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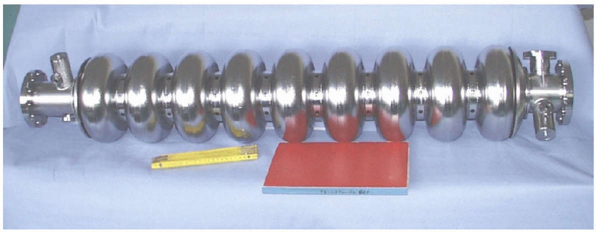

Piezo-Assisted Blade Tuner: Cold Test Results

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Abstract

The new simplified version of the piezo-assisted Blade Tuner has been tested at DESY in the horizontal cryostat CHECHIA in September. The tuner mechanism has been characterized at room temperature and one high gradient cavity of the last production has been recently tuned and equipped with a properly modified helium tank. In view of its possible adoption for the ILC, the cheaper stainless steel version of the tuner has been chosen for the September tests. In this paper the results are presented and discussed.

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The new simplified version of the piezo-assisted Blade Tuner has been tested at DESY in the horizontal cryostat CHECHIA in September. The tuner mechanism has been characterized at room temperature and one high gradient cavity of the last production has been recently tuned and equipped with a properly modified helium tank. In view of its possible adoption for the ILC, the cheaper stainless steel version of the tuner has been chosen for the September tests. In this paper the results are presented and discussed.

INTRODUCTION

The Coaxial Blade Tuner is a compact and cost effective tuner design, with no interference with the cavity end group area [1]. The integration of piezoelectric ceramic ("piezos") actuators adds the fast tuning capability to the Blade Tuner prototype already tested with success at DESY on the superstructures. It is mandatory for the superconducting accelerating structures, with high pulsed accelerating gradients, to compensate the Lorentz Force Detuning (LFD). In fact at high gradient the LFD, being proportional to the square of the accelerating field, could be up to 1 kHz over the whole RF pulse, with a cavity bandwidth slightly higher than 200 Hz. On the other hand, the resonance shift is quite slow, so an electromechanical device such a piezoceramic actuator is suitable for the purpose of fast compensation of the cavity detuning [2], [3]. Finally, it is even possible to extend the use of the piezos, inserting them in a closed loop, for the active compensation of the microphonic noise. In the perspective of large scale production in sight of the ILC and XFEL projects [4], two new blade tuners prototypes have been designed and built, a titanium and a stainless steel version. They both have been optimized to minimize material and construction costs, while fulfilling the reviewed performances required for the high gradient cavity operation up to 35 MV/m. The stainless steel version of the Blade Tuner (Slim SS Tuner) has been installed on a ZANON produced TTF cavity, the Z86 cavity (according to DESY classification number) to be tested inside the horizontal cryomodule CHECHIA.

TEST AT ROOM TEMPERATURE

Before starting the cold tests in CHECHIA, preliminary measurements on the blade tuners have been performed at room temperature at LASA to verify the main design parameters. To do this without the final assembly with the helium tank and the nine cell cavity, a special device has been designed, see Fig. 1, that hosts a single cell for RF measurements and reproduces the stiffness of the real installment. Both stainless steel (named as Slim SS) and Ti (Slim Ti) model of the Slim Blade tuner have been evaluated, together with a Superstructure tuner model (SuTu IV) taken as reference. During the tests the forces were monitored using button load cells, while micrometer range gauges were used for the measure of displacements. The number of turns performed by the driving screw has been measured and assumed as the input variable for the tests.

