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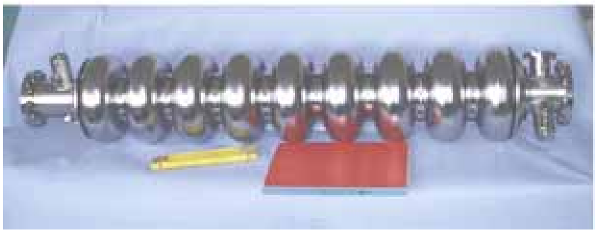

Integration of piezoelectric actuators in the piezotuner developed at Saclay

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Abstract

Two piezoelectric actuators PICMA #6 and PICMA #7 were prepared at IPN Orsay. These piezostacks, equipped with calibrated thermometers, were integrated (item #8.4.3 of WP8) in the new lateral PiezoTuning System (PTS) developed at Saclay. The fixture of the actuators, which is a critical part of the PTS, was carefully designed to fulfill two main requirements: 1) avoid shear forces and/or torsion forces to the actuator, 2) fit very precisely (e.g. ~10 µm tolerance in the longitudinal direction or axis of the piezostacks) into the PTS in order to avoid loss of mechanical contact during cool down to 2 K. In this report, we will describe the preparation procedure along with the dimensional measurements performed and thermometer calibration data. In the second section, we present the installation of the PTS into CRYHOLAB facility. Then the characterization results at cryogenic temperature (displacement, dielectric properties, preloading effect) are summarized. Finally, the experimental program of the scheduled tests with the SRF TESLA cavity #C45 in CRYHOLAB facility is described.

Preparation of the piezostacks

In the frame of CARE WP8, IPN Orsay had prepared two piezoelectric actuators PICMA 6 and PICMA 7 (Fig. 1) for their integration (item #8.4.3) in the new PiezoTuning System (PTS) developed at Saclay [1]. The fixture of the actuators is a critical part of the PTS so it was carefully designed to fulfil two main requirements: 1) avoid shear forces and/or torsion forces to the actuator, 2) fit very precisely (e.g. ~10 µm tolerance in the longitudinal direction or axis of the piezostacks) into the PTS in order to avoid loss of mechanical contact during cool down to 2 K. To fulfil the first requirement, a cone on sphere system is used: a) two hemispherical stainless steel pieces are glued at each extremity of the piezostacks (Bonding agent: epoxy STYCAST 2850FT), b) two stainless steel holders conically shaped are sandwiched between the actuator and the fixture. Note that a mechanical preloading to the actuator is needed in order to increase the life time for dynamic operation (i.e. pulsed mode of the accelerator). In the actual PTS, the cavity acting as a spring is used for preloading the piezostacks [1].

