DEVELOPMENT OF AN ACCEPTANCE TEST PROCEDURE FOR THE XFEL SC CAVITY TUNERS

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Abstract

Cavity tuners are needed to precisely tune the resonant frequency of TESLA SC cavities for European XFEL linac [1,2]. Although several units of the currently used device, originally designed at Saclay for TTF and then developed at DESY, have been manufactured and tested so far, a permanent installation like the XFEL poses higher requirements in terms of reliability and reproducibility. XFEL indeed requires about 1000 [3] tuners to be produced in a relatively short time and then to simultaneously work in cryogenic environment, each of them being equipped with a stepper motor driving unit and two piezoelectric actuators (Piezos). In this frame, an acceptance test procedure, here presented, has been studied, its main goal being the cross-check of issues affecting reliability: installation, mechanical coupling of active elements to cavity, motor and fast actuators functionality. An electronic equipment has been developed for driving signals, sensors and data management, specifically aiming toward an automatic and user-friendly routine in view of a large scale application. The procedure has been then applied for calibration purposes of a sample cavity assembly, the experimental results are also presented.

INTRODUCTION

During the final XFEL cryomodule assembling, the production rate will be of a module per week. This means that, for each of the eight cavities per module, a fast tuner assembly must be ready to work with full functionality with very a low failure rate.

In this frame, our proposal with the activity here presented is an automated apparatus to be used, according to a specific test routine, to check the correctness of piezo-tuner assembling on the cold mass string before module installation in the linac. This apparatus should consider for testing all the active elements installed as well as the mechanical components of the tuner. Moreover, it is important not to require any specific knowledge of electromagnetism or cryogenics to its operator: the testing routine should be performed with ease by the same team responsible for cryomodule assembly after a simple training phase, not involving the use of test instrumentation like Network Analyzers.

THE XFEL PIEZO TUNER

The tuning system for XFEL cavities consists of a stepping motor with a gear box and a double lever with a screw-nut system (Figure 1). This tuning assembly is installed at the helium tank side opposite to the power coupler and exploits the high longitudinal tuning sensitivity of TESLA resonators: the cavity is stretched by the tuner, changing its resonant frequency. The tuner is provided with fast tuning capability by means of a couple of piezoceramic actuators, that compensate cavity deformations responsible for frequency detuning and caused, among other causes, by Lorentz Force during pulsed operation with high accelerating gradient [1,2].

The leverage system is designed in order to provide a sufficient demultiplication factor, around 1/25, to reduce stresses on the stepper motor and to enhance sensitivity. The stepper motor is driving a copper-beryllium alloy (CuBe) screw through a reduction gear stage (harmonic drives or planetary gears) thus leading to a final sensitivity below 1 Hz /step and to a total static tuning range of about 800 kHz.

The piezo integration has been obtained avoiding a complete redesign of the mechanical assembly: only one tuner support, opposite to the stepper motor side, has been modified and in place of the existing tuner support rod, a compact titanium frame (piezo fixture), has been designed to host 2 piezo stacks in parallel. This double stack configuration allows keeping a spare actuator for redundancy while, if no replacement is needed, using it as a mechanical sensor. This solution, although not specifically designed for this feature and therefore significantly limited, has been anyway repetitively and successfully operated at gradient up to 36 MV/m [4].
Several assemblies of this kind have been so far installed, both in TTF and in FLASH linacs, performing satisfactory reliability and life-time in cryogenic operations.

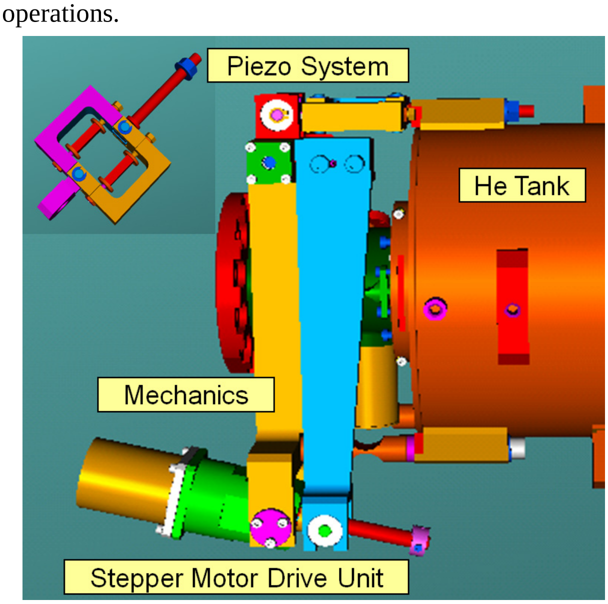

Figure 1: A 3D representation of the XFEL piezo tuner with its main components once installed on a cavity.

