SUCCESSFUL QUALIFICATION OF THE COAXIAL BLADE TUNER

Angelo Bosotti, Carlo Pagani, Nicola Panzeri, Rocco Paparella, INFN/LASA, Segrate (MI)
Clemens Albrecht, Rolf Lange, Lutz Lilje, DESY, Hamburg
Jens Knobloch, Oliver Kugeler, Axel Neumann, BESSY GmbH, Berlin

Abstract

Cavity tuners are needed to precisely tune the narrow-band resonant frequency of superconducting cavities. The Blade Tuner is installed coaxially to the cavity and changes the resonator frequency by varying its length. Piezoceramic actuators add dynamic tuning capabilities, allowing fast compensation of main dynamic instabilities as Lorentz Forces, under pulsed operations, and microphonic noise. A prototype piezo Blade Tuner has been assembled on a TESLA cavity and extensively cold tested inside the horizontal cryostats CHECHIA (DESY) and HoBiCaT (BESSY). Then, as suggested by test results, few modifications have been implemented thus achieving the current Blade Tuner design. The introduction of thicker blades re-distributed along the circumference allows increasing its stiffness and fulfilling European and American pressure vessel codes, while ensuring the requested performances at the same cost. The paper will present the successful characterization tests performed on the prototype, the extensive mechanical analyses made to validate the final model and the results from qualification tests of first revised Blade Tuner produced, to be installed in the second module of ILCTA at FNAL.

PROTOTYPE TESTS

The blade tuner working principle is to transfer azimuthal rotation, provided by a stepper motor into longitudinal motion by means of bending blades [1]. The device that has been tested inside CHECHIA and HoBiCaT is an enhancement of the TTF superstructures tuner, where the design has been simplified in view of the ILC requests, and completed with the insertion of the piezo for dynamic tuning operations.

Two prototypes of this device have been realized, one made from Titanium and the other from Stainless Steel (SS) with Inconel blades. The two new tuners where first tested at LASA at room temperature to check mechanical properties: after these tests we decided to use the SS – Inconel tuner for cold tests [2,3].

The first cold test inside horizontal cryostats has been performed, inside CHECHIA, at DESY, in pulsed RF regime. Then two other test sessions with CW RF have been done inside HoBiCaT, at BESSY. The tuner has been installed at DESY on the Zanon n°86 cavity (Z86), using a modified He tank, with the insertion of a central bellow, to allow for coaxial tuning operation. For the CHECHIA test, a stepper motor from Sanyo inc. has been installed, equipped with an harmonic drive component set. Two low-voltage, multilayer piezo from Noliac, 40 mm long and with 10x10 mm^2 cross section, have been installed as active elements.

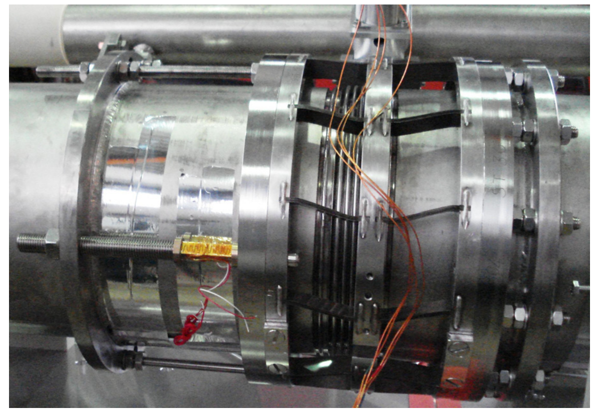

Figure 1: The Blade Tuner completely installed before cold test at BESSY; piezo actuators are in place and preloaded. The central bellow is also visible.

The correct preload to the piezo is given using the screws connected to the piezo supports. The goal pre-load value, about 1.5 kN on each piezo, is reached when the cavity is cooled at 2 K, taking into account all the cavity length changes, due to thermal contractions and pressure gradient sustained during the cooldown operation. During CHECHIA tests on September 2007, the entire Lorentz force detuning (LFD) shown by Z86 cavity at full gradient, about 300 Hz, has been successfully compensated in different load conditions. This was achieved using just one piezo, fed with one third of the nominal maximum driving voltage.

After the test in pulsed regime at DESY, the tuner was transferred to BESSY, to be tested from February to April 2008, inside the CW facility HoBiCaT. A Phytron stepper motor, provided with a planetary gear box, has been used in place of the former Sanyo stepper motor with harmonic drive gear (40000 half-steps per complete spindle turn instead of 35200). It must be remarked that this configuration was used for the first time for this application.

Among several other parameters (working point tuning range, piezo actuator DC tuning range, transfer functions and loading effect analyses), the whole tuning range has been extensively measured [2,3]. All the measurements are summarized in Figure 2, proving that the slow tuning performances meet expectations.

The cold tests inside CHECHIA and HoBiCaT facilities certified that the coaxial Blade Tuner has successfully overcome the prototype phase, providing a lot of useful information to optimize its design.

