A FULLY AUTOMATED DEVICE FOR CHECKING XFEL PIEZO-TUNER INSTALLATION

A. Bosotti, R. Paparella, INFN/LASA, Segrate (MI)
C. Albrecht, K. Jensch, L. Lilje, DESY, Hamburg, Germany

Abstract

The tuning system for XFEL [1, 2] SRF cavities is a device based on a double lever driven by a stepping motor with a gear box and a screw-nut system. The cavity is stretched by the tuner thus changing its resonant frequency. The tuner is also provided with fast tuning capability by means of two piezo-ceramic actuators (piezos), which compensate for cavity deformations that are responsible of frequency detuning. During industrial phase is mandatory to ensure a correct tuner assembling both for mechanical parts and actuators. This is provided by an automated device able to check the correctness of piezo-tuner installation on the cold mass string first and after installation in the cryostat, with very simple mounting requirements for the Module Assembling Team. In this paper this device is fully described, and first results on prototypes are shown together with its operation strategy.

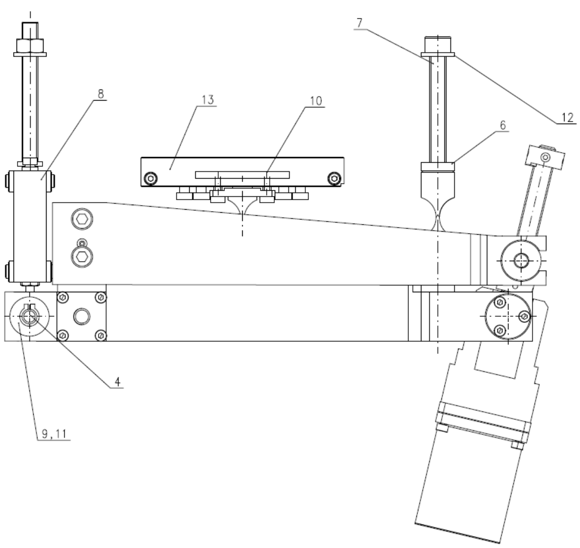

Figure 1: Top view of the XFEL tuner schematic.

PIEZO-TUNER

The tuner solution used for XFEL is based on the rugged device used for FLASH [3], with the introduction of the fast piezo detuning compensation capability, not previewed in the original design. The slow tuner device consists of a stepping motor with a gear box and a double arm. The moving parts operate at 2K in a vacuum. The frequency tuning range is about 400 kHz with 1 Hz resolution. The tuner used for XFEL is an evolution of this device, and is based on a tuner design used for 1.5 GHz cavities built by CEA Saclay [4]. This tuner is stiffer than the one used in TTF [2] and uses a double lever with a screw nut system. The cavity is now stretched by the tuner, in contrast with TTF were the cavity is squeezed, this has the advantage that the piezo elements are always compressed, in any tuning operations.

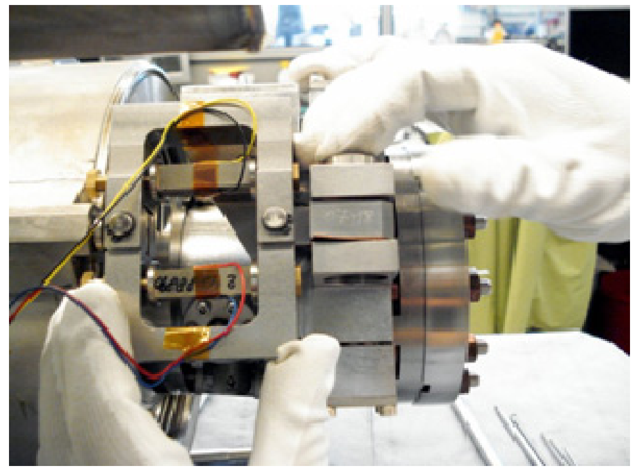

Figure 2: Piezo frame installation on the tuner.

