

LOW TEMPERATURE PROPERTIES OF PIEZOELECTRIC ACTUATORS USED IN SRF CAVITIES COLD TUNING SYSTEMS

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Abstract

High accelerating gradients (10MV/m for SNS, 33MV/m for ILC) at which SRF cavities will be operated in pulsed machines induce frequency shift much higher than the resonator bandwidth. This so-called Lorentz detuning should be compensated dynamically by means of an active piezo-tuning system. In the frame of the CARE project activities supported by EU, IPN Orsay participates to the development of a fast cold tuning system based on piezoelectric technology for SRF cavities operating at temperature $T=2K$. The aim of this study is the full characterization of piezoelectric actuators at low temperature including dielectric properties (capacitance, impedance, dielectric losses), radiation hardness tests (tolerance to fast neutrons), mechanical measurements (maximum displacement, maximum stroke) and thermal properties (heating, heat capacity). Results obtained in the temperature range from 2K up to 300K will be presented and discussed.

INTRODUCTION

High surface electromagnetic fields in SRF cavities induce mechanical deformations of the cavity wall ($\sim\mu\text{m}$) leading to a frequency detuning Δf_L of the same order of magnitude as the cavity bandwidth. This phenomenon is important for SRF cavities operating in pulsed mode. This so-called Lorentz detuning depends in quadratic way on the accelerating field E_{acc} . Moreover, this detuning, if not compensated, results in an additional RF power consumption. The corresponding Lorentz detuning factor for TESLA cavities $K_L (\sim 1\text{-}2\text{Hz}/(\text{MV}/\text{m})^2)$ leads to a detuning of hundred hertz ($\Delta f = -K_L E_{\text{acc}}^2$). It has been shown on TESLA cavities [1] that piezoelectric actuators encapsulated in a cold tuning system allows compensation of the Lorentz detuning. IPN Orsay participates on the development of cold piezo-tuning system for high intensity proton linacs SRF cavities. This paper summarizes systematic measurements performed at low temperature (1.8-300K) to provide full characterization of two types of piezoelectric actuators in the environment of SRF cavities.

BEHAVIOUR AT LOW TEMPERATURE

Dielectric Properties

Experimental setup and test procedure have been presented in previous papers [2] and allow systematic measurements in the temperature range from 1.8 up to

300K. Actuators tested are PZT piezostacks (Lead Zirconate Titanate) from Physik Instrument and Noliac companies. Dielectric properties consist of measuring with LCR meter capacitance C_p , resistance R_p and loss tangent $\tan(\delta)$ as function of temperature (fig.1).

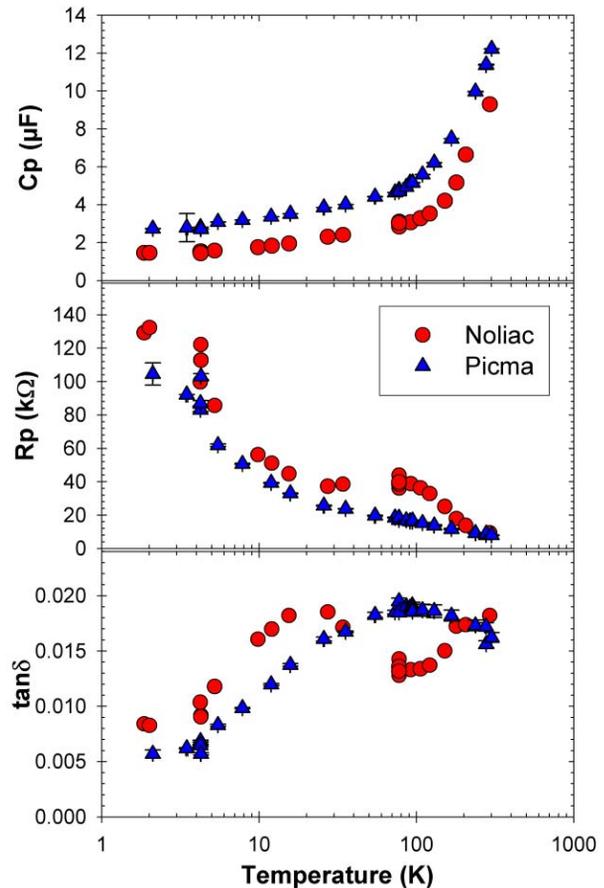


Figure 1: Dielectric properties versus temperature. Red Circle: Noliac; blue triangle: Picma.

These data show a strong monotonic decrease of the capacitance with the temperature. In contrast the loss factor of both tested actuators show a maximum respectively at $T \approx 20\text{K}$ (Noliac) and $T \approx 90\text{K}$ (Picma). This behaviour could be attributed to the piezo material and fabrication process which is supplier dependent.