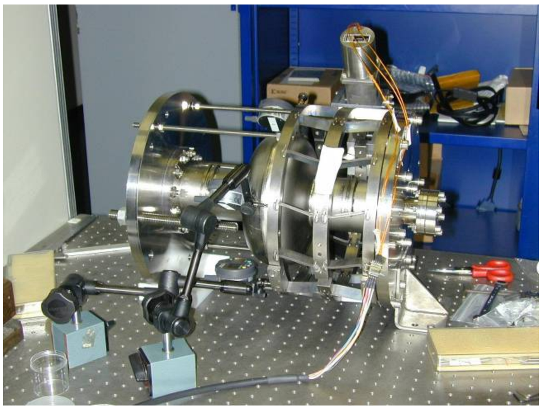

Fig. 1 - Slim Blade tuner installed in the test facility for room temperature checks

First of all, all tuners behaved as expected for what concerns the unloaded cinematic performances. Then a second series of test allowed us to evaluate the tuner behavior in its final configuration. In order to reproduce external conditions as near as possible to the working ones each piezo has been replaced by a proper combination of spring washers in series to a load cell, so that the total stiffness is almost equal to that of the 9 cell cavity integrated in the helium tank (about 3 kN/mm). The forces that should act on each piezo are separately recorded. The longitudinal tuner displacements in this configuration are shown in Fig. 2 and compared with those of the unloaded case (first test series).

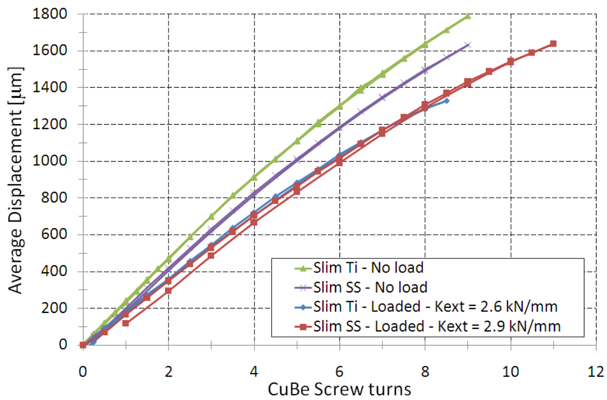

Fig. 2 - Comparison of loaded and unloaded results

The generated force is plotted as a function of the total tuner elongation, for different external stiffness, in Fig. 3. The maximum compressive load has been also checked for each tuner. Buckling of few blades, located close to the piezo holders, appeared for both slim tuner models at high load level. The slim SS tuner anyway proved to be able to sustain higher load level than the titanium one, repetitively showing a load limit of 6.15 kN.

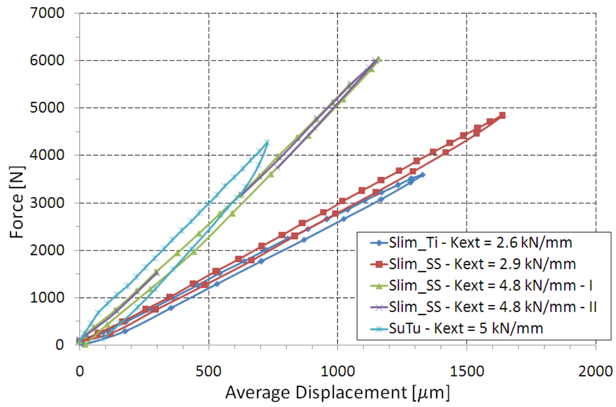

Fig. 3 - Compression force vs displacement curves

The results of these tests confirmed that the stainless steel slim version is reliable and it is stiffer and stronger than its counterpart titanium version. Therefore it has been chosen for first cold test to be performed in the horizontal cryostat CHECHIA. Some additional modifications have been anyway implemented in order to adapt the slim tuner to the old modified He tank available for cold test in CHECHIA: four stainless steel half rings have been realized to be sided to both the existing outer rings of the tuner. The Slim tuner CAD model with those additional element installed is visible in Fig. 4. Moreover, FEM analysis of the Slim SS tuner with the additional outer ring installed gave as result an expected increasing of 10 % in the maximum sustainable load limit, thus a limit load of 6.7 kN will be further on considered in the evaluation of the safety factor.

