A NEW TUNER FOR TESLA

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Abstract

The TESLA cryomodule design, with very low clearance within cavities, and the performance required to the Tesla cavities, in term of Lorentz detuning, pointed out hard requirements on the tuner system that can not be completely satisfied by the actual TTF design. To achieve the required stiffening and tunability range within the clearance requirements we designed a tuning system based on a complete flexural system. The main movement is driven by a leverage system to amplify the forces and increase the resolution to the required one. We present the design, the conceptual and technological solution of the tuning system and of its components. Warm characterization of the main components and cold tests confirmed the expected performances. Four tuners of this new design have been installed on the superstructures helium vessel to be operated during the superstructure tests on TTF, scheduled for this summer.

1 INTRODUCTION

The design of the TESLA cryomodule, that has been, deeply studied and presented in the TESLA TDR [1], is driven by the request of the very high filling factor to reduce the accelerator length or to increase the effective accelerating field. One of the main improvements has been achieved in the interconnection between cavities. The TTF modules have installed cavities with a constant distance of 1384.8 mm, corresponding to a cell-to-cell distance of about 350 mm. The cavity interconnection is realized by means of a bolted bellow. In the TDR design the bellow has compressed stainless steel flanges, which reduce the total cell-to-cell space to 283 mm, as shown in Figure 1.
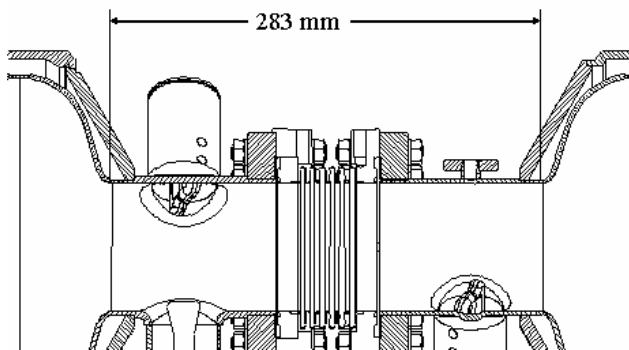

Figure 1. Reference geometry for the cavity interconnection. The bellow has compressed stainless steel flanges reducing the total distance between two consecutive cavities to 283 mm, cell to cell.

This solution is incompatible with the actual tuner design [2], because its overall dimension exceeds the available space. Hence a new tuner, fulfilling the expected clearance requirements, has been developed. A second constraint, from the Lorentz detuning, drives the necessity to upgrade the TTF tuner design in order to be compatible with the 34 MV/m accelerating field, needed for the TESLA 800 upgrade. The last constrain comes from the stiffening requirements of the tuner mechanism.

The tuner is designed to be coaxial with the cavity and, as the TTF one, by means of the helium vessel it deforms the cavity geometry, changing the length of the entire system and consequently the resonance frequency. This design has been originally inspired by an idea of H. Kaiser [3] that studied a possible tuner for the superstructure option in TESLA

2 TUNER DESIGN

The tuner assembly is mainly composed of two parts, the movement leverage and the bending rings. Figure 2 shows the complete assembly of the tuner as mounted over the cavity helium vessel.

The leverage system provides the amplification of the torque of the step motor, dramatically reducing the total movement and increasing the tuning sensitivity.

The step motor is rigidly connected to the helium vessel and produces a rotation of the big arm in the center of the tuner. The movement of the big arm induces the rotation of the bending system that changes the cavity length.
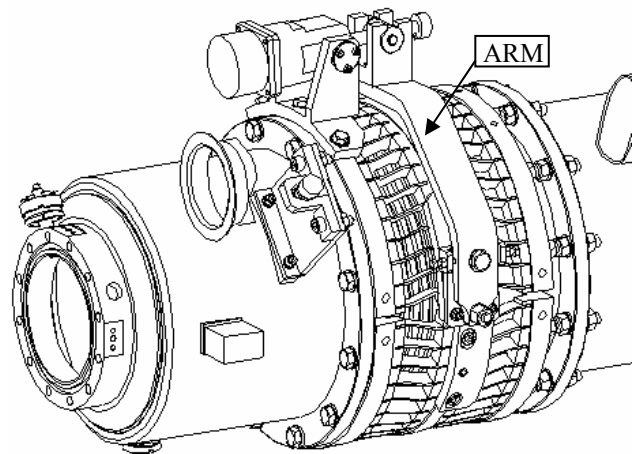

Figure 2. Drawing of the tuner assembly with on the top the leverage system, and all around the vessel the bending rings with the "blade" plates that produce the axial movement.

The bending system consists of three different rings: the two external rings, which are rigidly connected to the helium tank, and the one at the center, symmetrically divided in two halves. The big central arm is connected to the bending system in a way to produce the right rotation and the correct axial movement that provides the tuning.