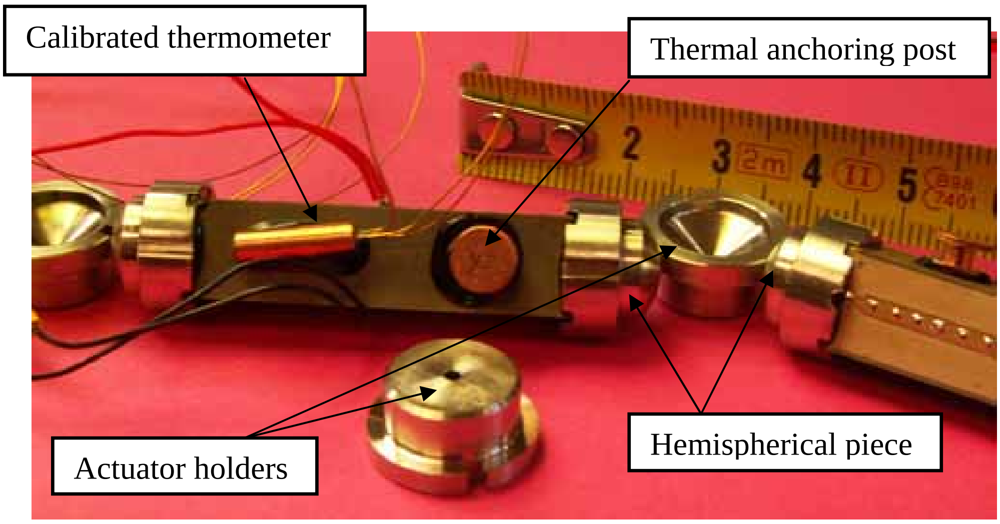

Fig. 1 : Piezoelectric actuators ready for integration into Saclay PTS

The overall lengths L of the actuators, including their holders (Fig. 2), were measured with a high precision by the company Gavard who fabricated these elements leading to the following values: L_6=51mm $_{-0}^{+5\mu m}$ and L_7=51mm $_{-0}^{+7\mu m}$ for the piezostacks PICMA6 and PICMA7 respectively.

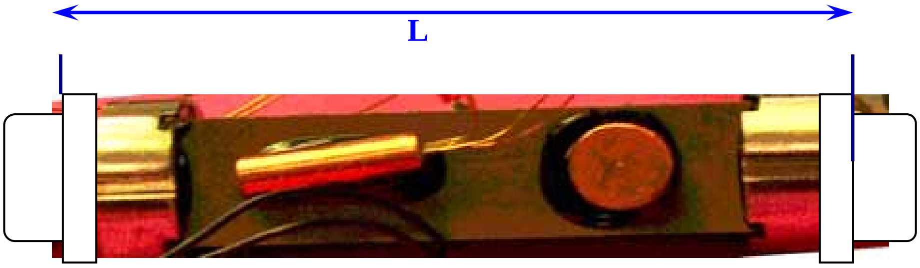

Fig. 2: Definition of the overall length L

Further, precise measurements were performed by Gavard company using micrometer and three-dimensional machine: the data are within the specifications illustrated in Table 1.

Specification	Measured
$15^{+0.2}$	15.11
7.5	7.5
Φ12g6	11.987
3.01	3.01
Φ11	11.02
4.7	4.69
60°	60°
1.7	1.72
$6.25^{-0.2}$	6.1
Φ1.5	1.52

Table 1: Comparison of the measured dimensions with the specifications

Moreover, each actuator is equipped with an Allen-Bradley thermometer (Table2) which was calibrated at IPN Orsay facility [2] (Fig. 2) in the temperature range 1.56 K-71 K.

Piezoelectric actuator	Thermometer
PICMA#6	CRT_AB_5038N17
PICMA#7	CRT_AB_5038N18

Table2: References of the calibrated thermometers

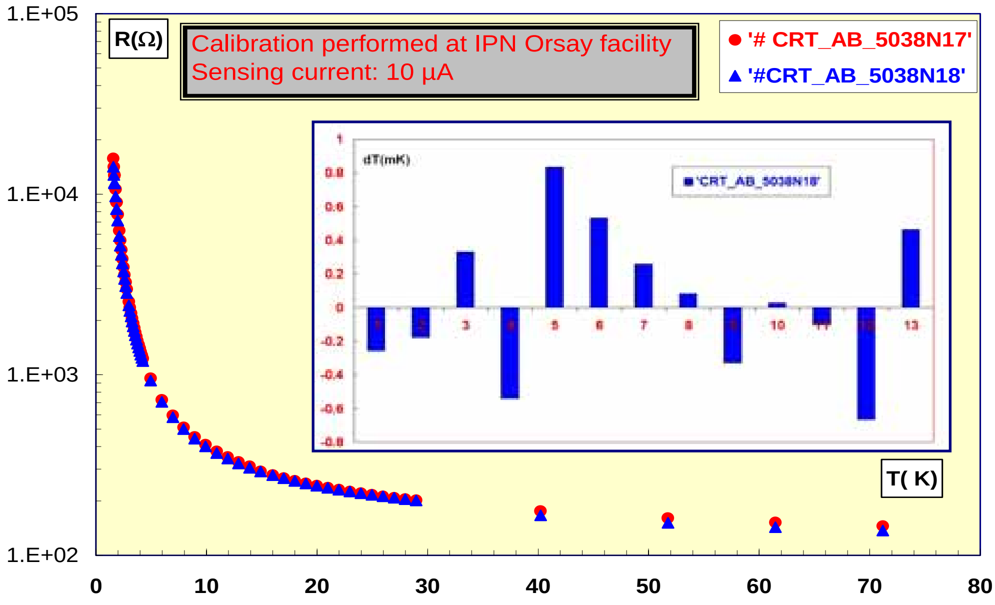

Fig. 2: Calibration curves and fit error histogram (insert) in superfluid helium region (1.56 K-2.1 K).