Fig. 4 - The additional adaptation rings, in grey, installed for the Slim tuner

BLADE TUNER TEST IN CHECHIA

Since the final version of the modified He tank with central bellow and stiffer end dishes design has not yet been manufactured, an old design modified He tank has been adapted and TIG welded on the cavity to perform these tests. To allow the modified helium tank installation on the Z86 cavity, two rings at the cavity ends have been electron beam welded at Lufthansa machine shop. The two ends of the Z86 cavity, showing the rings are displayed in Fig. 5. The Z86 cavity integrated in the modified helium tank, with support disks and bellow, after TIG welding at DESY and ready for Blade tuner installation, is instead shown in Fig. 6.

The Z86 cavity best performance in vertical cryostat has been E_{acc} = 24 MV/m with Q = $1.5 \cdot 10^{10}$, and has never been tested in horizontal cryostat. So considering that in horizontal cryostat tests the cavity performances seldom exceed the vertical cryostat ones (often this are even worse), we expect E_{acc} = 24 MV/m as the maximum field that could be obtained during the CHECIA test.

Fig. 5 - Z86 cavity after the rings EBW at Lufthansa facility

Fig. 6 - Cavity integrated in the modified helium tank in Halle III machine shop at DESY

The coaxial blade tuner installation has been performed in the machine shop of Halle III at DESY during the first week (# 35) of September. The tuner parts before assembling are shown in Fig. 7.

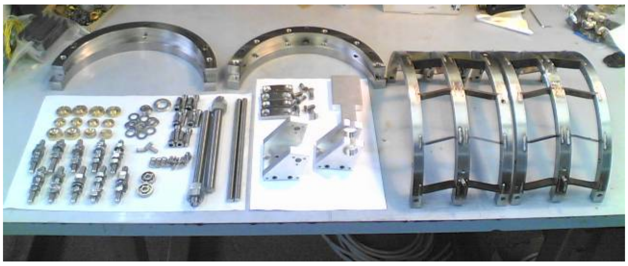

Fig. 7 – Tuner components before assembling

A stepping motor from Sanyo Inc. has been installed together with the usual TTF gear-box and harmonic drive (Fig. 8). Safety bolts on the 4 support screw rods have been installed too. Two 40 mm long and 100 mm^2 cross section Noliac piezos have been inserted symmetrically, with respect to the tuner axis, to perform the active LFD compensation. The complete tuner assembly, showing one of the two piezos is shown in Fig. 9.

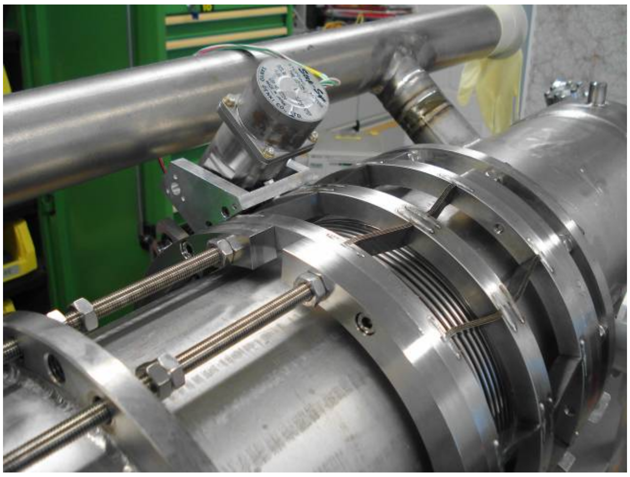

Fig. 8 – The stepping motor installed on the Slim SS Blade Tuner.