Dynamical Properties

To measure the maximum displacement ΔX of the actuators, a Jena amplifier was used and provides excitation voltage in the range from -10V up to 150V. The maximum voltages supported by actuators are respectively 120V for Picma and 200V for Noliac. Notice that for Noliac the maximum applied voltage (150V) is

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much lower than the maximum operating voltage. The data presented on figure 2 show a strong decrease of ΔX with the actuators temperature. This behaviour is usually observed [3] and it should be stressed that ΔX vs T curves are very similar to C_p vs T data. Obviously C_p and ΔX are tightly correlated [2].

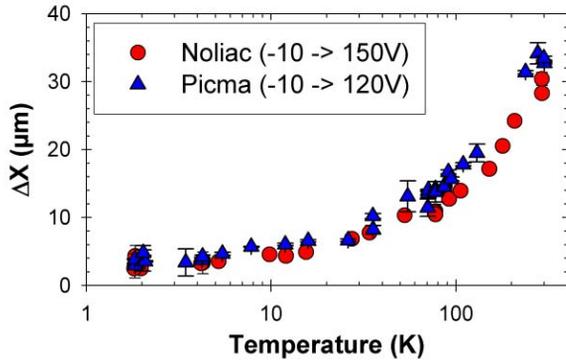


Figure 2: maximum displacement versus temperature. Red circle: Noliac; Blue triangle: Picma.

As active tuning systems will be used in pulsed machines, effect of voltage modulation has to be studied. A sine signal is applied to the actuators and temperature is recorded as function of time. Typical data are presented on figure 3 as function of amplitude V_{mod} and frequency f_{mod} of the signal. The dielectric heating ΔT is proportional to the dielectric power P_{diel} according to the relation $\Delta T = R_{th} \cdot P_{diel}$ where R_{th} is the thermal resistance measured by the method presented in a previous paper [2]. P_{diel} is given by the well-known relationship $P_{diel} = \pi C_p f V^2 \sin \delta$.

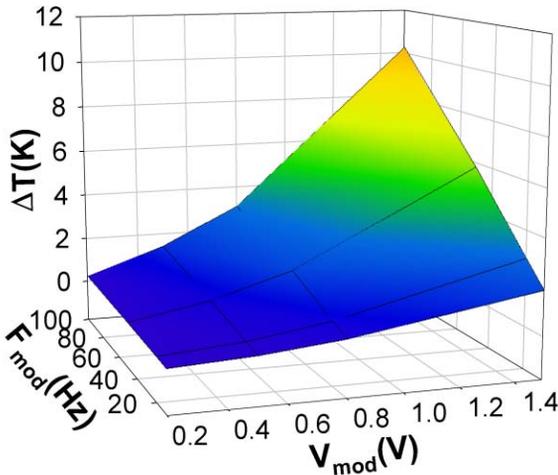


Figure 3: temperature elevation as function of frequency and voltage of sine signal for noliac at $T_{bath} = 1.8K$.

These data show clearly a heating ΔT proportional to f_{mod} and a quadratic dependence on V_{mod} .

RADIATION HARDNESS TEST WITH FAST NEUTRONS

Experimental Set-Up

In the frame of CARE project, an experimental program aimed at investigating the effect of fast neutron on piezoelectric actuator after an exposure equivalent to the dose received after 20 years in the environment of TESLA SRF cavities (10^{12} neutrons/cm²). Experiments were performed at CERI cyclotron located at Orléans (France) using its neutrons irradiation facility. The setup is based on the cryostat developed at IPN Orsay already used to study various cryogenic sensors for LHC by J. Collot et al. [4]. The cyclotron delivers a deuteron beam (25MeV, 35μA) on a thin (3mm) water-cooled Beryllium target to produce fast neutrons using the break-up reaction ${}^9\text{Be}(d, n){}^{10}\text{B}$. The advantage of this method is to produce low gamma contamination (~20%). A total integrated dose more than 10^{14} n/cm² is achieved in 20 hours of exposure.

New aluminium made insert was developed for actuator irradiations tests to reproduce conditions similar to insulation vacuum of the cryomodule. More precisely actuators are not directly cooled by liquid helium but only by conduction through a supporting frame immersed in Helium bath ($T = 4.2K$). Four actuators equipped with Allen Bradley sensors are mounted in chamber.

Neutron yield was measured with the activation reaction ${}^{58}\text{Ni}(n,p){}^{58}\text{Co}$ on high purity nickel foils mounted all around the actuators. By counting the gamma activity from ${}^{58}\text{Co}$ at 810 keV in a Ge-Li detector, the effective neutron dose is measured with a standard deviation less than 25% (fig. 4). Dielectric properties are first measured in the test cell without beam prior to radiation tests. Then, the deuteron beam is thrown on the Be target by increasing progressively the current from 1 to 35 μA. During all radiation tests, dielectric properties are on-line measured as well as the beam parameters. It should be stressed that due to heating by neutrons beam, some parameters (e.g. C_p) increases with beam intensity. The final dielectric properties measured after neutron exposure, are compared to the values before radiation.

