COLD TUNING SYSTEM DEDICATED TO 700 MHZ SUPERCONDUCTING ELLIPTICAL CAVITY FOR PROTONS LINAC

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Abstract

A first prototype of a slow cold tuning system have been developed for SRF 700 MHz (β= 0.65) cavity dedicated to high intensity protons linac. This tuner, which is based on the CEA "Soleil" type tuning system, has been tested at cryogenic temperatures in the "CRYHOLAB" test facility. The first experimental results show a good mechanical behaviour and should be completed with long term tests. In parallel, a piezo-tuner is under study: it will be equipped with piezoelectric actuators for fast tuning purpose (Dynamic compensation of Lorentz forces effect, microphonics…). Full characterizations of piezoelectric actuators from various firms were performed at low temperature in order to measure the electromechanical parameters (stroke, dielectric, thermal and mechanical properties) needed for the mechanical design and optimization of the fast tuner.

COLD TUNING SYSTEM

The Cold Tuning System (CTS) developed for a superconducting 700 MHz elliptical cavity, dedicated to CW high power protons linac, is based on the CEA system developed for the "Soleil" cavities. It consists of a mechanical system driven by a cold stepping motor (Fig.1) and moto-reductor (PHYTRON®) with a resolution of 8.10^4 microsteps per turn. This CTS includes a ball screw with a step of 2.5 mm and a double lever arm mechanism with a ratio of 10. The tuning stroke design target at T= 4.2 K is ~ 2 mm: the cavity is deformed in only one longitudinal direction (e.g. cavity under tension or compression). This nominal stroke corresponds to a tuning range in terms of frequency Δf=500 kHz. Moreover, standard ball bearings are used for all the hinges of the mechanisms. The main design parameters of the CTS are illustrated in Table 1.

Table 1: CTS mechanical parameters

Tuning sens. (kHz/mm)	Cavity stifness (N/mm)	Tank stifness (N/mm)	CTS stifness (N/mm)	Resol. (nm)	Resol. (Hz)
250	1600	55000	15000	1.37	0.34

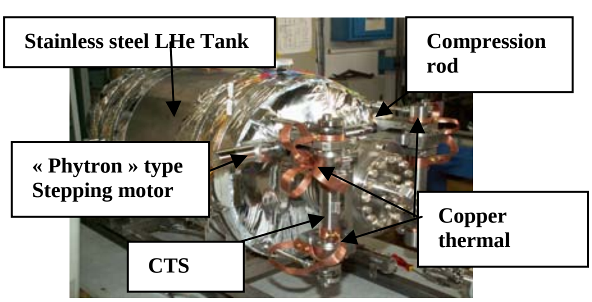

Figure 1: 700 MHz cavity and its CTS.

The CTS was attached to a β= 0.65 SRF elliptical bulk niobium 700 MHz cavity equipped with a stainless steel helium tank and tested in the "CryHoLab" test facility.

For this test, the CTS was attached to the cavity beam tube flange on one side and left free at the helium tank connexion on the other side. A preload force corresponding to a cavity elongation of 0.3 mm was applied at T= 300 K. Due to the atmospheric pressure load on the cavity, the CTS remains in compression during cool down at T= 4.2 K despite the differential thermal contraction between stainless steel and Niobium. Copper thermal anchors were attached to the system in order to reduce the temperature gradient of the ball bearing assemblies during cool down. Several thermometers mounted on different parts of the system show a maximum temperature difference of ~50 K during cool down from 300 K to 4.2 K.

During the test, the measured resonant frequency f of the cavity was very instable and showed oscillations of the order of +/- 500 Hz, which limited the precision of the measurements. Several up (increasing f) and down cycles (decreasing f) were performed with strokes ranging from 2 µm to 0.5 mm.

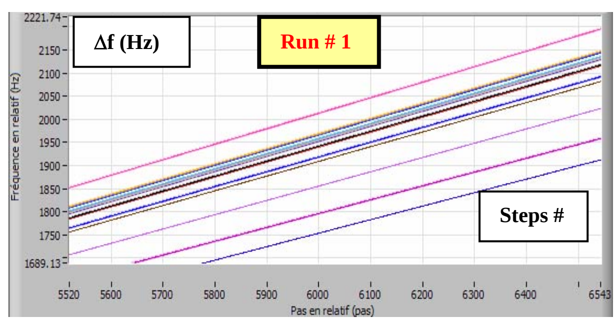

Figure 2a: Frequency shift versus motor steps (Zoom).

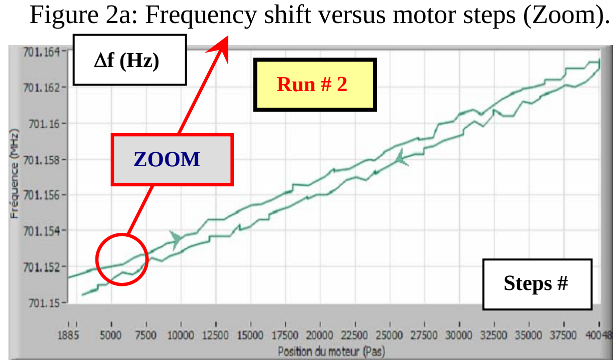

Figure 2b: Frequency shift versus motor steps.

