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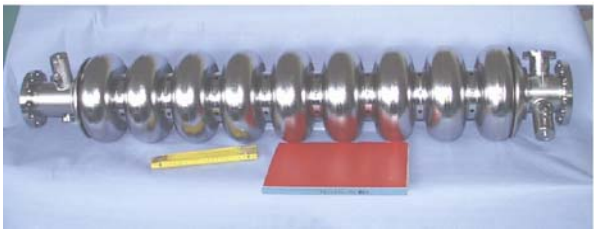

STATIC ABSOLUTE FORCE MEASUREMENT FOR PRELOADED PIEZOELEMENTS USED FOR ACTIVE LORENTZ FORCE DETUNING SYSTEM

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Abstract

To reach high gradients in pulsed operation of superconducting (SC) cavities an active Lorentz force detuning compensation system is needed. For this system a piezoelement can be used as an actuator (other option is a magnetostrictive device). To guarantee the demanded lifetime of the active element, the proper preload force adjustment is necessary. To determine this parameter an absolute force sensor is needed which will be able to operate at cryogenic temperatures. Currently, there is no calibrated commercial available sensor, which will be able to measure the static force in such an environment. The authors propose to use a discovered phenomenon to estimate the preload force applied to the piezoelement. The principle of the proposed solution based on a shape of impedance curve, which changes with the value of applied force. Especially, the position of resonances are monitored. No need of specialized force sensor and measurement in-situ are additional advantages of proposed method.

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INTRODUCTION

For the X-Ray Free Electron Laser (XFEL) and for the TeV Superconducting Linear Collider (TESLA) a tuning system is developed. Its main goal is to keep the internal resonance frequency of the cavity constant. Perturbations in cavity shape have two main sources. One of them is a microphonics and another is a Lorentz force [1÷3].

One tuning system was designed to compensate both effects. Moreover, it is integrated with the existing step motor system, used for cavity pretuning [1]. The tuning system consists of the frame in which two piezo elements (PEs) are assembled. One of them works as a dynamic force sensor, while the second one as an actuator. PE devices are identical, hence there is possible to use them as a sensor or an actuator or use both as actuators.

The PEs must work during each pulse, thus the proper lifetime must be guaranteed. For ten years working period without any breakdown with repetition rate up to 20Hz more than 10^{10} cycles is foreseen. The PEs might reach such a lifetime, only if they are properly preloaded. From literature and manufacturers datasheets of piezostacks, one might conclude that the best preload is around a half of the blocking force. For our case the blocking force is 3kN, hence the preload should be set between 1,0kN and 1,5kN. Unfortunately, an access to PE is only possible during module assembly but mentioned preload ought to be reached at the cryogenic temperature (CT) - below 2K and low pressure (several mBars). The precise preload force adjustment becomes difficult task due to the complexity of system and the different thermal coefficient of expansion (TCE) of used materials. Also during changing the pressure additional forces appears. As a consequence it is very hard to calculate or estimate the preload force change during cooling down and pumping. Even if a proper approximation will be done, there is need to verify the result. Therefore an absolute force measurement is needed. Currently, a commercial-use absolute force sensor for temperature below 10K does not exist.

The authors propose to use one of two observed effect caused by applied force: either a capacitance change of PE or a impedance resonances shift of the PE. The detailed information about performed experiment is presented in following chapters.

Currently, five types of PEs are investigated in three institutes (DESY, INFN, IN2P3). The devices come from five different manufacturers: EPCOS (PZT/Nd34), PI Ceramics (PICMA), PiezoMechanik (PSt150/10/60), NOLIAC (Pz27 and Pz29) and Piezo JENA (#9222). The EPCOS PE has been tested for 2 years; the others are quite new ones. As a consequence this publication will focus mainly on the EPCOS PE.

Four types of experiment were done. Firstly, the resonances were measured at room temperature (RT); secondly the characteristic of the PEs was investigated at CT. Then, the calibration was used to determine the preload force in real system in CHECHIA cryostat. At the end, the capacitance change due to the applied force at RT is presented.

ROOM TEMPERATURE EXPERIMENTS

The electrical impedance was first measured at RT, during PE classification. The impedance resonances were the parameters, which were investigated.

Each PE was characterized individually. It was assembled in series with a piezoresistive force sensor - model 8415-6002 from BURSTER Company. At the top of the fixture there was a screw to adjust the force applied to devices. The stiffness of the frame was more than 10 times higher than stiffness of PE.

