

# COLD TESTING AND RECENT RESULTS OF THE BLADE TUNER FOR CM2 AT FNAL\*

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## Abstract

An extensive validation activity has been conducted since year 2007 for the coaxial Blade Tuner for TESLA SC cavities. During this activity, performances and limits of prototype models have been deeply investigated through detailed test sessions inside CHECHIA (DESY) and HoBiCaT (BESSY) horizontal cryostats as well as F.E. modelling and analyses. The result is an improved design for the Blade Tuner, specifically meant to satisfy the incoming ILC-level performance requirements, fulfil pressure vessels regulations and keep Ti / S.S. material compatibility. Recent Blade Tuner activities and results will be presented in this paper in view of the installation of 8 units in the second cryomodule of ILCTA - New Muon facility at Fermilab, and also of our contribution to both incoming S1-Global (KEK) and ILC-HiGrade projects. The manufacturing process of the first set of 8 tuners, from production to room temperature validation for the whole series, will be also reviewed. Then the incoming cold test will be presented. Special effort has been made in evaluating the accuracy and repeatability of fast and slow tuning action at few Hz range.

## FROM PROTOTYPE TO THE ILC BLADE TUNER

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 a reviewed design of the TTF superstructures tuner, where the design has been simplified in view of the ILC requests, and completed with the insertion of piezoceramic actuators (piezo) for dynamic tuning operation. Two prototypes of this device have been realized, one made from Titanium and the other from Stainless Steel (SS) with Inconel blades.

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 and equipped with an harmonic drive component set, while for BESSY tests a Phytron. stepper motor provided with a planetary gear box has been used (here used for the first time for this kind of application ). For

both tests two low-voltage, multilayer piezo from Noliac, 40 mm long and with 10x10 mm<sup>2</sup> cross section, have been installed as active elements. The correct preload to the piezo is given using the threaded piezo support rods. 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 and pressure changes due to cooldown thermal contractions.

During tests the entire Lorentz force detuning (LFD) shown by Z86 cavity at full gradient, about 300 Hz, has been successfully compensated for different load conditions. This was achieved using just one piezo, fed with one third of the nominal maximum driving voltage.

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]. Finally a static frequency shift of 5 kHz has 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].

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. Few modifications have been introduced incrementing the tuner strength and stiffness, in order also to satisfy the requirement recently set in terms of pressure vessels regulations.

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. A non uniform distribution of the blade packs was introduced in order to avoid it. The final design (Figure 1) 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 space.

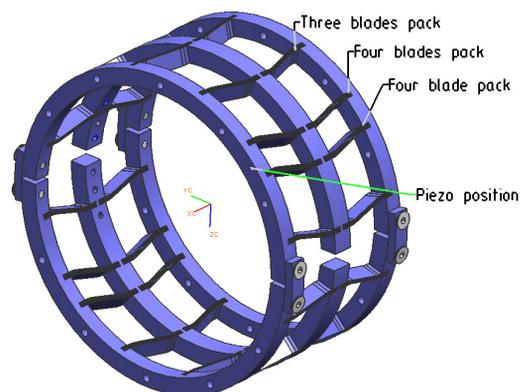


Figure 1: Improved blade tuner design with the upgraded blade positions and distribution

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Globally, 23 blades are used on 180° for a total of 92 blades on the whole tuner, 4 less than the previous design. The present configuration is reported in Figure 1.

The need of increasing 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 global stiffness of the tuner that now is higher than 30 kN/mm in almost the entire tuning range.

Finite elements modeling (FEM) and analyses have been performed in order to simulate all the possible load cases and working conditions to which the tuner will be subject. This procedure also allows obtaining the stresses in the tuner rings, blades, bolts and driving shaft [3].

For what concerns the compression load, the analyses account for the preload on the piezo and the moving of the tuner up to the maximum tuning range: a collapse load of 12.5 kN is achieved, higher than the required limit of 10.8. The tensile limit load has been determined applying four forces to the point corresponding to the safety bars, 16 kN is considered as the limit traction load, higher than the required one of 13.8 kN [3].

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.

