The Fast Piezo-Blade Tuner for SCRF Resonators

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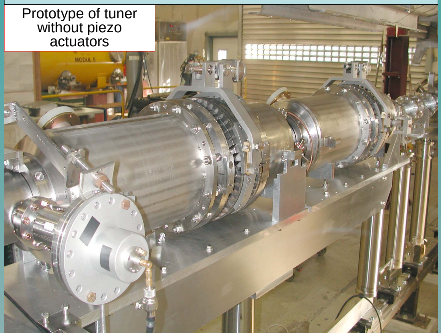
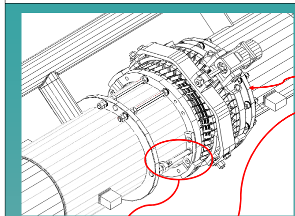
The prototype for the superstructure

The design of a coaxial tuner solution was originally motivated from the need of a cold tuner for the TTF superstructures tests. The coaxial blade tuner was then proposed both for the reduced cavity spacing foreseen by the TESLA TDR and for the superstructures, and prototypes without piezo actuators were built and tested in the CHECHIA horizontal cryostat and on the TTF linac in 2002. During both tests the blade tuner performed as expected in terms of stiffness, frequency sensitivity and tuning capability.

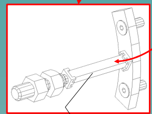
Prototype of tuner without piezo actuators

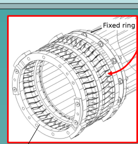


Integration of active tuning



The tuner assembly is mainly composed of three parts:
- the movement leverage
- the bending rings
- The piezo actuators





The piezo actuators provide the fast tuning capabilities needed for Lorentz Force Detuning (LFD) compensation and microphonics stabilization

The design is compatible with other active elements, as magnetostrictive actuators.

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 titanium plates (blades) that, by means of an imposed azimuthally rotation in opposite direction of the two halves of the central ring, can elastically change the cavity length.

How we designed it?

Requirements	Frequency range [kHz]	Axial movement [μm]
Slow tuning		~ 1500
Fast tuning	~ 1	~ 3

Part	E (MPa)	K (N/μm)
He tank (K_H)	119000	440
Tuner (K_T)	119000	25
Cavity (K_C)	105000	3.213
End disk (K_W)	105000	27.1
Piezo (K_P)	---	2 x 105
Tank bellow (K_B)	119000	0.228

The axial mechanical behavior of the full system (cavity + He tank + tuner) has been investigated by means of spring models.

Load case: δ_{Tuner} = 1 mm (slow tuning)

Part	Axial force (N)	Axial displ. (mm)
He tank + end disk	-2812.5	-0.110
Tuner	-3037.0	1.000
Cavity	2812.5	0.876
Piezo	-3037.0 / 2	-0.014
He bellow	224.5	0.986

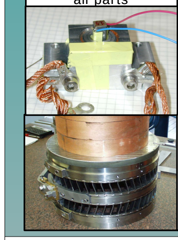
Load case δ_{Piezo} = 1 μm (fast tuning)

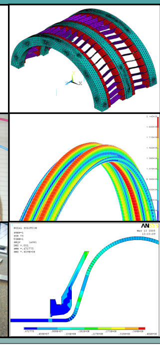
Part	Axial force (N)	Axial displ. (μm)
He tank + end disk	-2.540	-0.100
Tuner	-2.743	-0.110
Cavity	2.541	0.790
Piezo	-2.743	1.000
He bellow	0.203	0.890

Due to the low stiffness of the end disks, only 87% of the displacement applied by the tuner is transferred to the cavity. For the fast tuning action a further contribution comes from the tuner stiffness, and 79% of the displacement applied by the piezos is transferred to the cavity. In particular, to provide the values required, the piezo has to assure a maximum stroke of ~ 4 μm at 2 K. The use of stiffer end disks for the He tank connection would slightly reduce the requirements on tuner/piezo excursion.