The current XFEL design [1, 2] previews 101 accelerator modules installed, corresponding to 808 cavities each one provided with its piezo tuner device. During a series production assembly errors could occur, such as connecting the piezos with wrong polarity or wrong preload for the chosen tuning position. The first mistake makes the piezo not responding to the driving signal. Furthermore this could lead to piezo performances deterioration if a big signal is applied with wrong polarity due to partial domain re-alignment and partial change of the polarization (“butterfly” effect) [5]. The other mistake degrades the piezo tuning efficiency. Last but not least, a functionality check can discover if any tuner component is working properly and has not been damaged or broken during shipping, storage or assembling.

TUNER TEST PROCEDURE

The main idea behind the tuner test procedure under development, is the production of a complete electronic device capable of performing a functional check of the cavity tuner actions. The test must be performed for each unit before cryomodule closure, and its successfulness is the proof that the installation has undergone without critical errors, and that main functionalities are all working properly. The experimental validation test will be performed in a proper stage of the cryomodule installation procedure, when the entire cold string is out of the cryomodule.

When tuner validation test starts, it is expected that the operator gets close to the cavity under test with the electronic rack, and interfaces the test device to the cold

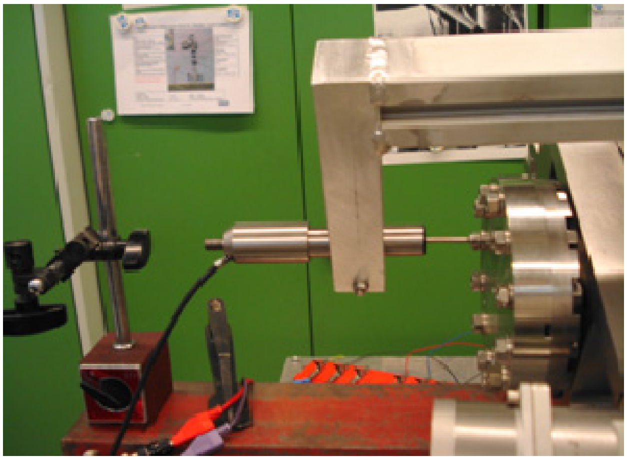

Figure 3: LVDT sensor installed in its frame.

mass. The main steps could be summarized into three easy operations:

- Install, on the cavity end side close to the tuner, a simple frame containing the displacement sensors required (Figure 3).
- Connect piezo, sensors and motor cables to the rack.
- Start the test routine and wait for the results.

Basically the test procedure is divided into three main sequences:

- Check both piezo capacitance values using a handy capacitance meter. This first operation is very simple and is the direct proof that the piezos has not been damaged or cracked (piezoceramic is very fragile and great care must be taken to avoid that the device accidentally falls down).
- Move the stepper motor while monitoring the displacement sensors and keeping the piezo in open-loop condition. The sign of piezo discharge after connecting them to the read-out electronics, will show if the piezo cabling polarity is right or wrong. In addition this will be a check of a good motor functionality.
- Feed one of the two piezo (alternatively) with a test sinusoidal signal and monitor the response of both the other piezo and the sensors installed. This will be a direct measurement of the piezo efficiency, to be compared with the expected one.

DEVICE DESCRIPTION

The philosophy adopted during the design of the Piezo Tuner Test device, is that everything is packed inside a single chassis, to be considered like a black box by the module assembling operators, and fully controlled by a program running on a personal computer, that performs all the checkups required after the installation of the sensors, that are up to three Voltage Linear Displacement Sensors (LVDT) to be connected to the cavity moveable parts with the help of supporting frames, as the one shown in Figure 3. The main blocks that constitute the test device are shown in Figure 4.