### ACCEPTANCE TESTS FOR FIRST SET

The first small series composed by 8 units has been manufactured by Ettore Zanon S.p.A. (Italy) and delivered by July 2008. An accurate process of validation then 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 device realized at LASA laboratory

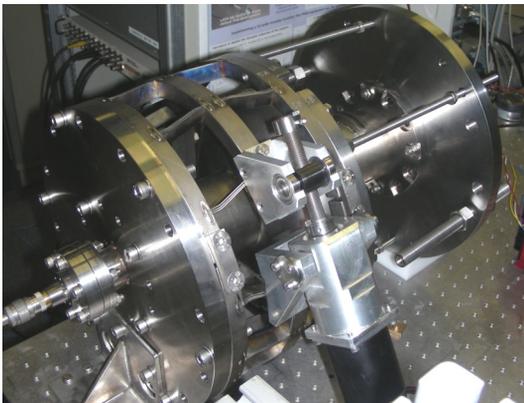


Figure 2: One of the ILC design Blade Tuner installed in the single cell test device at LASA for room temperature acceptance measurements.

This device allows making use of a pre-determined external load, in order to replicate with good approximation the force-displacement coupling as seen by the tuner in its actual cavity environment (stiffness of about 3 kN/mm, mainly determined by the cavity).

Some limitations related to the actual test conditions are considered for these tests, for instance tuning range is

limited to 11 motor spindle turns. It corresponds to the maximum safely available displacements at room temperature, since plastic strains could occur in the blades for a larger stroke.

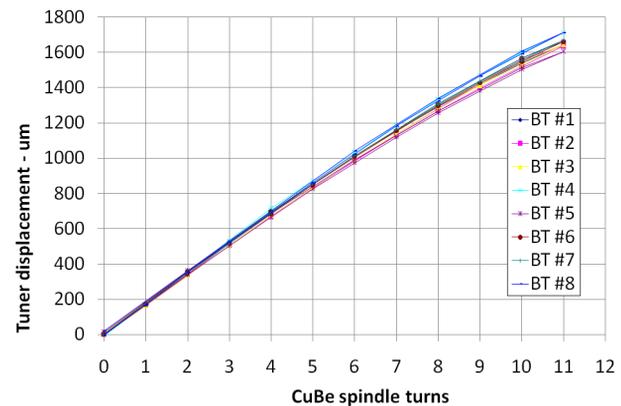


Figure 3: All results collected for tuning range measurements, in terms of tuner stroke, for produced ILC design Blade Tuners.

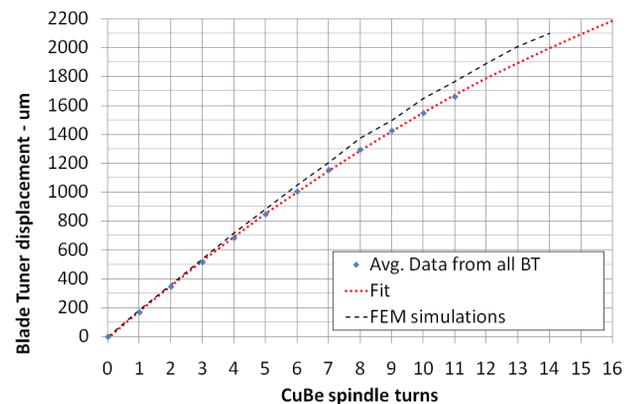


Figure 4: Comparison of data average from acceptance tests and expectations from FEM analyses produced units.

The 8 units series has been entirely tested and results confirmed to be well in agreement with expectations, both in terms of homogeneity of produced units and in terms of correspondence with FEM predictions. In both cases results are in within 5 % error, a tolerable discrepancy also in the latter case taking into consideration that idealized constraints (infinitely rigid drive unit for instance) have been considered in FE simulations. Data are presented in Figure 3 and 4, they are related to tuner stroke measured as average displacement at piezo actuators positions.

The strength of the Blade Tuners has also been verified successfully applying a compressive load up to 10 kN to each tuner, the maximum allowed in our test facility to safely operate it at room temperature. 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 encouraging, confirming the numerical simulation data where the estimated stiffness is greater than 30 kN/mm on the almost entire tuning range.