More than the required 600 kHz of tuning range has been achieved (Figure 2), with a tuning sensitivity of 1.5 Hz/half-step. The hysteresis of the first load cycle in the former test inside CHECHIA (red curve) has been almost cancelled in the successive cycles.

A static frequency shift of 5 kHz has moreover been obtained driving the piezo up to their maximum DC voltage, therefore a great margin for the active compensation of dynamic LFD is ensured also for high gradient pulsed operations [3].

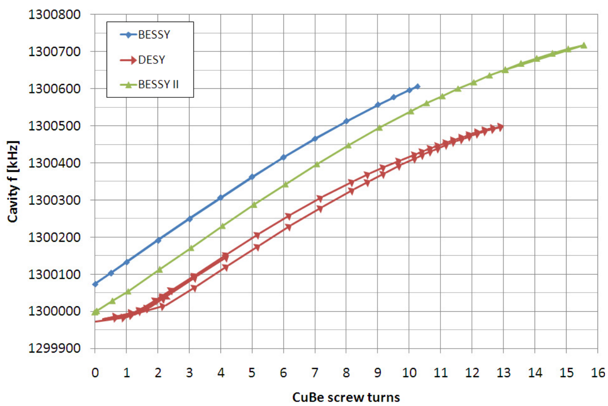

Figure 2: Tuning range tests in CHECHIA and HoBiCaT.

FINAL TUNER DESIGN

In view of the construction of eight tuners to be installed in the new ILCTA_NML test facility, few modifications have been introduced allowing to increment the tuner strength and stiffness, in order to satisfy the requirement recently set by the XFEL project in terms of pressure vessels regulations. Taking into account all the possible load cases, both in work condition, transitory phases and accidental overpressures, the Blade Tuner is required to withstand at least 10.9 kN compressive load and 13.8 kN tensile load [4].

Moreover, the load acting on the tuner is applied in only two points, therefore breaking the original symmetry and over-loading the blades closer to the piezo position. The weight reduction has amplified the problem, therefore a non uniform distribution of the blade packs was introduced in order to avoid it. The final design has 2 packs of 4 blades, each positioned as near as possible to the piezo position, while 5 packs of 3 blades each are equally distributed along the remaining free space. Globally, 23 blades are used on 180° for a total of 92 blades on the whole tuner, 4 less than the previous design.

The actual configuration is reported in Figure 3. Moreover the need to increase the axial strength due to the requirement of the XFEL certification tests lead to thicker blades whose thickness is now increased from 0.5 mm to 0.8 mm. All these modifications have also a positive consequence on the stiffness of the tuner that now is higher than 30 kN/mm in almost the entire tuning range

Some finite elements analyses have been performed in order to simulate all the possible load cases and working conditions to which the tuner will be subject. This analytical model also allows obtaining the stresses in the tuner rings, blades, bolts and driving shaft [4].

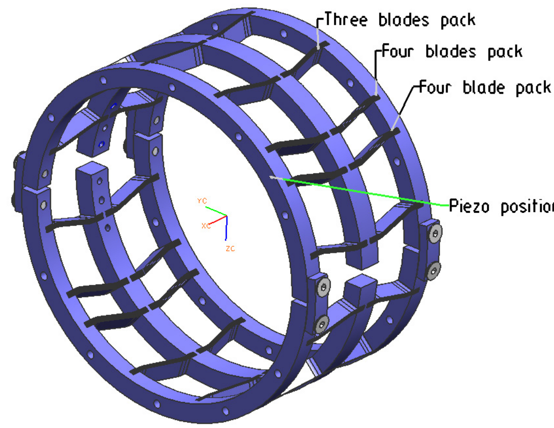

Figure 3: Improved blade tuner design with the upgraded blade positions and distribution.

For what concerns the compression load, the analyses account for the preload on the piezo, the moving of the tuner up to the maximum tuning range and an additional load growing up until the tuner collapse: a collapse load of 12.5 kN is achieved, higher than the required limit.

The tensile limit load has been determined applying four forces to the point corresponding to the safety bars. These are the elements that allow the force transfer between the helium tank and the tuner. For a traction force of 16 kN some plastic strains occurs in the blades, therefore this can be considered as the limit traction load, higher than the required one of 13.8 kN.

Finally, the force acting on the driving threaded spindle has been considered and used to evaluate the motor requirements. Given the piezo preload value, the tuner position and the friction (efficiency coefficient $\eta = 0.159$) the total maximum torque required is equal to 3.0 Nm. As a reference, a Phytron 2.5 A motor equipped with a 1:100 gearbox and operated at 1 A current is still able to drive the tuner with great margin, generating a nominal torque value of 12 Nm.

In conclusion, the final Blade Tuner design fulfils the requirements set by the XFEL and ILC projects both in terms of structural strength and tuning capabilities [4].