We performed the measurements of the electrical properties of the piezostacks before and after their integration into the PTS. These tests were done with a LCR meter at room temperature (T~300 K) and the results are shown in Table 3 (actuators free) and Table 4 (actuators in PTS). The observed differences (Cp, Rp and tg(δ)) are due to preloading.

Piezostacks	PICMA#6	PICMA#7
Capacitance (µF)	12.63	12.92
Parallel resistance (kΩ)	5.07	3.53
Loss tangent	$1.24\,10^{-2}$	$1.27\,10^{-2}$
Impedance module (Ω)	126.0	123.0
Impedance phase (°)	-87.56	-88.55

Table 3: Electrical properties of actuators before integration in PTS (T~300K, sensing voltage: amplitude =1 V amplitude, frequency =100Hz, four wires method)

Piezostacks	PICMA#6	PICMA#7
Capacitance: Cp (µF)	12.58	12.87
Parallel resistance: Rp (kΩ)	3.41	3.53
Loss tangent: tg(δ)	$1.85\,10^{-2}$	$1.95\,10^{-2}$
Impedance module (Ω)	126.4	123.6
Impedance phase (°)	-87.88	-88.10

Table 4: Electrical properties of actuators after integration in PTS (T~300K, sensing voltage: 1 V amplitude, frequency : 100Hz, two wires)

Installation on the cavity in CRYHOLAB

The actuators were integrated into the PTS then the assembly was mounted on the cavity C45 and installed in CRYHOLAB test facility (Fig. 3-Fig. 4). The whole device is now ready for cryogenic tests which started on April 11, 2006.

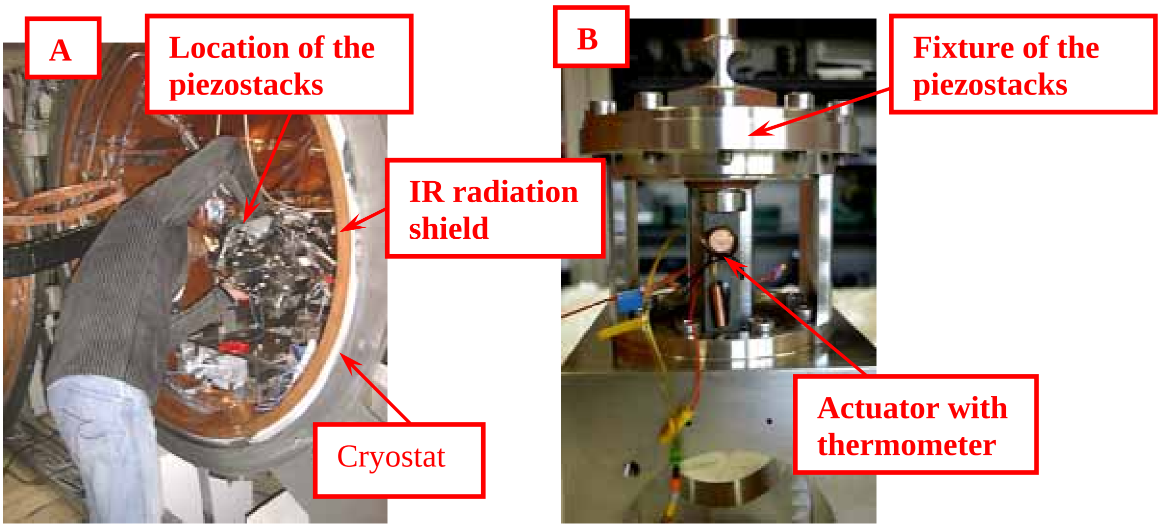

Fig. 3: A) Mounting the PTS in CRYHOLAB, B) close view to the fixture of actuators for integration in the tuner.

