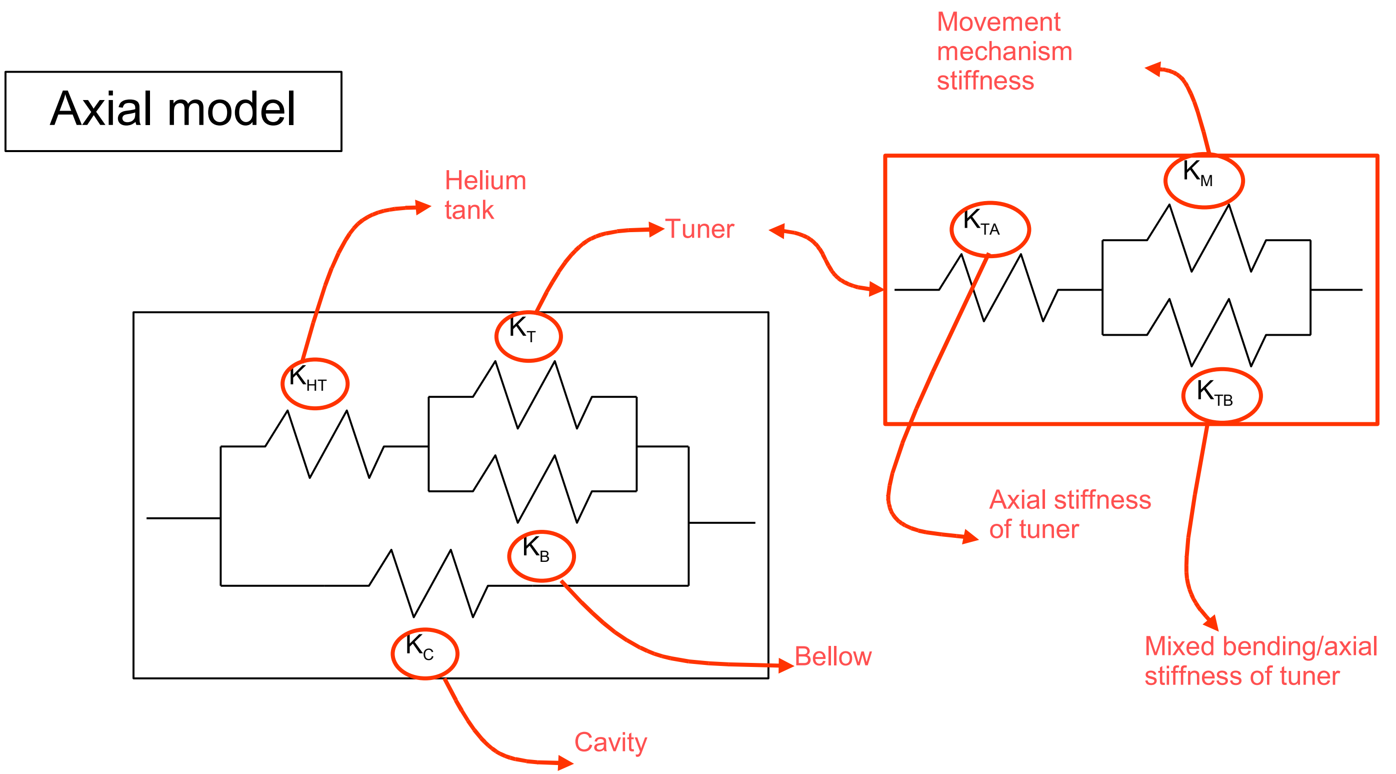
- It is a simple configuration;
- Low part number;
- The cavity elasticity is used to provide the piezo preload;
- Piezo capabilities seem to satisfy the requirements;
- Different piezo with different lengths and cross sections can be used (up to 72 mm length)
- Open possibility to use one piezo as actuator and the other one as measurement device. Is the stroke sufficient in this case?

Still to investigate…

- Piezo cannot sustain shear or bending forces, the system should avoid these excitation;
- With respect to the superstructure configuration, the tuner has no bending and shear stiffness due to the presence of the piezo actuators;
- Equilibrium and continuity of the helium tank has to be guaranteed by the cavity and the bellow;
- The assembling procedures are being revised in order to minimize the forces on the piezo.