ILCTA BLADE TUNER VALIDATION

A set of eight Blade Tuner units have been manufactured by Ettore Zanon S.p.A. (Italy) for CM2 and will be installed in the next months at the FNAL test facility ILCTA_NML (see Figure 4).

With the delivery of the eight units, an accurate process of validation started. It includes both a visual and dimensional check for all components and an experimental test procedure at room temperature based on an ad-hoc single cell test facility realized at LASA laboratory. At the time of writing the evaluation is not finished for all the devices and although the room temperature (RT) testing poses some limitations to the maximum displacements and forces to be applied (plastic strains can occurs in the blades from the 12^{th} screw turn), the tested models fulfill our expectations.

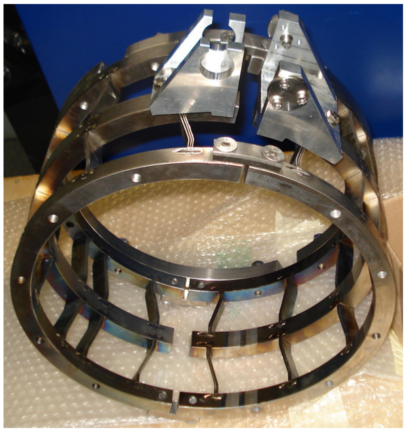

Figure 4: One of the Blade Tuner manufactured for ILCTA_NML facility at Fermilab.

The tuning range has been measured up to 11 turns of the driving screw, the maximum displacement safely achievable at RT. Experimental data are reported in Figure 5 and compared to the FEM simulations results.

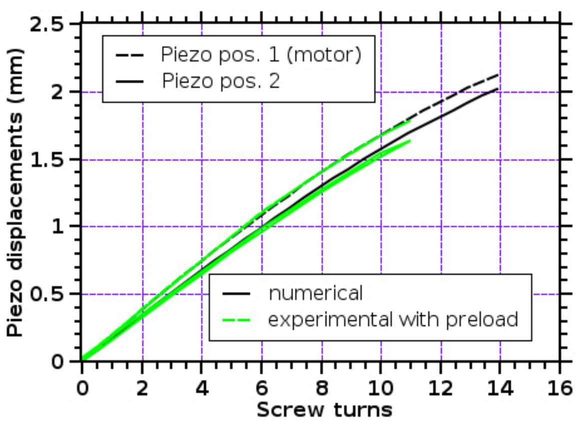

Figure 5: Tuning range results for ILCTA tuner, experimental vs. simulation at room temperature.

The strength of the Blade Tuners has also been verified applying a compressive load of 10 kN to the tuner, the maximum allowed in our test facility to safely operate it at room temperature. Results of this compressive load test are reported in Figure 6.

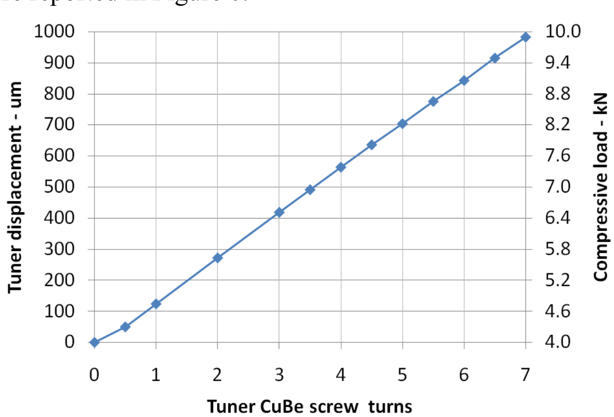

Figure 6: Compressive load test on ILCTA tuner

Moreover the tuner stiffness was evaluated in operative conditions, i.e. when the load is transferred through the piezo elements to the cavity. Also in this case the experimental results are positive, confirming the numerical simulation data where the estimated stiffness is greater than 30 kN/mm on the almost entire tuning range.

CONCLUSIONS

After the cold tests inside CHECHIA and HoBiCaT facilities, it is possible to say that coaxial Blade Tuner has successfully passed the prototype test. More than 600 kHz of tuning range has been achieved at cold, with a total load of about 7 kN, successfully withstood by the tuner with no failure. Pulsed tests inside CHECHIA have shown the tuner high effectiveness in LFD compensation, this latter confirmed in the CW tests driving the piezo with DC voltages up to 200 V, where a static frequency shift superior to 5 kHz has been obtained. The analyses of the results allowed us to implement few improvements that have a significant impact on the strength and stiffness of the device. The new design fulfils the requirements set by the XFEL and ILC projects both in terms of structural strength and tuning capabilities.

This last version has been manufactured in eight units by Ettore Zanon S.p.A. (Italy) and will be installed in the next months at the FNAL test facility ILCTA_NML. Produced units have meanwhile been involved in a detailed acceptance test procedure at room temperature, still ongoing.

First results obtained confirm that their performances in terms of tuning range, hysteresis, stiffness and load bearing capability meet our expectations.

ACKNOWLEDGMENTS

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