Electromechanical properties of PICMA and NOLIAC piezostacks at cryogenic temperature

The electromechanical properties of two actuators (PICMA and NOLIAC) were measured as function of the temperature at IPN Orsay [3-5] piezostacks characterization facility: the corresponding data are presented in Fig. 4-Fig. 6.

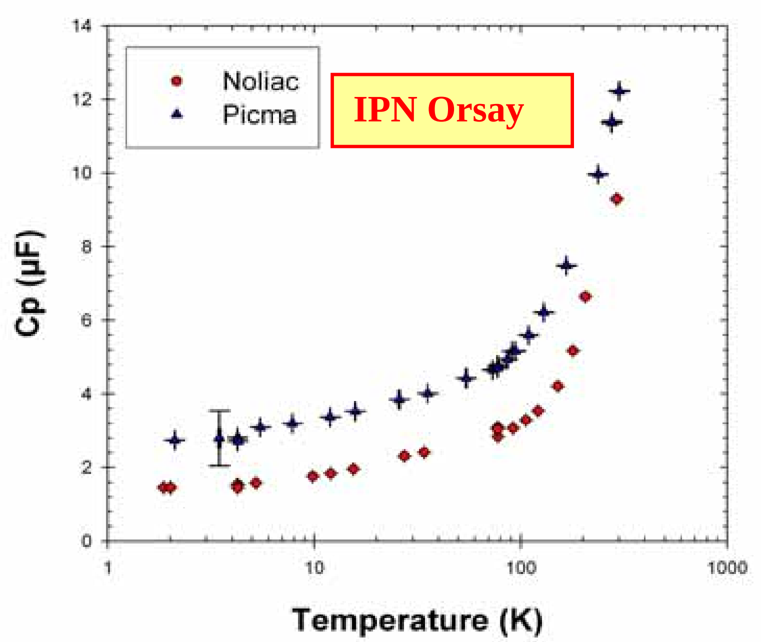

Fig. 4: Capacitance versus temperature for actuators PICMA#1 and NOLIAC#1 .

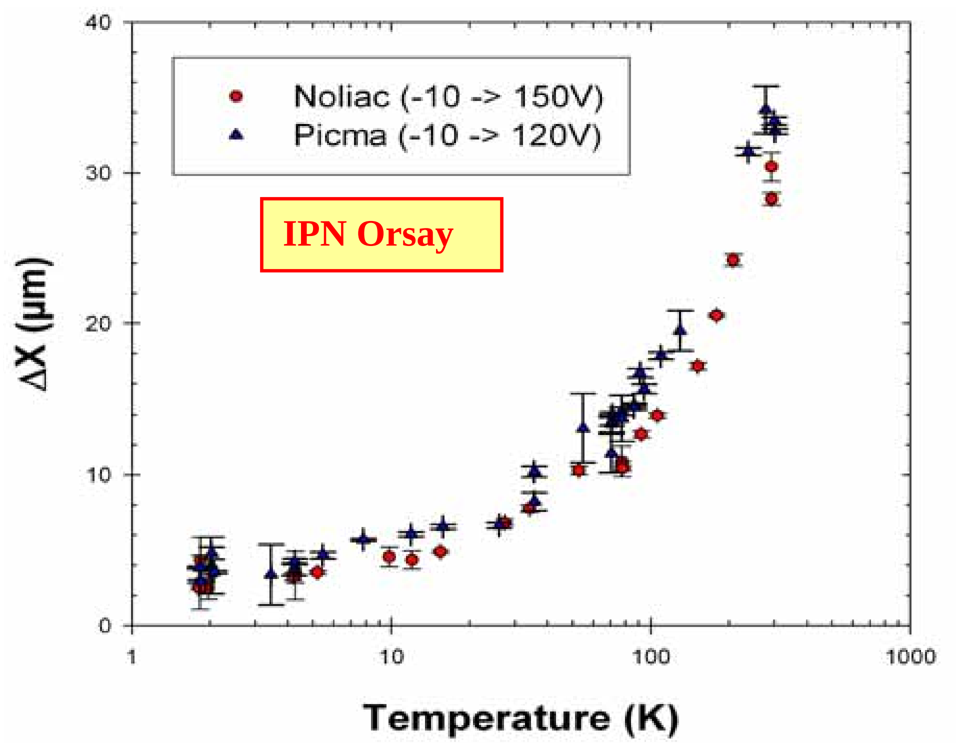

Fig. 5: Full range displacement versus temperature for actuators PICMA#1 and NOLIAC#1.