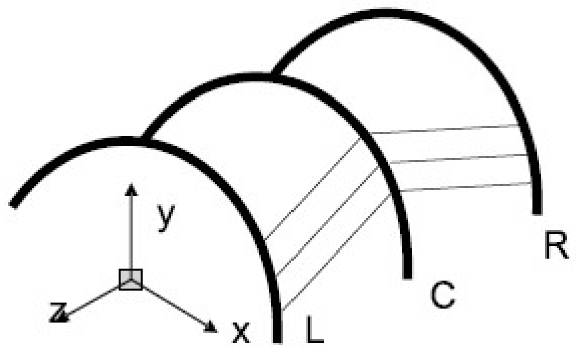
How does it work? Simplified structural model

- Tuner – Cavity – Helium tank system:
  - Axial behavior has been investigated in quasi static conditions
  - Bending behavior is being investigated
  - The most complicated part is the tuner: axial, bending and shear stiffness have to be considered



Tuner characterization

- The tuner is a stiff component
- Relative displacements of the rings produce reactions at the boundaries: they can be used to evaluate the axial, bending and transverse stiffness



1 - DOF

$x \rightarrow u, \theta$

$y \rightarrow v, \phi$

$z \rightarrow w, \psi$

2 - Only "admissible" displacements are considered

$U_{LC} = U_C - U_L$

$W_{LC} = W_C - W_L$

$\psi_{LC} = \psi_C - \psi_L$

3 - Forces and moments can be evaluated

$x \rightarrow Fx, Mx$

$y \rightarrow Fy, My$

$z \rightarrow Fz, Mz$

4 – Using symmetry

$Fx_L = Fx_R = -\frac{1}{2} Fx_C$

$Fz_L = -Fz_R \quad Fz_C = 0$

$Mz_L = Mz_R = -\frac{1}{2} Mz_C$

Stiffness matrix

- Finite element analysis have been performed on half model of the blade tuner. The following characterization has been obtained without leverage system:

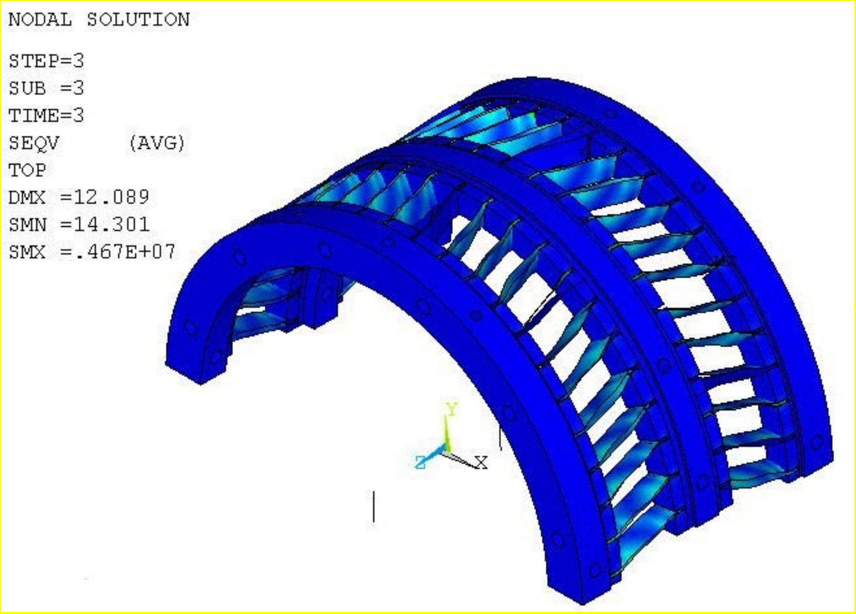
$$\begin{Bmatrix} F_x \\ F_z \\ M_z \end{Bmatrix} = \begin{bmatrix} 14180 & 24950 & -840285 \\ 24950 & 164248 & -5449750 \\ -840285 & -5449750 & 184420000 \end{bmatrix} \begin{Bmatrix} u_{LC} \\ w_{LC} \\ \psi_{LC} \end{Bmatrix}$$

$Fy_L = Fy_R = Fy_C = 0$

$My_L = My_R = My_C = 0$

$Mx_L = Mx_R = Mx_C = 0$

If the second half tuner is considered



Von Mises stresses for ψ_{LC} = 0.05 rad

Comparison with experimental tests

- An experimental test has been performed in axial direction. Two different configurations were considered:
  - central ring constrained by the mechanism;
  - central ring constrained by a rigid steel part.

Figure 4: experimental setup

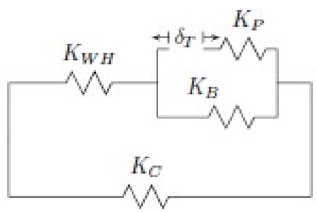
Configuration	Test (μm/kN)	3D model (μm/kN)
line Two rigid links	12	8.316
Mechanism	40	—

Table 1: comparison between experimental and analytical results

Axial behavior

- The axial behavior of cavity has been predicted. The following hypotheses were assumed:
  - mechanical properties at 300 K;
  - quasi-static working conditions, no inertia forces;
  - Helium tank bellow with 7 peaks;
  - Two or three piezo, 40 mm length, 10x10 mm section