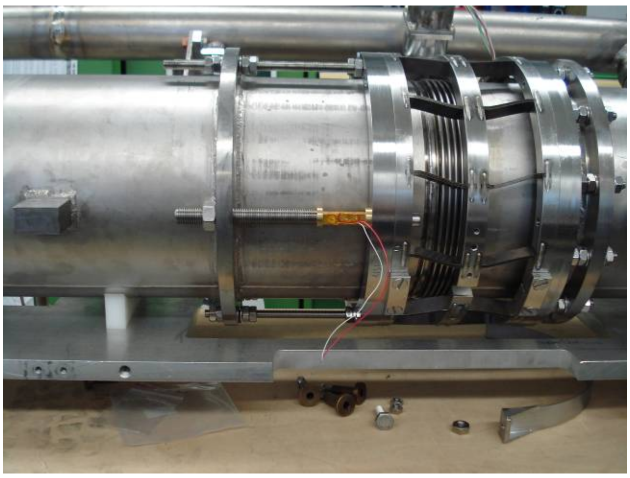

Fig. 9 - The Slim SS Blade tuner completely installed, piezo actuators are in place and preloaded.

Finally, a μ-metal foil has been adapted to fit the installed slim tuner and provide magnetic shielding to the cavity. The cavity was then inserted in CHECHIA to be cooled down for the power test. The cavity inside CHECHIA is shown in Fig. 10, were a part of the magnetic field shield can also be seen. During cooling down operations, the tuner must stand different load conditions, going from compression to tension. Therefore the piezo-ceramic main characteristics and the cavity resonant frequency were constantly monitored to check that everything behaved as expected.

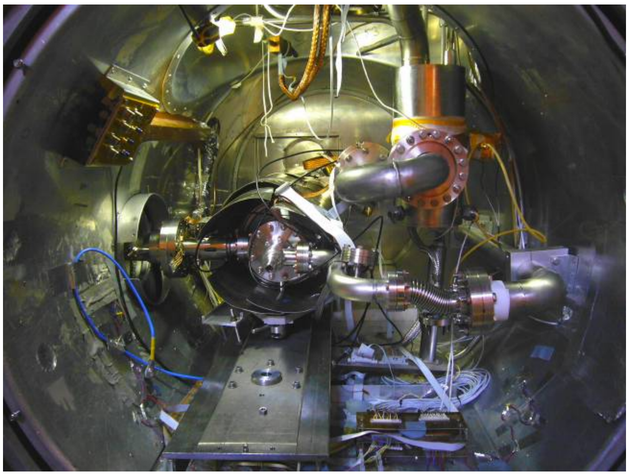

Fig. 10 – The Z86 cavity inside CHECHIA.

At the beginning of week 36, 2K stable conditions have been reached with a cavity resonant frequency of 1299.975 MHz, a value higher than that we have foreseen in the preparation phase mainly due to the uncertainty of the safety bolts positioning. The correct nominal 1.3 GHz resonance frequency was reached using the tuner driven by the stepping motor. After that the LFD compensation tests started. To compensate the detuning either one or both piezos, driven by a voltage pulse, apply a force in the opposite direction of the deformation induced by the Lorentz force, that decrease the resonant frequency. The characteristics of the pulse that drives the actuators are the same as those used in CMTB module 6 piezo test, a single sinusoidal pulse 2.5 ms width [5]. The maximum compensation efficiency is reached setting the proper time delay between the RF input power and the piezo driving pulses. The right pulses synchronization has been investigated sweeping around different piezo pulse timing, and the optimum one resulted to be an advance time of 0.95 ms before the RF pulse. At the nominal 1.3 GHz resonant frequency the found LFD detuning, around 330 kHz, was successfully compensated with just one piezo actuator. Since the mechanical pre-load on piezos was found lower than the designed value (at this frequency), different pre-load conditions have been tested, tuning the cavity to higher frequencies then the nominal one. Again the entire Lorentz force detuning shown by Z86 cavity at full gradient has been successfully compensated in each piezo configuration. The detuning is computed by a Matlab® script that samples the amplitude and phase of the forward ($U_{forward}$, $\phi_{forward}$) and of the transmitted powers (U_{probe}, ϕ_{probe}) and find the frequency difference $\Delta\omega$ through the following relation ($f_{1/2}$ is about 230 Hz, where of course $\omega_{1/2} = 2\pi f_{1/2}$) [5]:

$$\Delta\omega = -\frac{1}{2\pi}\left(\frac{\partial\phi_{probe}}{\partial t} - 2\omega_{\frac{1}{2}} \cdot \frac{|U_{forward}|}{|U_{probe}|} \cdot sin(\phi_{forward} - \phi_{probe})\right)$$