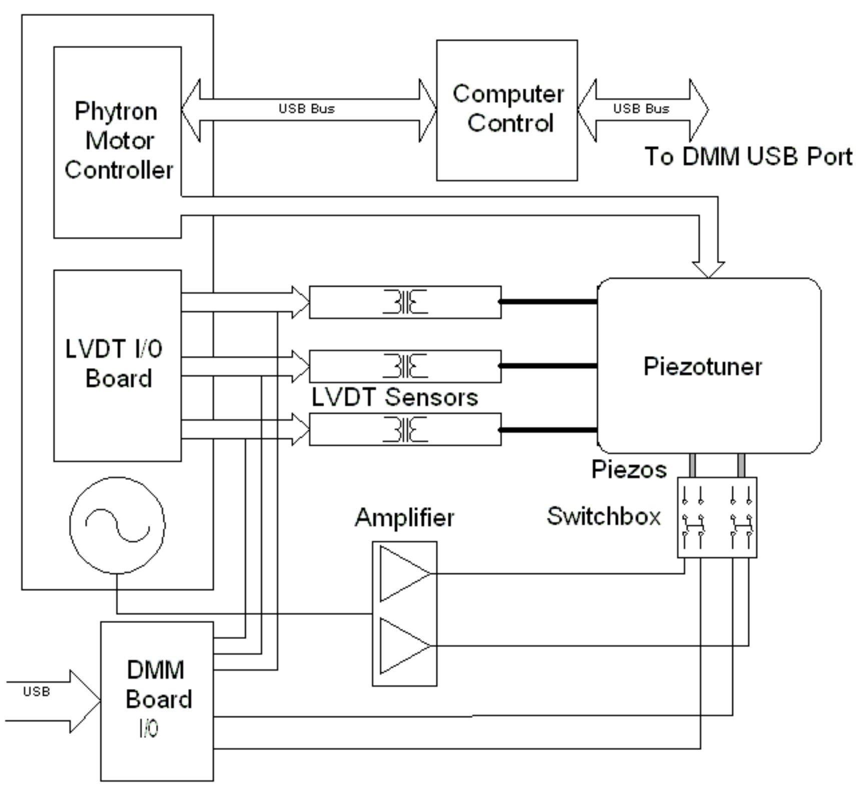

Figure 4: Block Diagram of the tuner test device.

Actually, we have chosen to leave the piezo-amplifier out of the device rack, albeit leaving the connection to the source and to the piezos to be tested on the instrument front panel, for easy and secure connections. The reason of this choice is that in this way maximum flexibility is left to the choice of the amplifier to be used to feed the piezos during the operation controls. This can be the device used by the Low Level RF controls during machine operations, if available, or simply a bench top instrument, like the 200V@250mA Piezomechanik LE 200-070 device used for tests at LASA laboratory.

Solartron Model AC15 LVDT sensors are used to acquire the tuner and cavity longitudinal displacements. In this kind of sensor the moving rod is the magnetic core of a transformer, unbalancing of its position results in a linear modulation of the driving AC signal, and the resulting net signal is a measure of the rod drift.

LVDT sensors are interfaced to ad hoc control boards (Solartron CAH Eurocard board), that send excitation signal to the LVDT coils and reads the signals coming up to two sensors, providing a DC output signal proportional to the displacement acquired. The board allows different setting of the gain to scale the output signal in a way that it is a direct reading in volts of the displacement, or any other linear function of it, decided by the user best convenience. The basic setup of the device is to use the full course of the sensor, which is 30 mm range; sensitivity 1 μm, but shorter working range could be chosen with higher sensitivity. The CAH board DC outputs, proportional to the displacement measured are sent to the digital multimeter board (DMM board). The latter is in fact a input-output device and is the heart of the test device; its tasks are to read the analog signal coming from the LVDT sensors control boards and the voltage across the piezos, together with the acquisition of their discharges, to generate analog control signal and finally to control relays switching through TTL digital signals. The purpose of the relays is to select which one of the two piezos would act as actuator, to be connected to the piezo-amplifier, and which one is the sensor, to be connected to the DMM board.