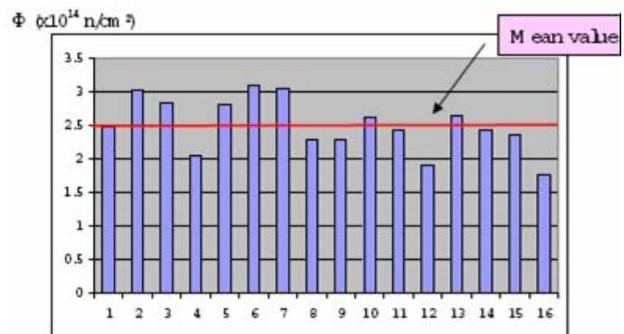


Figure 4: neutron dose distribution measured by nickel foil all around Picma actuators.

Results and Discussion

Values of dielectric properties for Picma2 and Noliac2 before neutrons exposure are presented in table 1.

Table 1: Initial dielectric measurements.

	T(K)	Cp(μ F)	Rp (k Ω)	Tan δ
Picma2	4.436 \pm 1e-3	2.7440 \pm 1e-4	100.9 \pm 0.2	5.75e-3 \pm 1e-5
Noliac2	5.143 \pm 2e-3	1.5383 \pm 3e-4	103.9 \pm 1.9	1.00e-2 \pm 2e-4

Dielectric parameters after stopping radiation and waiting cool-down of the actuators are compared to initial values to measure the relative deviation. The errors bars are calculated by considering the shift of Allen Bradley thermometers which have been measured in the past [4]. This uncertainty is used with previous data presented in the first part.

Results on Picma and Noliac show that capacitance due to irradiation decreases but not in a significant way according to the error bars. The radiation effects are more pronounced on R_p. In fact, this parameter presents a decrease of few percents as compared to initial value and could be attributed to a slight degradation of the actuators. Similar effects are shown concerning the dielectric losses.

Finally, the experimental data show that no irreversible damage (e.g. leakage) is observed for neutron dose equivalent to 20 years of machine operation. Moreover as the maximum displacement is correlated to capacitance one could expect that actuators performances should not be degraded (e.g. maximum displacement). But the slight modification of R_p as tan δ induced by neutrons radiation could enhance dielectric losses.

CONCLUSION

These experimental results show that both actuators fulfil the ILC requirements. Maximum displacement at 1.8K is higher than 3 μ m equivalent to $\Delta f \sim 900$ Hz and the linear dependence between C_p and ΔX (T \leq 100K) is a useful way for displacement calibration. Picma and Noliac actuators present no major damage after exposition under high neutron yield. Finally, the choice of a type of actuator will depend on the design of the fast active tuning system. All data presented allow simulating the behaviour of actuators and SRF cavities used on future machines.

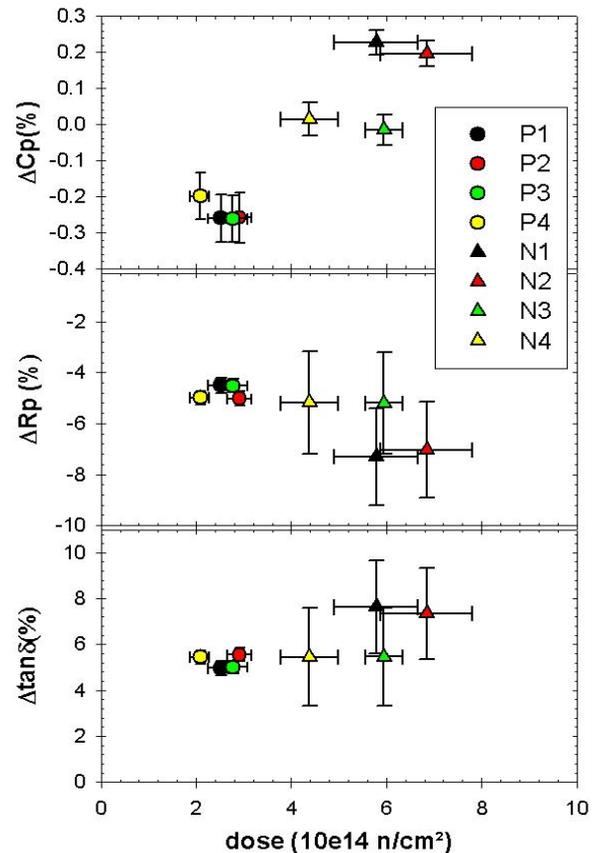


Figure 5: relative variation of the capacitance, resistance and loss tangent as function of neutron dose for Picma (P, circle) and Noliac (N, triangle) actuators.

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