THE TUNER TEST DEVICE

In view of XFEL, the massive experience gained by the group working at DESY on FLASH and, formerly, TTF linac is of primary importance in pointing out all the issues related to the piezo tuner installation. Some concerns in particular have been here considered, all of them being potentially preventable with an efficient diagnostic during the assembly phase:

- "Dead on arrival" piezo actuators or, although much less probable, stepper motor drive unit.
- Piezo cabled with incorrect polarity, leading to a large failure probability.
- Piezo installed with incorrect compressive preload force, also leading to a loose or null action on the cavity.
- Mechanical leverages installed incorrectly, thus preventing active elements tuning action.

Taking these possible mistakes into consideration for the acceptance test procedure will significantly reduce the possibility of having the fast and slow tuning capabilities not working properly once the cryomodule will be closed and cooled down, that means when it will be no more possible to fix them.

The Experimental Setup

A reference scheme for the Tuner Testing Device is shown in Figure 2. A prototype of this device is currently under realization at LASA laboratory, it will be rack mounted and fully computer controlled via a LabView program, which is the only interface to the operators. The operators will be able to start the check routine and display results through the control panel, after having placed the proper sensor and cable probes on the device to be measured.

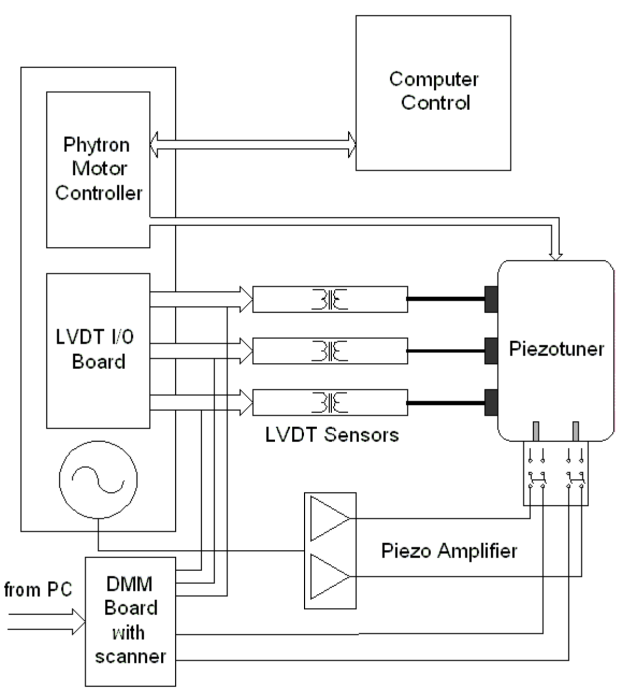

Figure 2: A reference scheme for the experimental setup.

Sensors in use are linear displacement transducers, up to three units for the baseline design. The dislocation of He tank, tuner arm and cavity compared to their nominal position will be monitored. In addition piezoelectric duality actuator / sensor will be used: the piezo stack will generate a voltage proportional to its strain.

A devoted mechanical support structure is currently under development, it will be used to host electrical connectors and displacement sensors on place. Its design must be carefully studied in order to allow for an easy mounting / dismounting across the inter-cavity space and installation on free reference planes available on the cold string.

Referring to Figure 2, the main blocks characteristics are the following:

- Stepper motor controller: according to our baseline design, a commercial unit from Phytron (MCC-1) is used. Differently from linac scenario, attention is paid in this case on the possibility to use microstepping feature in order to minimize stresses on the motor that requires a limited use at room temperature.
- LVDT: LVDT is an acronym for Linear Voltage Displacement Transducer. These devices will act as the displacement probes during the test routine. The device chosen is the Solartron Model AC15, which is an LVDT inductive displacement transducer, where a magnetic core, solidal with the probe tip, travels inside a hollow bobbin formed by windings connected to an external generator. This class of sensors grants the possibility of jointly having a micrometric scale resolution, needed for piezo induced strain readout, and a wide working range of 30 mm required to easily put the sensor on place.
- LVDT Control: the displacement sensor is efficiently controlled via a Solartron CAH Eurocard board. This board supplies the LVDT transformer windings with a proper AC voltage and using the principle of lock in amplifiers reads the sensor displacement trough a calibrated voltage. With this set up, the sensitivity reachable is up to few µm for all the whole range: both motor and piezo induced strains can be measured.
- Piezo Amplifier: it is used to feed the piezo actuators that are characterized by a large capacitance. One of the units already designed and used by FLASH LLRF team will be employed [4]. Two output channels are needed, with an output voltage of 150 V with 200 mA rms current.
- DMM Board: The Digital Multimeter Board is the device that works as an analogue interface with the LVDT control board and the piezos when used as actuators. Our choice is falling on a cheap Multifunction Data Acquisition USB Module, provided with analog and digital I/O channels and analog outputs, the latter to be used as signal generator for the piezo stack used as actuator.