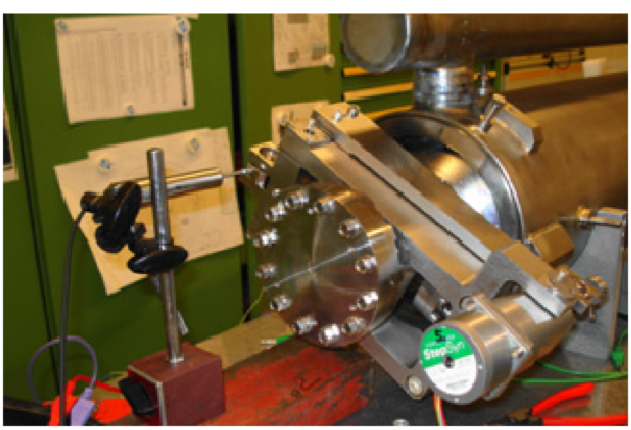

Figure 5: Piezo-tuner installed on C26 cavity at DESY.

The board is a Keithley KUSB 3102A device, with 16 Analog Inputs (8 in differential mode), 8 Digital Outputs, 8 Digital Inputs and 2 Analog Outputs. The reading resolution is 12 bits. The board is interfaced with the computer control through USB connection. An oscillator board is used to generate a low frequency sine wave to feed the piezo-amplifier. The amplitude of this signal is linearly modulated from zero voltage up to its final value (and vice-versa) with a DC signal generated by the DMM board.

Finally, a Phytron MCC 1 USB Stepper Motor Controller is used as the driver of the stepper motor installed on the tuners. This device is connected to the computer control via USB interface too. This motor controller provides the possibility to operate the unit in a micro-stepping mode, so that the current pulse to each motor coils is smoothly shaped and abrupt current variations are avoided. This feature will be used in the definitive test routine in order to minimize mechanical and thermal stresses on the drive unit.

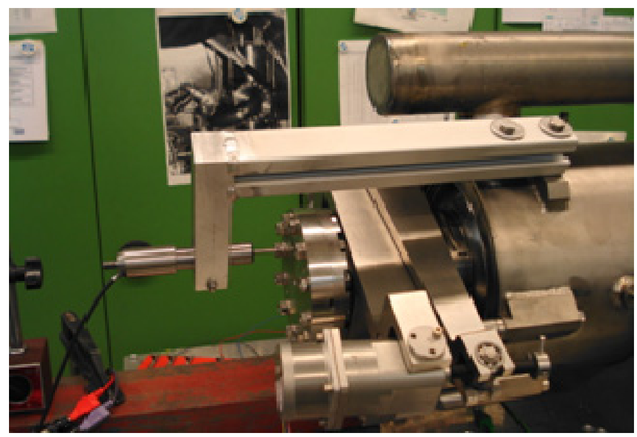

Figure 6: Sensor frame fixed to the two reference M8 holes on the cavity helium tank.

TEST SETUP AT DESY

Sensors and read-out electronics has been tested on a complete cavity module equipped with piezo tuner. An old cavity, C26, has been equipped with the XFEL Tuner. The cavity Helium tank is of old design corresponding to Cry I cryomodule. Moreover the cavity has sustained treatments such as annealing at 800°C, which could introduce a difference in the cavity stiffness if compared to more recent cavities. Anyway these issues have been safely neglected since the aim of the test is to demonstrate that the device is able to detect a malfunction that could happen and to determine the device sensitivity.

The tuner has been installed so that the tuning range starting point is close to the XFEL design one, with the lever arms closing during tuning (increasing frequency direction). It has been equipped with a piezo frame correctly preloaded (2 kN preload force). The test was successful. All signals acquired were well readable and reproducible, even when the tuner was set close to its neutral point, so that only a little force from the cavity was expected to act on it. All the test steps can actually be performed as designed. Wrong or imperfect connections has been set on purpose and detected.

A key result for this test has been identified to be the definition of the most convenient shape and location required to the sensor test frame in order to be easily installed on the cavity module, by the assembling team operators. Moreover the right strategy has to be outlined, together with the best moment to perform the tuner check during the industrial assembling phase. For this purpose, the LVDT displacement sensor, and its readout electronics provided with different calibrations, has been put in different places to check different sensitivities and figure out where the best places to interface them with the cavity are.