The impedance was measured using a dynamic Signal Analyzer (SR785) for frequency range from 50Hz up to 100kHz.

According to the theory of piezoelectricity, a single resonance and anti-resonance pair should be observed. For multilayer piezoelectric (i.e. for NOLIAC) devices several such a pair was observed. Usually, there was two main resonances pairs which were investigated.

The frequency of resonances depends on boundary condition. When the PE is stressed the resonance is shifted to higher frequency values. A resonance frequency shift versus an applied force for EPCOS PE is shown in figure 1.

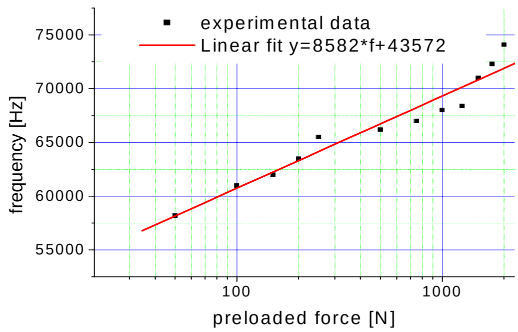

Figure 1: Resonance position frequency shift caused by applied force at RT.

The correlation between measurement points and the exponential approximation is over 0.97. Numerous run was performed to verify stability in time. The resulting spread is less than 2%. The impedance measurement was also performed for several PE from the same manufacturer line. The obtained statistics shows that PEs behaves in similar way (the value of resonance frequencies might vary from actuator to actuator by around 5%).

Encouraged by the preliminary tests at RT, the decision to perform similar experiment at CT has been made.

LOW TEMPERATURE EXPERIMENT

To perform impedance measurement at 4K for different PE preload, a dedicated cryostat was developed. A possibility to apply a known force to PE has been implemented. A proper device was built in INFN, Milan.

An insert for a vertical cryostat has been designed to support measurements in the liquid helium (LHe) environment. This insert allows to mount the PE in a box under isolation vacuum.

The design of the experimental setup is presented in figure 2. The insert grants the possibility to exert a known force on the DUT, keeping it under cryogenic conditions. This is achieved via an external device, placed at the top of the insert, in which spring-washers are coupled to a screwed ring to generate the test force (up to 2.5 kN). This force is transferred by a long steel (G10) rod to the PE. A calibrated load cell, working at RT, is in series and measures the generated force.

The box is immersed in LHe in order to cool the PE down to 4.18 K. This temperature can be considered as a good approximation of the real operating temperature of

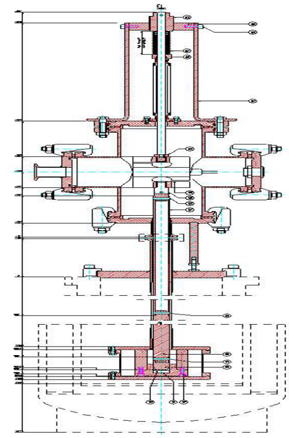

Figure 2: Vertical cryostat setup.

the PE, with respect to the electro-mechanical properties of the PE itself. Unfortunately, as the tests show the PE temperature was unstable and varies from 4K up to 10K. The temperature inside the box was even unstable, when the box was completely surrounded by liquid helium for some hours. Also compressing the actuator leads to a temperature increase proportional to the increasing load. Moreover, to reduce self-heating effect during tests the PE was supplied by only 100mV voltage.

Up to now, two PEs from EPCOS (type LN 01/8002) were characterized. As previously the impedance curve shows two resonances: the series resonance around 30 kHz and parallel resonance (so-called anti-resonance) above 53 kHz – both values for an unloaded piezo.

Data points were spread on different temperature values due to temperature stabilization failure. The 3D interpolating function was developed considering the temperature as a parameter. The results are plotted in figure 3.

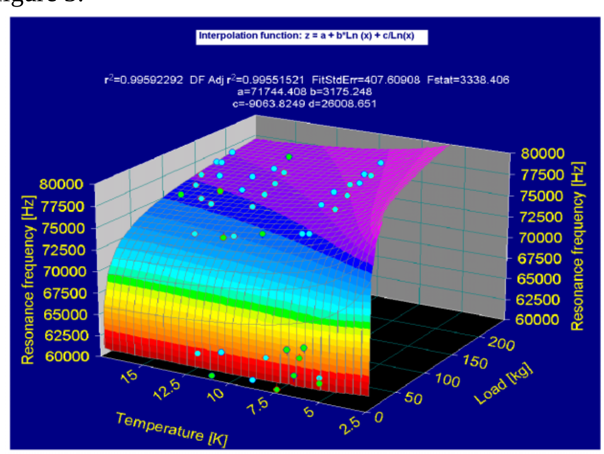

Figure 3: 3D interpolation of position of resonance versus applied force and temperature for EPCOS piezo.