The data (Figure 2a) show a good linearity of the cavity frequency shift (Δf) versus motor steps characteristics. The mean value of the slope of Δf vs. steps curves for several cycles is 0.33 Hz/step and this figure is very close to the theoretical value which is 0.34 Hz/step. Note that the CTS tuning characteristics is reproducible: neither the stroke range nor the history changes the slope. Moreover, the data (Fig. 2b) show a hysteretic behaviour: the width of the hysteresis is ~ 1kHz. These values were also measured during the tests at room temperature for different mechanical loads applied to the CTS. The causes of this loss of zero (e.g. loss of steps on the stepping motor, backlash…) are still under investigations.

PIEZO TUNER DESIGN

Conceptual design

The study of the integration of a piezoelectric actuator on the CTS is in progress. Due to the small stroke of the piezoelectric stacks at 4 K (1.8 µm -3.5µm), the foreseen solution is to amplify this stroke by mean of lever arms. A first conceptual design is shown Figure 3.

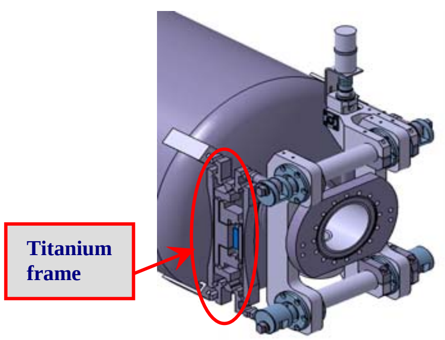

Figure 3: Piezoelectric tuner.

The actuator is supported by a titanium frame that featuring three lever arms. This frame is placed between the helium tank and the CTS: it will replace the compression rods of the initial CTS. Firsts FEM simulations show an increase of the cavity stroke (Fig. 4).

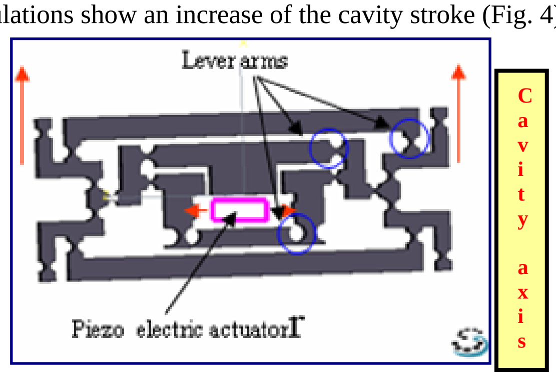

Figure 4: Mechanical support for amplifying the displacement of the piezoelectric actuator.

More precisely, in the case presented here, the horizontal displacement of the actuator is amplified by a factor 3 in the cavity longitudinal direction (vertical direction in Fig. 4). Simulations are in progress and the system will be optimized, according to the following main design constraints and criteria:

a) Load on the piezoelectric actuator during tuning and transient steps (pressure loads, thermal contractions…) by adjusting the lever arms ratios.
b) Adjustable preloading device integrated in CTS.
c) The actuator tuning range by adjusting the lever arms ratio and/or heat the piezostacks in order to increase its stroke.
d) Increase the stiffness of the plate the cavity longitudinal direction by adjusting the hinges flexibility and beam stiffness, or by adding parallel springs.

Piezoelectric actuator requirements

The general operating conditions are:

1- Operating temperature 2 K- 70 K in insulation vacuum, no liquid helium cooling and weak thermal coupling to Liquid Helium (Lhe) vessel.
2- Vacuum (10^{-7} to 10^{-5} mBar).
3- Helium partial pressure up to 10^{-4}.
4- Condensing water possible during warm up of the cryomodule.
3- No tensile, shearing or tilting forces.

The main requirements are illustrated in Table 2.

Table 2: Main requirements of the actuator

Parameter	Requirements
Life-time (Cycles)	10^{10} cycles
Stroke (at T=2 K)	3 µm @ 2 K
Blocking Force	>3.5 kN
Compression Preload	1 kN
Young Modulus	45 GPa
Cross-Section	10x10 mm^2
Length	30- 40 mm
Control speed	1µm/100µs
Inductivity	<10 mH
Maximum current	20 A
Maximum voltage	120 V –200 V
Maximum rate of current change	10^4 A/s
Minimum rate of voltage change	1 V/µs

CHARACTERIZATION RESULTS OF PIEZOELECTRIC ACTUATORS AT CRYOGENIC TEMPERATURE

A dedicated facility was designed and successfully used for the characterization of piezostacks at low temperature: the experimental details, measurements method and the first results were presented previously [1-2]. The actuators tested, are low voltage PZT (Lead Zirconate Titanate) piezostacks from three different companies: Piezosystem JENA, NOLIAC, PICMA from PI. Several actuators of different production series from JENA were investigated [1]. These actuators, were rejected because five main drawbacks and limitations: a) maximum stroke much less than 3 µm at 2K, b) insufficient blocking force : ~1kN @ 300K, c) low mechanical stiffness: 25N/µm, d) lack of fabrication reproducibility from batch to batch, e) very short lifetime when operated at 2 K (electrical breakdown and/or mechanical damages).