The best moment to perform the test has been identified, and it is when the cold string is completely assembled and the inter-cavity bellows are removed, right before lifting the entire string to fix it to the gas return pipe. A second reduced test (without displacement sensors) could be performed at the end of the module installation.

An efficient and easy way to reach reference site for sensor frame installation has been identified in the two threaded M8 holes on the He tank edge left free after the cavity safety flange removal, as shown in Figure 6. At the moment chosen for the test the bottom pair of holes is free in each cavity of the string.

With the displacement sensor body installed in the frame, its moving core must be put in contact with the cavity flange to monitor its strain. At the moment of testing the flange does not offer any useful surface. The idea was then to use the three angular reference dip on the cavity flange side to clamp the flange itself to a custom made ring. Once fixed this ring is solidly connected to the flange.

Before the test, up to four LVDT sensors were considered to be simultaneously used to measure cavity and tuner arms strains. Actually, after these test the idea is to focus more on the cavity displacement measurements and eventually to discard the tuner arms. This solution is moreover supported by the fact that the test performed confirmed that the LVDT sensor chosen are actually capable to detect also the cavity displacement induced by the piezo action.

The starting idea to calibrate the LVDT sensors to be used in its full path of 30 mm, for easing its installation, has been changed in favor of a proper design frame, that can reduce the LVDT path to few mm (+/- 2 or +/-3 for instance), and so increasing the sensor sensitivity. This goes from the former one of 0.7 mV/µm to 3.3 mV/µm.

The amount of motor displacement required in the first sequence of the test has been evaluated in the range from half copper beryllium screw turn up to a maximum of one complete turn. For reference, one screw turn corresponds to 35200 motor half/steps, about 60 µm cavity strain or about 25 kHz frequency shift. It is mandatory to avoid cavity displacements that could lead the cavity into the plasticity region, thus changing the cavity design tuning and field flatness. A good safety margin can be achieved by avoiding a strain over 100 µm. Also, the piezo signal amplitude has been evaluated and can be safely set to be a sinusoidal waveform with 100 Vpp of amplitude and 17 Hz frequency.

The cavity displacement in response to piezo action has been proved to be useful to determine if piezos are in contact with the cavity, even for small preload force. Up to now it is not possible to quantify the amount of preload to the piezo sensors just monitoring cavity displacements and not the cavity frequency shift. This is mainly due to control electronic constraints, but activity on this issue is still ongoing.

Some Test Results

Some experimental results are here presented and commented. Meaningful numerical values are shown in the following tables.

In the first test the motor was moved initially by half turn and after by a complete turn. After the motor is stopped, the two piezos are connected to the DMM by closing the relays, and their discharges are acquired.

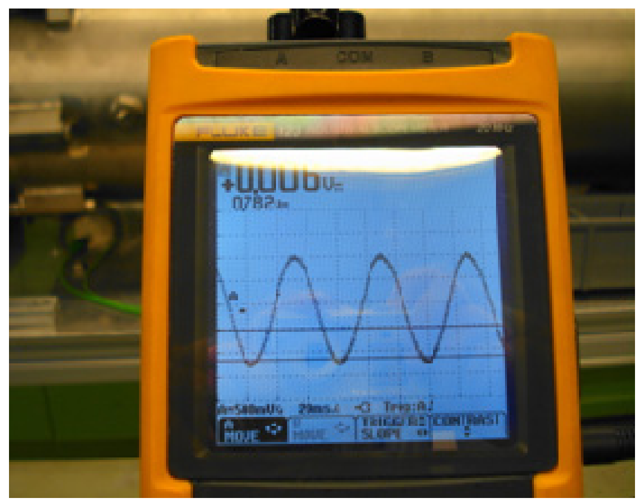

Figure 7: Signal coming from the piezo used as sensor: right polarity and good coupling are shown.

The LVDT readout is acquired for reference, too. The discharges are well readable and their positive sign is the proof that the piezos are correctly wired. Results are shown in Table 1.