The measured full range displacement is close to ~3 µm at T=2K. This displacement of 3 µm will allow the compensation of a Lorentz detuning Δf=1 kHz, which is the target for a TESLA nine cells cavity resonating at the fundamental mode frequency f_0=1300 MHz. Note that the actuators PICMA#6 and PICMA#7 were not characterized at cryogenic temperatures. Consequently, the data of Fig. 4-Fig. 6 obtained [5] with the piezostacks PICMA#1 and NOLIAC#1 will be used to estimate their properties and performance.

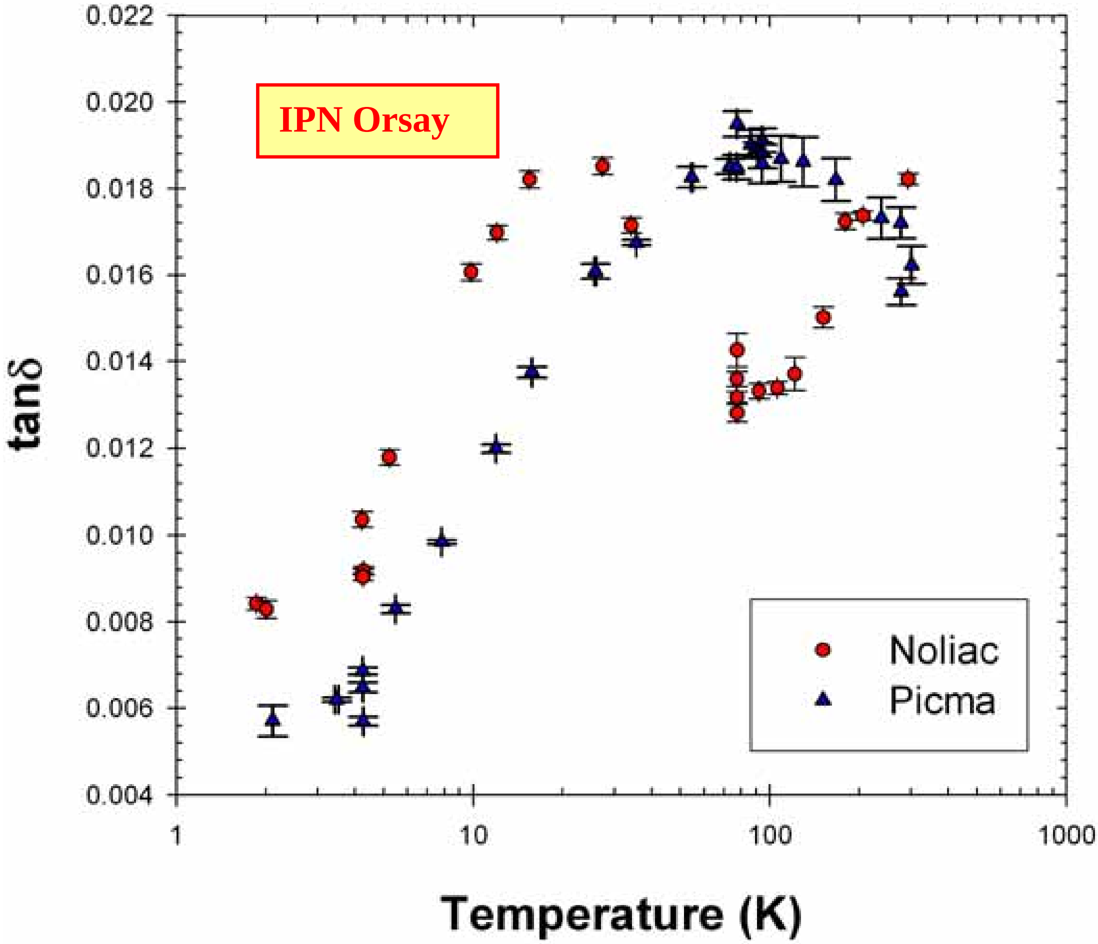

Fig. 6: Loss factor versus temperature for actuators PICMA#1 and NOLIAC #1.