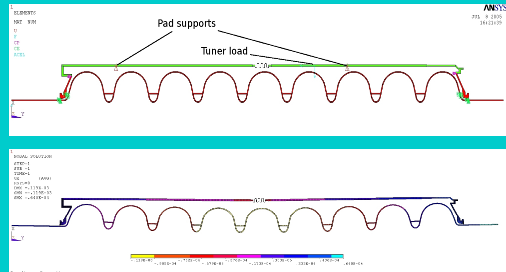
The piezo preload is varying with the slow tuner action, therefore a suitable pre-tuning strategy needs to be assessed to ensure that, during the slow tuning action, the preload remains within valid operation limits. Furthermore, we have to ensure that the piezo preload has to be always lower than its blocking force. For the chosen piezo, with a cross section of 10 x 10 mm^2, a blocking force of 4 kN (each) is expected and a maximum slow tuning action of ~ 800 kHz can be safely applied, which is at least a factor of two higher than the current warm-cold frequency reproducibility at the TTF.

Numerical and experimental evaluation of mechanical characteristics of all parts





Due to the change of the Helium Tank with the introduction of the bellow, an accurate evaluation of the vertical displacement is required. The maximum sagging computed (0.12 mm) is less than the admissible tolerance of concentricity of dumb bells (0.6 mm), therefore the new configuration can be accepted with confidence.



Analysis of displacements under dead load: maximum displacement obtained of 0.12 mm

Piezo actuator testing and comparison

Guidelines for piezo choice	Blade tuner piezo specifications - Working point, **2K** -	Needed properties, for piezo at room temperature
Blocking force	**4 kN** open loop. To guarantee almost full stroke when working against the cavity spring load	**Cross section higher then 10 x 10 mm²** blocking force is mainly not affected by temperature
Max. stroke	**4 μm** To provide the designed fast tuning range	**60 μm 40 mm stack length** stroke reduction of 90% is considered when cooling to 2K but a margin is advisable
Stiffness	**>> 25 N/μm** To preserve the total tuner/helium tank stiffness	**k > 100 N/μm**
Control speed	**> 0.01 μm/μsec** To avoid the control loop radically exceeding actuator intrinsic dynamic	**Resonance frequency higher then 10 kHz**, with no applied load
Load limit	**> 10 kN** To avoid damaging during assembling, conditioning or cooling down	
Size	**≤ 15 x 15 x 72** To fit in the current tuner design	
Control voltage	V_{max} **< 200 V** low voltage piezo electric actuators, to limit piezo self-heating in cryogenic environment	
Long life	**1.5 10^9 cycles** Equivalent to 10 years of standard operation at 2K	No explicit guarantees from manufacturers! Only some guidelines: **Preload: 10-30% of load imit. No tensile forces. Vacuum, clean env.**

PI-888 life time test:

A reliability test was performed with a simplified prototype setup:

- **Physik Instrumente PI P-888.90 PIC255** piezo, a good representative of the kind of ceramic to be used in active tuner at cryogenic temperatures
  - **Liquid N2** temperature
  - A **screw + spring + rod** exerts the preload on piezo
  - **Sinusoidal** driving signal to piezo

Basic layout of test:

Start	**26 Nov 2004**
Stop	**20 Dic 2004**
Hours	**622**
Cycles	**1.505 10^9**
Frequency	**117 Hz** for **4 days**
	497 Hz for **6 days**
	997 Hz for **16 days**
Average preload	**1.25 kN**
Average Temp.	**80 K**

Results:

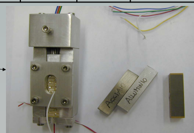
	Befor e	After
Capacity [μF]	13.6	13.6
Res. Freq [kHz]	45.9	45.2
Max stroke [μm]	40.2	38.3

Many piezo models from different manufacturers have been deeply characterized relating to their main extensive properties