The Test Routine

In order to exploit the test setup described and the issues to be addressed, a detailed measurements routine has been developed. It is based on three simple measurement sequences:

- Sequence #0: Piezo capacitance is measured directly using a portable DMM with capacitance meter and compared to expected nominal values.
- Sequence #1: Stepper motor is moved by a small amount. Tuner and cavity induced displacements are recorded while piezos are left open circuited so to charge up. Then piezo voltage during discharge is read allowing determining if cabling polarities are correct.
- Sequence #2: Piezo actuators, each one individually, are driven by a sinusoidal signal at a low frequency. Resulting tuner and cavity displacements are recorded, together with the voltage across the piezo used as sensor.

The correctness of the installation of tuner mechanical components will also be determined by the results of such test routines: the correct stroke transfer ratio between piezo and motor to cavity as well as the lack of backlash in direction inversions will represent proofs of a correctly installed assembly

The latter two sequences will be now described in details:

Test sequence #1:

1. Both piezos will be kept open-loop while motor will be moved 10000 half-steps pulling the cavity (about + 7.5 kHz cavity frequency) and compressing (thus charging up) piezo stacks.
2. The longitudinal displacement induced by the motor will be acquired and compared to expectations, thus validating the stepper motor installation and performances.
3. Both piezos will be then connected by the switch to the high impedance analog voltage input of the DMM board, to acquire piezo discharge through 10 MΩ input resistor. If the cabling polarity is right a positive discharging voltage will be recorded.
4. Stepper motor will be moved back to its initial position. Once again displacements will be recorded and analyzed as well as piezo discharge curves to have an immediate cross-check.
5. Piezo actuator cabling error is fixed if needed.

Test sequence #2:

1. Once correct piezo wiring polarity is determined, piezo #1 will be driven by a sinusoidal signal with Vmin = 0 V, Vmax = 100 V and frequency 13 Hz (the frequency value is not mandatory. Each odd number in the range of some tenth Hz can be used as frequency value).
2. Harmonic response from piezo #2 and from the displacement sensor will be acquired and analyzed. Linearity, amplitude and phase of each response will be compared to expected values, thus validating the piezo #1 installation and performances.
3. The point above is repeated switching the roles of the piezos: piezo #2 will be driven and piezo #1 will be used as a sensor, then the same measurements will be performed thus validating also piezo #2.

In conclusion, it is important to underline that the realization of a reference database, containing threshold values required for accepting or discarding test results, is of primary importance for its successful application to the XFEL linac. In view of this, the tuner test device will be firstly applied to incoming pre-series production of three XFEL cryomodules.

CURRENT STATUS AND PERSPECTIVES

A prototype version of the tuner testing device has been already developed at LASA laboratory. It features the electronic equipment already realized as the LVDT I/O interface and sensors jointly with elements different from the final ones but still significantly similar. The facility realized for testing (Figure 3) indeed hosts a Blade Tuner with piezo stacks from Noliac and a Phytron motor with Harmonic drive, it is currently in use to finalize the software that will take care of the test routine.

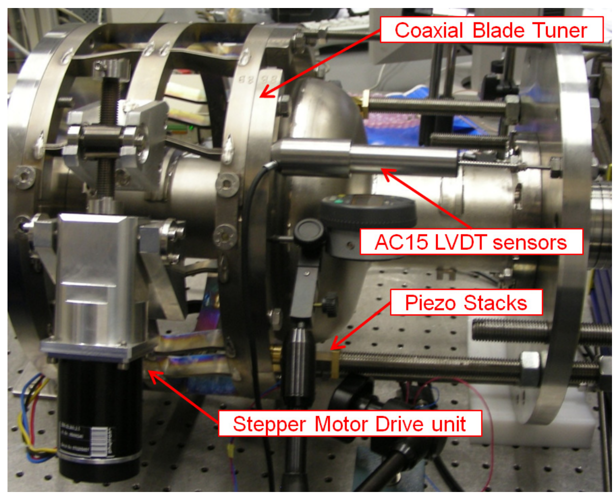

Figure 3: Tuner test bench at LASA laboratory in Milan.

Meanwhile all the components to realize the final system has been chosen and ordered, and will be acquired soon. In short times the device acceptance test will be performed on a single cavity module at DESY.

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[4] M. Grecki, J. Andryszczak, T. Pozniak, K. Przygoda, P. Sekalski, Compensation of Lorentz Force Detuning for SC Linacs (with Piezo Tuners), EPAC'08, Genoa, 2008, MOPP129, p. 862.