PICMA actuators results

These new prototypes actuators from PI are not calibrated: we used the calibrated JENA actuators and the displacement sensor for the calibration of PICMA piezostacks and NOLIAC actuators [1-2]. The calibration consists of measuring the full range displacement ΔX versus temperature (Fig. 5).

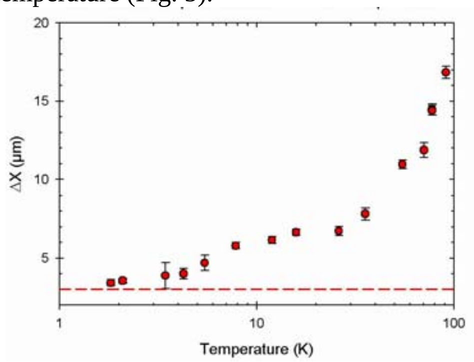

Figure 5: Variations of the full range (V_{max}=120 V) displacement with temperature (Actuator: PICMA#1).

The slope of ΔX vs. T curve decreases strongly with temperature: ΔX decreases by a factor of ~13 when T decreases from 300 K (ΔX=38µm) down to 2K (ΔX=3.5µm) and this result is in the range of values previously reported by other authors [3]. Moreover, the heating ΔT vs. modulation voltage amplitude V_{mod} and frequency is shown in 3D plot (Fig. 6). The observed heating (i.e $\Delta T = R_{th}.P_{diel}$, with R_{th}: thermal resistance) is well described by the well-known expression of the total dielectric losses P_{diel} (i.e. $\Delta T \propto P_{diel} \propto f.V_{mod}^2 \sin(\delta)$).

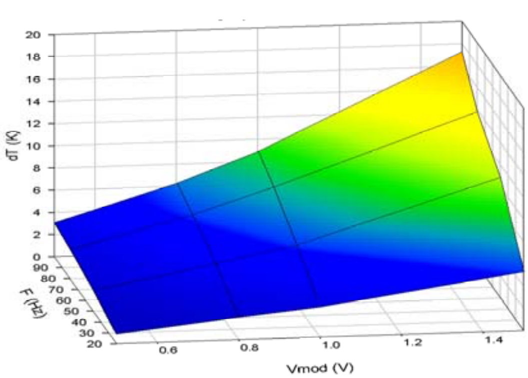

Figure 6: 3D plot of the dielectric heating ΔT vs. modulation voltage amplitude and frequency.

Note that the small departure from the quadratic dependence observed at high values V_{mod} and or f is attributed to nonlinear effect resulting from the dielectric constant ε_r and $\sin(\delta)$ which depend on T [1-2].

NOLIAC actuators results

The full range displacement versus T of a NOLIAC actuator is shown in Fig. 7: the shape of ΔX vs. T depends on the actuator material and fabrication process. For NOLIAC actuators, as compared to PICMA and JENA piezostacks, we did not observe any saturation effect at T= 2 K. For PICMA and NOLIAC actuators type, ΔX=2.7µm-3.5µm @1.8K leading to a theoretical detuning compensation $\Delta f \approx$1kHz for TESLA cavities.

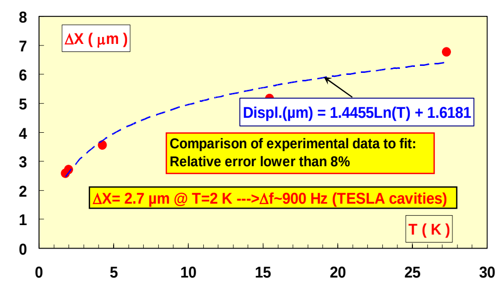

Figure 7: Variations of the full range (V_{max}=120 V) displacement with temperature (Actuator: NOLIAC#1).

Irradiations with fast neutrons at T~ 4 K

Furthermore, four PICMA and four NOLIAC actuators were subjected to irradiation tests (CERI institute) at T=4.2 K with a fast neutrons beam (Energy spectrum: 1-15MeV). A total dose of ~2.10^{15}n/cm^2 was achieved in 16 hours: neither damage nor anomalous behaviour [4] or performance degradation of these actuators was observed. Only capacitance C_p increase, which is probably due to a thermal effect (i.e. heating with neutrons) were observed.

ACKNOWLEDGEMENTS

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