THE COAXIAL TUNER FOR ILCTA_NML AT FERMILAB

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Abstract

The piezo Blade Tuner prototype has been successfully tested inside the horizontal cryostat, CHECHIA, at DESY and in HoBiCat, at BESSY, Berlin. As suggested by the cold test results, a few minor modifications have been implemented and a set of 8 improved devices is under construction for the installation in the second module of ILCTA at Fermilab. This reviewed design, together with a simplified helium tank in prototyping, should fulfil also the XFEL requests in term of performances and cost. In particular the use of thicker blades and their slightly different distribution along the circumference produces the increase of the tuner strength and stiffness that is needed in order to fulfil the pressure vessel regulations for qualification. As in the past, two equivalent devices, respectively in titanium and stainless steel, have been designed to maintain open the possibility of the use of a SS helium vessel once the required technology were developed. The results of the fatigue tests performed to validate the estimated life time are also presented.

INTRODUCTION

The original coaxial tuner design was subject to a large number of improvements [1]-[2] in view of a possible use in the future linear collider ILC.

The weight and the required installation space have been notably reduced, the driving mechanism has been simplified and the use of piezoelectric elements added the fast tuning capability to the original design. All the improvements have been implemented together with an important cost reduction and higher performances.

The first test performed in CHECHIA [3] confirmed the good design and provided answers to the tuning capabilities (slow and fast tuning), but pointed out some aspects that could be improved with little efforts. Therefore, in view of the construction of 8 tuners dedicated to the new ILCTA_NML test facility, small modifications have been introduced allowing to increment the tuner strength and stiffness, in order to satisfy the requirement recently set by the XFEL project.

DESIGN REQUIREMENT

The requirements set by the XFEL and ILC projects have been considered for the design of the blade tuner. In particular the procedures required for the certification of the pressure vessels in the XFEL project foresee the execution of test at room temperature on dressed cavity with a pressure inside the helium tank higher than 5.8 Bar. This value has been obtained by multiplying the design pressure by the safety factor defined in the European codes for pressure vessel.

Taking into account all the possible load cases, both in work condition and during transitory or test phases, the following structural requirements are needed:

- minimum compression strength: 10.9 kN
- minimum tension strength: 13.8 kN

The max tensile load can occur during the certification tests at room temperature, while the max compression load occurs with the tuner at the maximum extension if an accident occurs to the cryomodule producing an overpressure of 1.1 Bar in the isolation vacuum.

Besides these structural requirements the tuner must assure the following performances in terms of tuning capabilities:

- slow tuning: 0 – 600 kHz;
- fast tuning during flat-top: 0 – 750 Hz

DESIGN IMPROVEMENTS

In the last year the behaviour of the stainless steel blade tuner has been fully examined by means of experimental tests performed at room and cryogenic temperature. The tests at room temperature were set up in our laboratory (LASA) with the use of a single cell and an ad-hoc device to provide the right reaction force to the tuner movement. The goal of these tests was to verify the stiffness, the strength and the correct operation of the tuner from the mechanical point of view.

The horizontal tests at cryogenic temperature, performed first in CHECHIA and then in HoBiCat [4] on a dressed 1.3 GHz cavity, allowed to fully characterize the tuner behaviour for slow and fast tuning. The maximum tuning range has been proved to be higher than 600 kHz, and the piezo elements, 40 mm long, were capable to compensate the LFD and microphonics at 23 MV/m with significant margin.

Although the tests were successful, we identified some possible improvements that have been implemented in the 8 tuner built for the FNAL test facility ILCTA_NML. These improvements are here described.

An issue is that, after the introduction of the piezo elements, the load acting on the tuner is applied in only two points, therefore breaking the original symmetry and loading only the blades closer to the piezo position. The weight reduction 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 previous and actual configurations are reported in Fig. 1 and Fig. 2. 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.

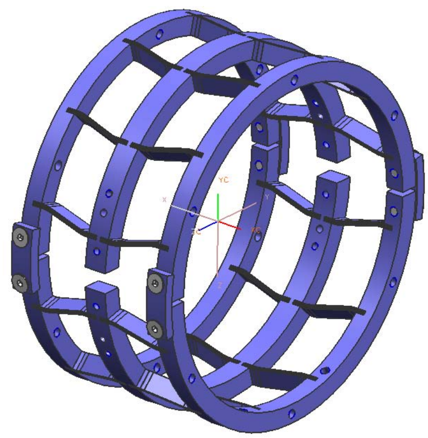

Fig. 1: blade tuner tested in CHECHIA and BESSY.