The rings are connected by thin titanium plates (blades) that can change the cavity length (compression and tension) as a result of an azimuthal rotation in opposite directions of the two halves of the center ring.

The blades are positioned in such a way that all reactions are internal forces and do not load the external vessel and the cavity. This solution provides much more stability of the working point. The blades are also the structural elements that increase the longitudinal stiffness of the tuning system.
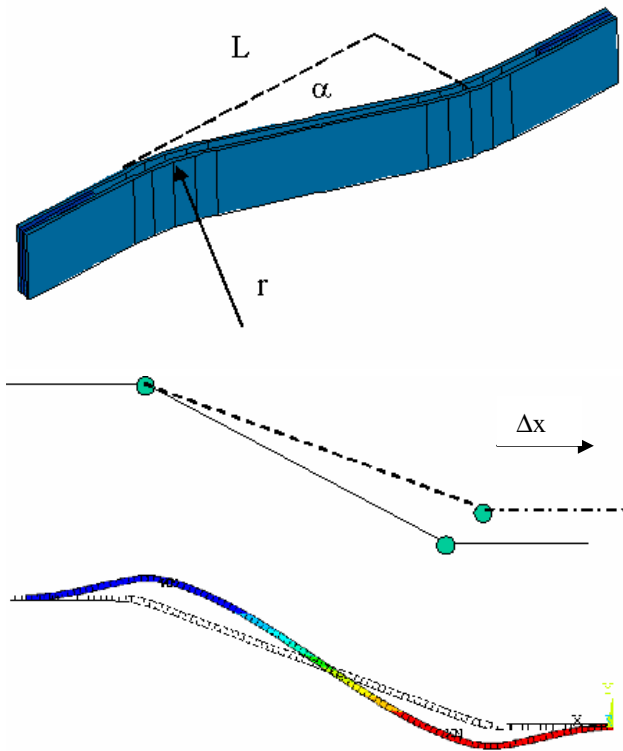

Figure 3 From top: parameterization for the analytical study of the blades; cinematic of the blades for the bending system during tuning; FEM test of the deflection of the blades for the longitudinal stiffening.

The shape and the dimension of the blades are the critical point for the definition of the mechanical properties of the entire mechanism, so we have deeply studied by analytical models and then performed FEM calculations to analyze the effective behavior of these components. Different blade dimensions and shapes have been tested, based on the parameterization shown in Figure 3. Stresses and deformations have been calculated in first order approximation by the elasticity theory and then checked with finite element codes.

The angle (α in the picture) and the total length 'L' define the cinematic properties of the structure, i.e. the ratio between lateral and axial movement, and as a consequence, they define also the force enhancement factor. The radius of curvature 'r' in the junction is optimized to reduce stresses. Two kinds of movements are considered in the analysis. The first is the "tuning" that is the common movement when one end is fixed and the other moves as result of the rotation of the half ring. The second deformation is that related to the "longitudinal stiffening test" where one end is fixed and the other can just slide. This is the situation with the tuner fixed in a position while Lorenz forces or pressure are loading the cavity or the Helium vessel and the tuner is providing the stiffening to the system.

With such parameterization and with an analytical approximation on the behavior of the blade system, the specifications in term of tunability range, longitudinal stiffening, tuning force, tuning sensitivity can be included in the geometrical design of the blades and in their optimal distribution (in number and position) on the rings.

The required axial stiffening of 20 µm/kN has been achieved using 80 double blades each 0.5 mm thick and 15 mm height as a good compromise between stiffening and operation range. The blades have been cutout from the same titanium plate and deep drawn to achieve the very high shape tolerances that guarantee the uniform distribution of stresses and deformation that is necessary for the correct operation of the bending system. A non uniform response of one part of the bending system would produce, in fact, an undesired lateral movement, compromising the entire system.

An intense use of the electron beam welding for the construction of the bending rings, together with an accurate development of the fabrication tools succeeded in the reduction of the costs with the definition of a reliable and stable production process (see Figure 4 for a detail of the welding of the blades during the production of the bending system).
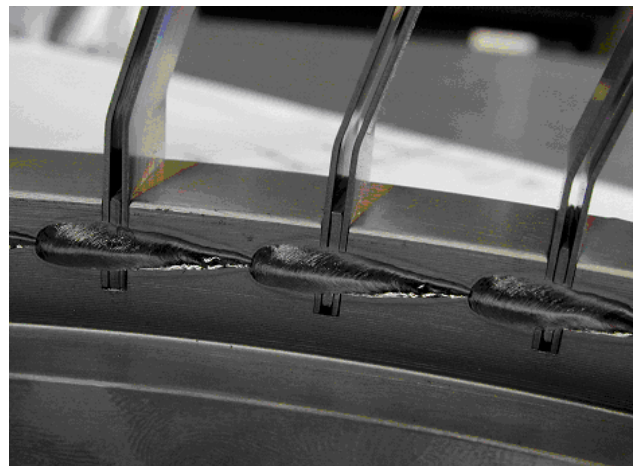

Figure 4 Detail of the blades welding on the half ring . Each bending element consists of a double blade with a spacer, for cost optimization

3 ROOM TEMPERATURE TESTS

To check the calculation and to verify the functionality of the bending system, some room tests have been carried out. Purposes of the tests are the measurement of the longitudinal stiffening with and without the step motor to define the stiffness both with and without the leverage system.