Table 1: Piezo discharge test

Screw turns / motor steps	Piezo discharge (Vpeak) V	LVDT sensor mV
0.5 / 17600	0.5	40 (full range)
1 / 35200	0.9	200 (3 mm range)

A second test has been performed feeding one of the two piezos with a sinusoidal signal of 17 Hz. The signal across the other piezo is acquired together with the LVDT output. Different motor rotations are performed to investigate on the changing of sensor sensitivities for different loading conditions. LVDT sensor calibration is changed too, and the increase of sensitivity is well evident when the sensor range limits are made smaller, as shown in Table 2. This test allows quantifying the amount of coupling between the two piezos. The comparison of the signal across the sensor piezo and the LVDT ones shows their correlation.

Samples of signals are shown in Figures 7 and 8, were bench top instruments have been here used to acquire signals instead of the DMM board interfaced with a computer, to easy the test procedure.

Table 2: One piezo is fed with sinusoidal signal

Screw turns /motor steps	Piezo V (V peak) V	Vpeak on sensor piezo V	LVDT cavity drift mV
0 / 0	20	0.6	2
0 / 0	60	1.6	3
0.5 / 17600	60	2	3
1 / 35200	60	2	5
1 / 35200	100	4	15
1 / 35200	80	1.5	25†
2 / 70400	80	1.5	30†
0 / 0	80	2	25†*
1 / 35200	80	2	30†*

* with frame installed, fixed to He tank and hosting the sensor
† short range calibration

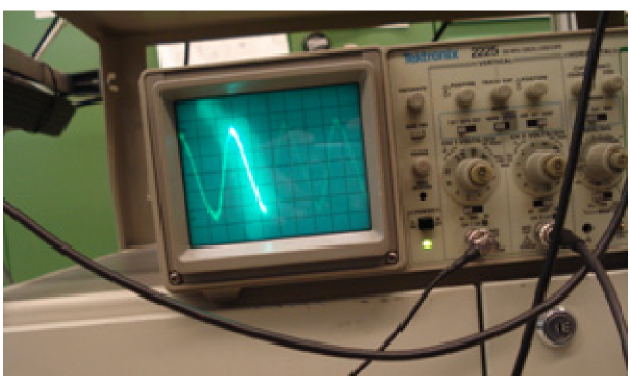

Figure 8: Cavity longitudinal displacement as seen by LVDT sensor: checking its amplitude and linearity is possible to check fast tuning capabilities.

The third test we want to report here is done changing the preload on the piezos, acting on the screws at the base of their support frame (the acting force is known from the number of screw turns). The motor is at starting position (zero turns) corresponding to the worst piezo loading case. Three conditions are taken into consideration: piezo completely unloaded (malfunction), piezo poorly loaded and piezo correctly loaded. The piezo chosen as actuator is fed with a sinusoidal signal of 80 V amplitude. The sensor piezo and LVDT sensor responses are acquired. From Table 3 can be seen that the unloaded case produces no signals on the sensors (just noise) and that this kind of malfunction is easily detected.

Table 3: Piezo preload is changed. A malfunction situation has been created unloading the piezos

Load conditions (both piezos)	Piezo Voltage V	LVDT mV
Unloaded	No response	No response
Just fixed by hand	1.5	5 - 10
screwed by tool (10 % full load)	1.5	30

CONCLUSIONS

A prototype device of the Piezo-Tuner test system has been tested at DESY on a typical cavity assembly with good results. The piezos and cavity drift signal are well readable and the values measured are repetitive. Moreover when ad hoc created malfunction occurred, this was detected by the system. Now the definitive device is in construction phase and in short time will be delivered to the XFEL assembling team.

REFERENCES

[1] http://www.xfel.net

[2] M. Altarelli et al. (editors), The European XFEL Technical Design Report, DESY, July 2006, DESY 2006-097.

[3] http://flash.desy.de

[4] P. Bosland, Bo Wu, Mechanical study of the «Saclay piezo tuner» PTS (Piezo Tuning System), DAPNIA - CEA Saclay, CARE-Note-2005-004-SRF.

[5] Designing with Piezoelectric Transducers: Nanopositioning fundamentals, from catalog Physics Instrumente, 09/2005.