The final choice fit all the requirements

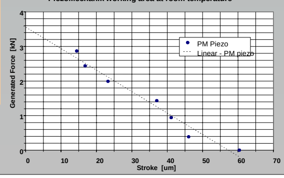
PROPERTIES	Unit	Noliac	Noliac	Epcos	PI	Noliac	Piezomechanik
Room Temperature		SCMA/S1/A/10/10/40/200/60/4000	SCMA/S2/A/10/10/42/200/60/4000	LN 01/8002	P-888.90	SCMAS/S1/A/10/10/30/200/42/6000	Pst 150/10
material		medium soft doped PZT-S1	medium soft doped PZT-S2	PZT-nd34	PZT-PIC 255	medium soft doped PZT-S1	
case/preload		no	no	no	no	no	Yes / 400N
length	mm	40 ± 0,5	42 ± 0,5	30	36	30 ± 0,5	64
cross section	mm²	(10 x 10) ± 0,2	(10 x 10) ± 0,2	6,8 x 6,8	10 x 10	(10 x 10) ± 0,2	
stiffness	kN/μm	0,1125	0,112	0.083	0.105	0.15	0.035
max. stroke	μm	60 ± 9	60 ± 9	40	35 ± 3,5	42 ± 6,3	80
blocking force (open loop)	N					6000	3500
blocking force (closed loop)	N	4000 ± 800	4000 ± 800	3200	3600 ± 720	4000 ± 800	
max. load	N	12000	12000		10000	12000	
res.frequency @ no load	kHz	38	36	52	40	51	
max. voltage	V	200	200	160	120	200	150
capacity: nominal	μF	8	14	2.1	12.4	5.7	
measured	μF	8.3		2.5	13.6	6.2	
Thermal Expansion	Ppm/K	-2.5				-2.5	

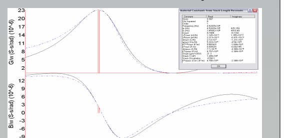
Some other piezo properties are currently under investigation:
- Piezo thermal shrinking
- Blocking Force vs. Stroke curve at 77 K
- Calibration of main parameters in order to use the piezo as force sensor at cryogenic temperatures



Device for the measurement of the thermal shrinkage

PiezoMechanik working area at room temperature

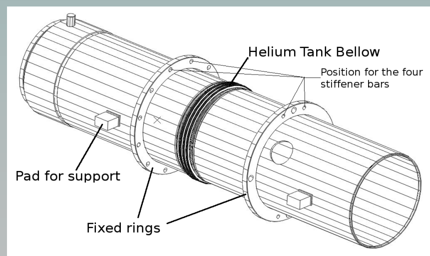




Example of impedance spectrum interpolation. Impedance is plotted as the spectrum of real and complex part of admittance over frequency.

Compatibility with CRY-3

Two rings are welded to the helium tank. The blade tuner is fixed to one of them by means of twelve bolts, while the other ring can receive up to four piezo actuators. Ad-hoc devices have been designed so that piezos of different section and length up to 72 mm can be accommodated.

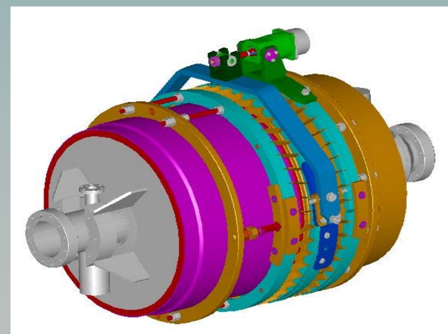


Because the tuner is fixed to the helium tank, a bellow is needed between the two fixed rings. The number of convolution has been computed in order to avoid any non-elastic strain in the bellow for a maximum axial displacement of 1.8 mm.

The position of pad supports has been reviewed in order to minimize the bending forces on the helium tank bellow and, of course, on piezo elements.

Four rigid bars have been foreseen between the blade tuner and the ring that receive the piezo actuators in order to stiffen the assembly during transportation. The same bars can be used as safety device in case of piezo breakage.

Adaption to low beta elliptical structures



In the context of the HIPPI subproject of the CARE program, our group is going to equip two low beta (0.47) 700 MHz elliptical cavities for high power pulsed measurements in CRYHOLAB at CEA/Saclay, to verify the feasibility of LFD compensation of these structures. The cavities have been tested in CW conditions up to 17 MV/m. The test of these structures under pulsed operation is particularly significant for the feasibility studies of superconducting high power proton drivers. A scaling of the coaxial tuner has been performed and the construction of the tuner prototypes for the HIPPI program is foreseen in late 2006

SRF 2005 - 12th International workshop on RF Superconductivity – New York – USA - July 10-15, 2005