Typical values of the piezostacks properties measured at the cavity operating temperature T=2K are listed in Table 5.

Parameter: name (unit)	PICMA	NOLIAC
Capacitance: Cp (µF)	2.74	1.46
Parallel resistance: Rp (kΩ)	105	132
Impedance module (Ω)	581	1090
Impedance phase (°)	-89.7	-89.5
Loss tangent: tg(δ)	$2.85\ 10^{-3}$	$4.15\ 10^{-3}$
Rp.Cp (ms)	286	193
Displacement: ΔX(µm) @Vmax	3 @120V	3@150V

Table 5: Typical values of electromechanical properties of piezostacks measured at T=2 K

Dynamic properties of PICMA piezostacks at cryogenic temperature and preloading effect

Moreover, the sensitivity of PICMA piezostacks to a preloading axial force was investigated and the corresponding results are reported and discussed thoroughly [6-8]. The variations of the piezostacks relative capacitance $\Delta Cp = Cp - Cp_0$ (Cp_0: capacitance at zero preload (F=0)) as function of the preloading force F at T= 2 K is shown in Fig. 7. Non linear effects are observed at low preloading force when F is increased from zero: they are due to friction, stick-slip among non linear phenomena in the preloading device mechanism (rotating arm, bellows,…). Further, these data clearly show a large hysteresis for increasing and decreasing the preloading force. This behavior could be attributed to the intrinsic irreversibilities in the piezoelectric material itself.

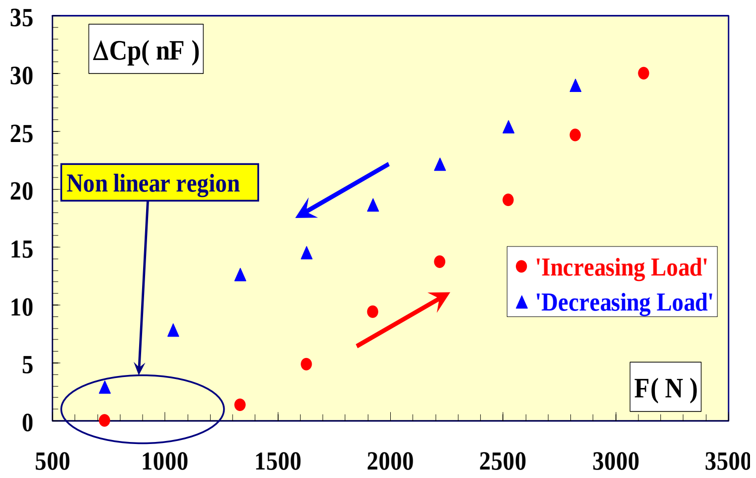

Fig. 7: Capacitance versus preload at T=2.05 K

At T= 2K, the measured sensitivity to preloading are 16nF/kN (respectively 10nF/kN) for F increasing (respectively decreasing).

The behavior of the piezostacks as dynamic force sensor was also studied at different cryogenic temperatures [6-7.. More precisely, we recorded the transient response of a PICMA actuator to a steep preload variation (Fig. 8).