A prototype of the bending system has been fixed on a accurate measuring machine while the central ring was fixed to avoid internal rotation (in this configuration, due to the symmetry of the inner ring, the tuner is in the same configuration of the operative one, simulating a leverage system with infinite stiffening), the same measurements have been repeated with the leverage mechanism to check its influence too. The structure has been compressed with different loads while monitoring, with micron precision sensors, the deformation of the mechanism.

To control the measurements reproducibility and to verify the good elastic behavior of the blades we performed load and unload sequences checking the repeatability of the loading curves.

Measurements results pointed out that good agreement with predicted stiffening constant has been achieved confirming the design and the manufacturing procedure of the bending system. In fact its stiffness resulted equal to 12 μm/kN.

The leverage system results to be very stiff too but some improvements are needed to achieve the TESLA requirements for very high gradients. In fact the overall stiffness results in 40 μm/kN that is higher than the design value (20 μm/kN). A leverage system completely based on stiffer bending joints is under development.

4 COLD TEST

The new tuners have been installed on a 9-cell TTF cavity with appropriate modifications to the helium vessel and flanges (see figure 6) and tested in the horizontal cryostat CHECHIA for mechanical and RF characterization at 2K

In particular tuning range and tuning sensitivity has been tested and compared with the original TTF tuner to check their compatibility with the TESLA and the superstructure requirements.

Table 1. Comparison between actual tuner and new tuner during the cold test

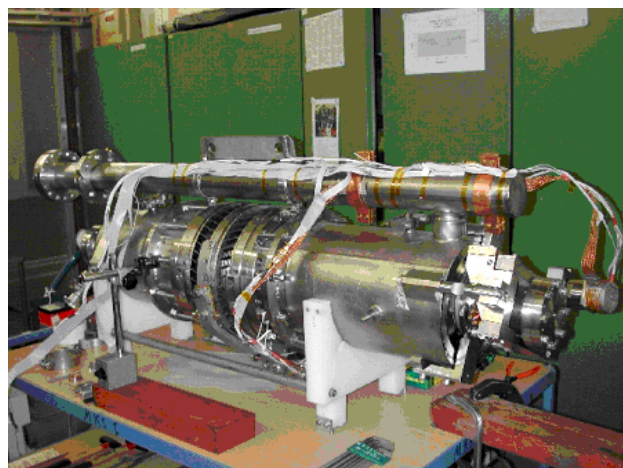|	Standard	New Tuner
Tuning range [mm]	1.9	1.0
Tuning range [kHz]	820	440
Sensitivity [Hz/step]	0.74	0.38
Δf. warm/cold [MHz]	2.30	2.3
ΔF (4.2K 2K) [kHz]	30	70

Figure 6. The new tuner installed on a 9 cell cavities before the test in the horizontal cryostat.

The same tests have been repeated on the 4 7-cells cavities of the superstructures [4] to have good statistics on tuner properties and to prepare them to be full tested in a properly modified TTF second generation module. According to specifications, tuning range results in about 1 mm, while the sensitivity is about 0.4 Hz/step. Table 1 summarizes the properties as measured in horizontal cryostat compared to the standard 9-cell tuner.

The conclusion of the cold test is that the new tuner satisfied the TESLA requirements even for the superstructure option.

5 CONCLUSION

The new tuner for TESLA has been presented with the criteria used during the design. Room temperature test and cold test confirmed the calculations in term of stiffening, tuning force and sensitivity. The tuner now assembled on a superstructure succeeded in the 2K tuning for operation and will be power tested by the end of the year. Future works include the possibility to add a piezo actuator for dynamic compensation during RF pulsed operation.

6 REFERENCES

[1] TESLA Technical Design Report, DESY-2001-000, ECFA-2001-209,TESLA-2001-000,FEL-2001-000, March 2001.

[2] R. Brinkman, et al. eds. "Conceptual design of a 500 GeV e+e- linear collider with integrated X ray laser facility", DESY Report, 1997–048 (1997).

[3] H. Keiser "New Approaches to Tuning of TESLA Resonators" presented at SCRF99.

[4] H. Sekutowicz et al., "Superconducting superstructure for the TESLA collider: A concept", Physical Review Special Topics AB, 1999.