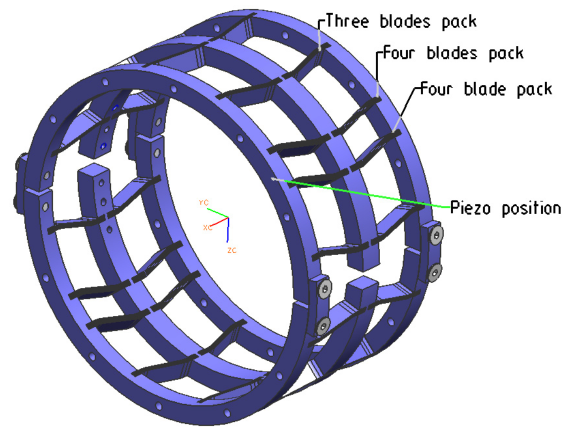

Fig. 2: improved blade tuner with the new blade positions.

IMPROVEMENTS VERIFICATION

Tuner strength

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. The main results here shown point out the tuner capabilities in terms of strength, stiffness and tuning range.

The FE model adopted is composed of 12435 solid 3D elements (11931 at 10 nodes, 504 at 20 nodes), 7920 shell elements adopted for the modelling of the blades, 323 beam elements to models the bolts. Connections, weldings and frictions are modelled by contact elements. This model also allows obtaining the stresses in the tuner rings, blades, bolts and driving shaft.

The axial strength results, both in compression and traction, are pictured in Fig. 3 and Fig. 4. For what concerns the compression load, the analyses account for the preload on the piezos, the moving of the tuner up to the maximum tuning range (12 screw turns) and an additional load growing up to the tuner collapse. From Fig. 3 it can be noted that the collapse load, 12.5 kN, is higher than the required one.

The traction limit load has been determined applying 4 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.

600 kHz of tuning capabilities have been kept, as for the previous version. It has to be noted that our computations are done assuming the material properties at room temperature and that for the yield limit the considered value is well below that at cryogenic temperature. The tuner tested at BESSY has been able to withstand a tuning range of more than 700 kHz without plastic deformations, due to the positive effects of the cold temperature [4]. A similar behaviour is expected for this improved tuner version.

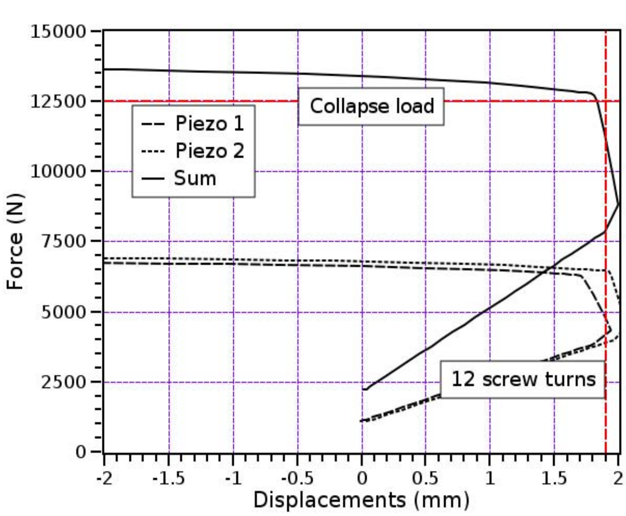

Fig. 3: FE results of the compression analyses.