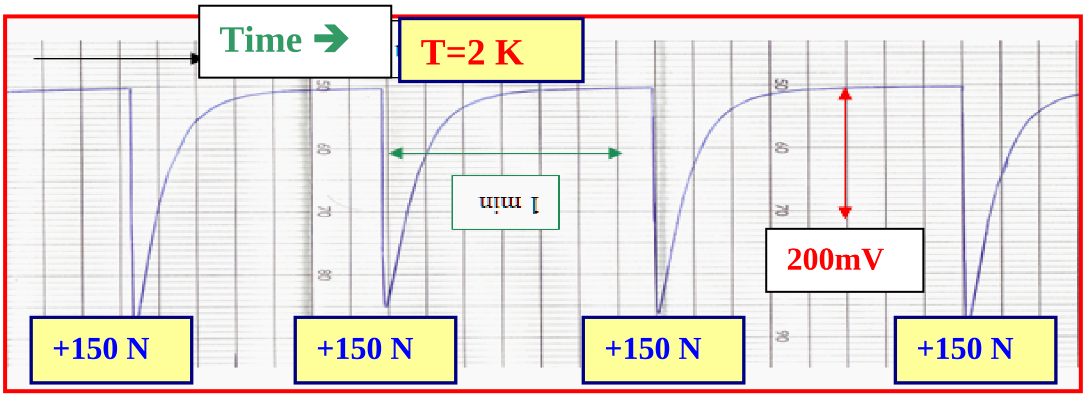

Fig. 8: Transient response of a PICMA type actuator to a steep preload variation ΔF=150 N at T= 2 K.

The results call for several comments:

1) The response (i.e. Voltage vs. time) of the piezostacks to a steep preload variation ΔF is exponential (charging of a capacitor).

2) The peak actuator voltage ΔV_p during this transient response is reproducible (i.e. standard deviation =3 %).

3) The peak voltage is proportional to the preload variation (i.e. $\Delta V_p \propto \Delta F$).

4) The phenomena is reversible (the sign of ΔV_p change with that of ΔF).

5) The actuator is a very sensitive dynamic force sensor.

6) The peak voltage is decreases strongly with the temperature: $\Delta V_p/\Delta F$=4.7V/kN at T=2K and $\Delta V_p/\Delta F$=21.4V/kN at T=4.2K)

Description of the experiments

In order to investigate the electro-acoustic behavior of the TESLA type cavity #C45 and measure the performance of the PTS developed at Saclay with PICMA actuators, the following tests in CRYHOLAB are planned for three weeks (10-27 April 2006):

1) Measurements of the transfer functions,
2) Study of the mechanical modes of the cavity including quality factors,
3) Study Lorentz detuning and detuning compensation with PTS,
4) Measurements of the actuators response to the applied preloading force;

The block diagram of the transfer function experiment is shown in Fig. 9. The test consists of measuring the amplitude and phase of the transmitted RF signal (through the mixer) as function of the frequency of the mechanical vibration of the structure generated by the piezoelectric actuator. The measurements were already performed at Room Temperature (R.T) on the cavity #C45with its Lhe tank. The experimental data will be presented and discussed in a separate report.

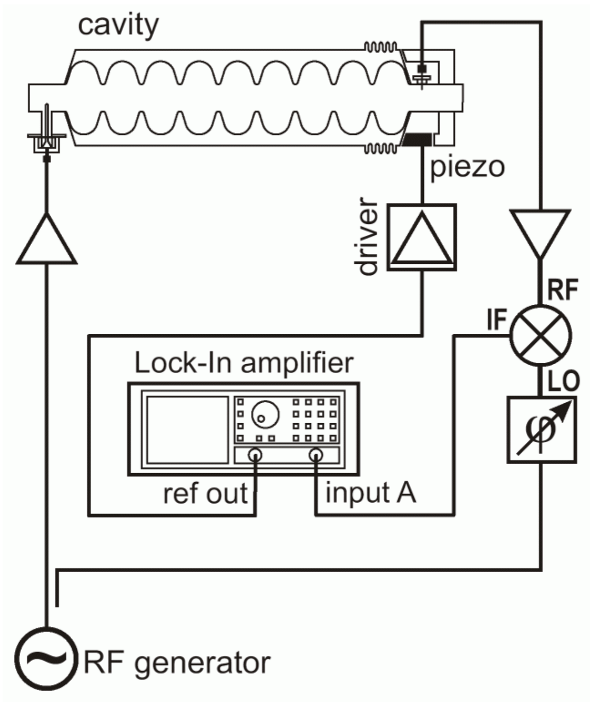

Fig. 9 :Block diagram of the experimental set-up

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