## SMALL RANGE TUNING ANALYSES

A special effort has been put in understanding the tuning performances of coaxial Blade Tuner when applied in a sub-micrometer range. This has been done with the aim of excluding the existence of any non linear behaviour at this scale, for instance due to sticking effect or free play in the tuner assembly or in the cavity constraints.

As a starting point, data collected from the large experience with the Blade Tuner prototype has been analyzed. These experimental results came from cold test performed in two different horizontal cryostats, where the mechanical and thermal constraints of the cavity under test are generally different from the linac cryomodule environment.

In this frame an additional critical issue is due to friction: test cryostats indeed typically involve teflon cavity supports, free to move over steel or titanium frames. For both these latter configurations, the static friction coefficient is significantly higher than the one of Ti pad rolling over CryIII rolling needles case, about 0.04 and 0.17 respectively against 0.0043 [4]. Results anyway, from both piezo and motor small range tuning, positively confirm that no stroke is loss and no unexpected behaviour are observed.

For example when piezo actuators are driven with a DC voltage (Figure 5) no deviations from the theoretical hysteresis curve expected from piezoelectric properties are visible. As a reference for sub-micrometer resolution issues, 1 V driving signal on one of the two piezo actuators installed in the prototype Blade Tuner corresponds to a cavity strain as low as 30 nm.

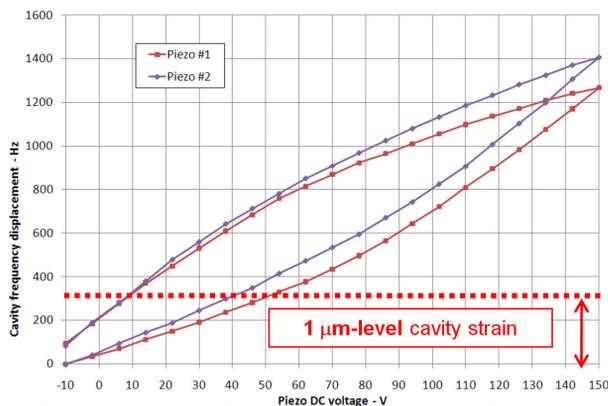


Figure 5: cavity frequency drift induced by piezo energized with DC voltage, Blade Tuner prototype test at BESSY.

In view of the cold test of Blade Tuner with revised design to be done at BESSY, albeit unfortunately delayed to allow further treatments of the test TESLA cavity Z86, additional investigations on this topic are foreseen.

In particular the same CryIII support scheme with Ti pad sliding on rolling needles will be reproduced at the HoBiCaT horizontal cryostat facility at BESSY, required components have been produced and will be installed in the near future. The possibility to simulate accurately the real

cavity constraints, while keeping the resonator locked to a PLL loop, will offer a unique possibility for understanding such issue.

Both stepper motor drive unit and piezo actuators will be used in these measurements, several automated tuning cycles will be performed in the sub-micrometer range (1 motor step  $\sim$  300 mV piezo signal  $\sim$  10 nm). Direction inversions in each cycle will allow determining the amount of backlash in the assembly; moreover it will be possible to feed piezo with an harmonic modulated signal in order to perform a locked measurement with the lock-in amplifier.

## CONCLUSIONS

The recent and detailed research activity for the development of a coaxial Blade Tuner capable to fulfill ILC and XFEL requirements can today be considered as positively completed. It led to a successful manufacturing and cold testing of a prototype inside CHECHIA and HoBiCaT facilities, concluded with good experimental results as well as an useful amount of information.

Such experience has then been of primary importance in the subsequent effort of revising the Blade Tuner design. Few improvements have been introduced with 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, as extensively proved during design phase with FE modeling and analyses.

Blade Tuners with revised design have been manufactured in a first small series of 8 units. Produced units had already undergone a detailed acceptance test procedure at room temperature, confirming that their performances in terms of tuning range, hysteresis, stiffness and load bearing capability meet our expectations

Important Blade Tuner installations are coming in short time: cryomodule n.2 of ILCTA\_NML at FNAL, US, and S1-Global facility at KEK, Japan. ILC-HiGrade program of EU FP7 is also ongoing, aiming to the realization of 24 high gradient cavities equipped with Blade Tuners.

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