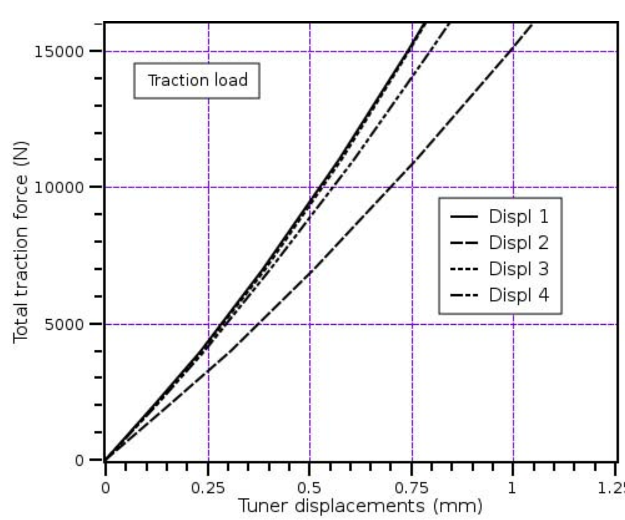

Fig. 4: FE results of the traction analyses

Motor torque

The force acting on the driving screw depends on the piezo preload and on the tuner position. At its maximum extension the axial force in the screw is lower than 1800 N. For an ideal screw-nut system and considering that the pitch is equal to 1.5 mm, the torque required at the end of the speed reducer is equal to 480 Nmm. Taking into account also the friction (efficiency coefficient η = 0.159) the total torque required is equal to 3.0 Nm. As a reference, the nominal torque value of the Phytron motor equipped with the 1:100 gearbox is equal to 30 Nm at 2.5 A of driving current. Being the used current of 1.0 A, it is anyway able to drive the tuner with margins with a still sufficient torque of 12 Nm.

FATIGUE CHECK

Tests performed in working conditions are significantly time-consuming and the identification of problems related to fatigue cycles in the blades would requires a considerable amount of time and money. For this reason some fatigue test has been performed on a simple blade assembly at the Structural Department of the Politecnico of Milano. These tests involved both inconel and titanium blades with thickness of 0.5 mm.

The setup of the test is reported in Fig. 5. The upper part of the test machine can move axially and has been driven with a sinusoidal motion law between 2 and 19 mm, therefore imposing a displacement to the blade pack varying between 1 and 9.5 mm. The displacement applied corresponds to a maximum stress of 960 MPa for the blades in inconel and 485 MPa for the blades in titanium.

The difference between the measured minimum and maximum reaction forces remained constants (see Fig. 6), with minor oscillations of the absolute values due to the precision of the used load cell.

After more than 100000 cycles no damage occurred to the blades, confirming the theoretical evaluation done on the basis of data available in literature [5].

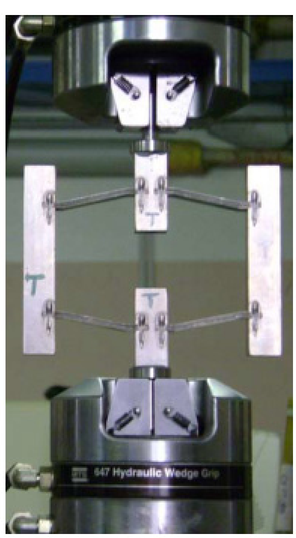

Fig. 5: specimen used for the fatigue test installed on the test machine at the Politecnico of Milano

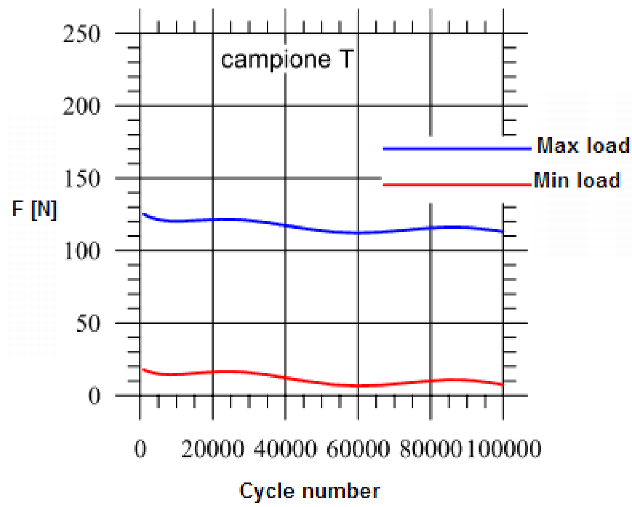

Fig. 6: fatigue test results (min and max reaction forces)

CONCLUSIONS

The coaxial Blade Tuner went through characterization test both at room and cryogenic temperature. The analyses of its behaviour and of the obtained results allowed us to implement minor 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 is currently being manufactured in 8 units by Zanon Company (Italy) and will be installed in the next months at the FNAL test facility ILCTA_NML.

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