Fine tuning



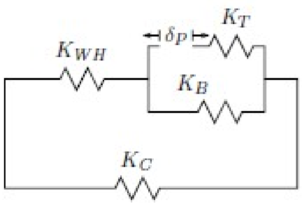
N. of piezos	2	3
Helium tank	-2.8125	-2.8262
Blade tuner	-3.037	-3.052
Cavity	2.8125	2.8262
Piezo actuator	-3.037	-3.052
Tuner bellow	0.2247	0.2258

Axial forces (N): tuner displacement =1 µm

N. of piezos	2	3
Helium tank + Washer disk	-0.1102	-0.1107
Blade tuner	1	1
Cavity	0.875	0.880
Piezo actuator	-0.014	-0.0097
Tuner bellow	0.986	0.9903

Axial displacements relative to the tuner displacement

Fast tuning



$$F_T = -2.7436\delta_P$$
$$F_B = 0.203\delta_P$$
$$F_{WH} = -2.5406\delta_P$$
$$F_C = 2.5406\delta_P$$

$$\delta_T = -0.1097\delta_P$$
$$\delta_B = 0.8902\delta_P$$
$$\delta_{WH} = -0.0995\delta_P$$
$$\delta_C = 0.7907\delta_P$$

Cinematic

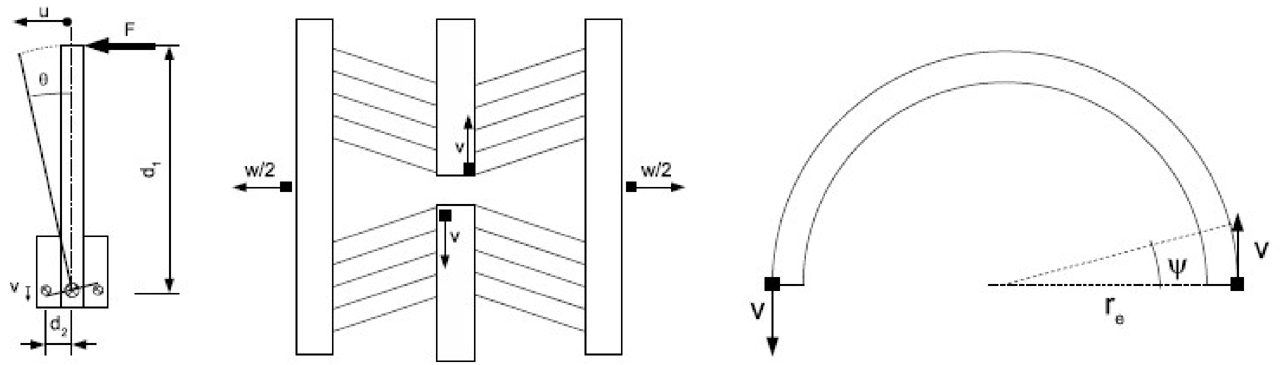


Figure 1: cinematic description of the fine tuning system

$$d_1 = 162.5 + 12 + 40 = 214.5 \text{ mm}$$
$$d_2 = 17.5 \text{ mm}$$
$$r_e = 300/2 = 150 \text{ mm}$$

$$\delta\theta = \frac{\delta u}{214.5}$$
$$\delta v = d_2 \delta\theta = \frac{17.5}{214.5}\delta u = 0.0816\delta u$$
$$\delta\psi = \frac{\delta v}{r_e} = 5.439 \cdot 10^{-4}\delta u$$

- **limit displacement by contact of the central rings**
  Central rings distance is of 7 mm only, therefore:

$$v_{max} = 7/2 = 3.5 \text{ mm} \Rightarrow \delta\psi_{max} = \frac{3.5}{150} = 0.023^{r} = 1.336°$$
$$u_{max} = d_1 \tan\theta = \pm 20 \text{ mm}$$

Tuner/Cavity stiffness

$$M_z = 146938u \text{ (Nmm)}$$
$$u_{LC} = 0.0881u \text{ (mm)}$$
$$w_{LR} = 0.0636u \text{ (mm)}$$
$$F_z = 56.07u \text{ (N)}$$

Conclusions

- The assembly procedure has been reviewed in order to include the right preload on piezo:
  - The cavity is tuned below the nominal frequency to transfer, through a 1 mm extension, the required pre-load to the two piezos.
- A safe maximum compression condition for the piezos of 4 KN at room temperature fixes the limit for the total tuning range, which includes fine cold tuning, preload and piezo action
- The stroke expected for the chosen 40mm piezo at LHe should be higher than the required 4μm to operate the TESLA cavity at 35 MV/m with a safety margin. If not, longer piezo should, and indeed can, be used.
- Once characterized at cold, with high cavity sensitivity, final length and section of the piezo actuator will be optimized and the option of operating just one piezo will be defined.