Plots of cavity detuning and phase of the RF transmitted power ("Probe") data are reported in Fig. 11 and Fig. 12, where it is shown that 300 Hz of detuning during the RF pulse flat top has been fully compensated and RF phase stability greatly improved. The graph shown here correspond to the best results obtained in the higher pre-load on piezo configuration, (i.e. 1.2 kN total pre-load force). This result is accomplished driving only one of two installed piezo actuators with less than 1/3 of the nominal maximum driving voltage (200 V @ RT).

Finally, the measurement of the slim blade tuner tuning range has been performed, using a Vector Network Analyzer to measure the cavity resonant frequency while moving the tuner stepping motor. A tuning range of 520 kHz has been achieved with 13 complete screw turns. The graph of the tuning range is shown in Fig. 13.

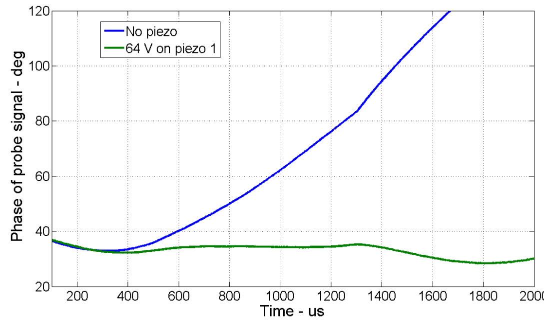

Fig. 11 - Phase of Z86 cavity probe with and without piezo active compensation

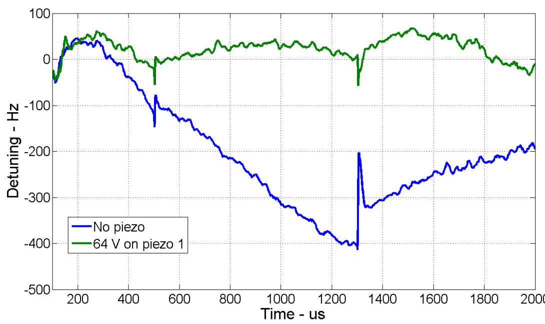

Fig. 12 - Z86 cavity detuning with and without piezo active compensation

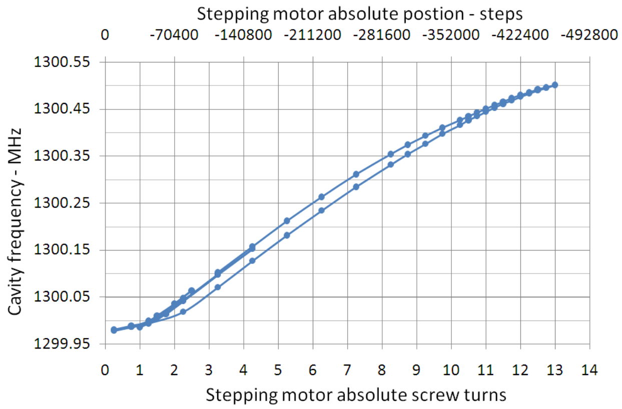

Fig. 13 - Blade tuner tuning range with 13 complete screw turns.

The tuner sensitivity, i.e. the frequency shift as a function of the screw turns, has also been computed from the test data and reported in Fig. 14. From the graph it can be seen that the peak sensitivity value of 50 kHz per screw turn expected by the tuner design is confirmed. Two complete turns were indeed needed from the lower end of tuning range for both piezo actuators to be in good contact with the tuner and to allow reaching the nominal tuner sensitivity. In this range, ad-hoc springs installed below piezo holders were keeping actuators firmly in place and only slightly detuning the cavity (generated force below 100 N).