CHECHIA TEST

At the end, an impedance measurement for PE assembled in a CHECHIA cryostat was performed. CHECHIA is a horizontal cryostat, in which a single high gradient cavity with full equipment i.e. couplers, a pretuning system with a step motor and active detuning compensation system with PE, is installed.

Because those two mentioned structure interact to each other, so it is possible to change the force applied to piezo by moving the step motor. The step motor can move up to 1 million steps what corresponds to 3µm. of length change of piezo fixture. The resonance frequency versus position of step motor is presented in figure 4.

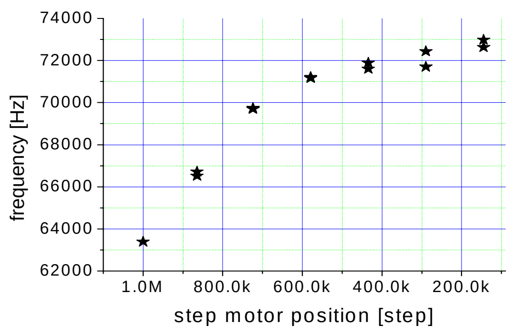

Figure 4: Resonance frequency of EPCOS piezo versus position of step motor.

By comparing the data presented in figure 3 and in figure 4, it is possible to estimate the force applied to PE in CHECHIA cryostat. The force on PE changes from 0,7kN for 0 step motor position to 70N for one million steps movement. The last result indicates that the piezo was almost completely loose and could fall out of the fixture. As a consequence, to maximize lifetime, the PEs should be stronger preloaded at RT, during its assembly (the preload force should be in range between 1,0kN to 1,5kN).

CAPACITANCE CHANGE

Recently, a measurement of capacitance change versus applied force was performed in IN2P3 [4]. As it was expected, the preliminary results done with Piezo JENA (#9222) stack shows that, the capacitance is also changing versus the piezo preload (see figure 5).

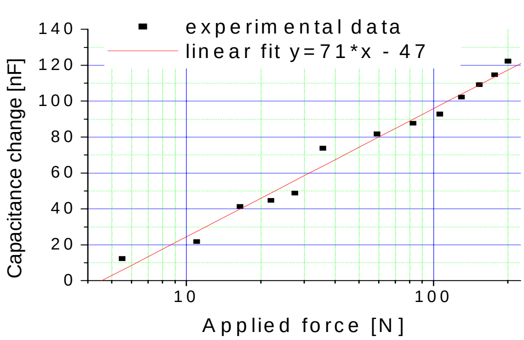

Figure 5: The change of capacitance of Piezo JENA (9222) versus applied force at RT.

The behavior of change is also exponential, as it was with resonance shift. It seems, that capacitance change is better method to determine the preload. However, to fully understand what happened with stressed PE, there is a need to perform more experiments. It also helps to develop a model, based on physical properties of piezostack.

CONCLUSION

Performed experiments are only the preliminary, but they prooved that it is possible to estimate the PE preload inside cryostat without any additional force sensor. To calculate an applied force it is necessary to measure impedance of piezoelement and compare with the calibration curve made before at desired crygenic temperature. However, the proposed method has some small disadvantages (i.e. many new resonances arise and significantly modulate the shape of amplitude and phase of the PE impedance with load, so it is hard to identify the resonance shift).

In principle, the series-resonance position (minimum of the impedance value) might be also characterized as a function of applied load.

Different types of piezoelectric actuators will be tested soon at CT and RT. In particular the PE from NOLIAC and PI should grant higher performances, due to their higher mass and greater dimensions. It means, that they should have lower resonance and anti-resonance frequencies and they should imply a sufficient sensitivity at the requested preload force.

Moreover, the capacitance change seems to be a good parameter for comparison. Nevertheless, there is need to perform more test especially at cryogenic temperatures. The capacitance change due to a PE breakdown (i.e. stack shortcut) need to be investigated carefully.

At the end, to be sure that our estimation is correct, the strain gauge sensor based on piezoresistive effect will be build and tested in Milan cryostat.

ACKNOWLEDGEMENT

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