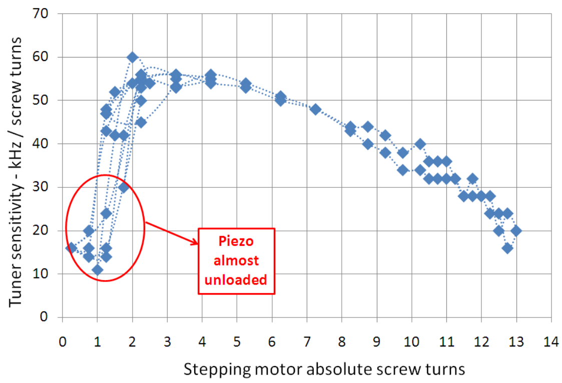

Fig. 14 – Frequency shift vs screw turns sensitivity for the Slim SS Blade tuner.

A comparison of the blade tuner performances with the present TTF piezo tuner ones are shown in Tab 1, where ACC6 refers to LFD test for cavities in FLASH module # 6. LFD results, averaged over ACC6 cavities, have been re-scaled for Eacc of 23 and 25 MV/m to correlate them to the blade tuner test data. In each case both the amplitude of piezo voltage and its ratio with the corresponding maximum nominal voltage (120 V for PI piezo, 200 V for NOLIAC) are shown.

Test	Tuner	PZT #	Load [kN]	Δω [Hz]	Eacc [MV/m]	Vpiezo [V]	V/Vmax
ACC 6	TTF	1		250	23	45	0.375
ACC 6	TTF	1		300	25	54	0.45
Z86	Blade	1	0.2	332	23	75	0.375
Z86	Blade	1	1.2	308	23	64	0.32
Z86	Blade	2	1.2	308	23	56	0.28
Z86	Blade	1+2	1.2	308	23	50	0.25

Tab. 1 – Comparison between coaxial and TTF piezo performances.

CONCLUSIONS

Although cold tests in CHECHIA have been performed in short time, results are more than successful. It is now certainly possible to confirm that the coaxial SS Blade tuner has successfully passed the prototype test. Every tuner component went through the complete cool-down and warm-up procedures without damages or failure. 520 kHz of slow tuning range has been achieved over 13 complete screw turns. The entire LFD shown by Z86 cavity at the maximum reached gradient of 23 MV/m has been compensated in different load conditions and with each possible piezo configuration. Moreover the Slim Blade piezo tuner revealed, when sufficient preload is set on piezos, an higher efficiency in LFD compensation if compared to present TTF tuner. Therefore, thanks to the experience gained during this test, the cavity preparation procedure will have to be refined to ensure the best piezo preload at the nominal resonant frequency. A LFD value higher than expected for the achieved gradient has been found. This is probably due to the limited axial stiffness of the old He tank used. With the final Helium tank design, that will be soon ready for construction, it is expected to restore or even lower the usual Lorentz force coefficient. Anyway, several issues shown by the performed measurements need further deepening test activity, and minor modifications to the tuning device must be taken into account to completely preserve the installed cavity from any potentially critical deformation. These further developments will allow to confirm stainless steel as the correct material choice for the industrialization phase, leading to significant cost reductions. Further analysis of Slim tuner performances will certainly came from the foreseen cold test session to be held at BESSY facility.

Finally, the present stage of coaxial tuner development, the Slim SS Blade tuner equipped with the cheaper piezo option, 40 mm stacks instead of 70 mm previously foreseen, can be considered as a valid reference design, surely fulfilling XFEL requirements. This tuner configuration with minor modifications, currently under development, and coupled to the final He tank can also fit the even more severe specifications foreseen for ILC.

ACKNOWLEDGEMENTS

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