NEW APPROACHES TO TUNING OF TESLA RESONATORS

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Abstract and Introduction

Tuning of *warm* TESLA cavities for frequency and flat field presently is done by plastic change of length of individual cells, leading to troublesome uncertainty of resonator length. A new type of tuning device has been build and tested to show marked reduction of this problem.

The tuner for the *cold* cavities in present TESLA structure consumes about 1/2 rf wave-length in cavity connection-region, crowding couplers, flanges and bellows located here which consume an rf wave-length in addition. A new type of tuner which is situated in the He-tank region is presented. It saves about 115mm per cavity of linac length.

The newly proposed "Superstructure" for TESLA necessarily needs such a tuner, since the group of four 7-cell cavities requires 1/2 rf wave-length space between cavities which could not accommodate the tuner in addition to couplers, rf-pick up and flange.

The proposed tuner acts to change the length of the cavity He-vessel which is fitted with bellows at the tuner position. The resonator, being rigidly fixed to both ends of the He-vessel, will follow the length change of the vessel, and therefore be tuned.

1 WARM TUNING SYSTEM

A new type of device for warm tuning of rf resonators, with goal to reduce tuning–induced length change, cell form distortion and bending of resonator axis, has been built and tested on a TTF cavity.

1.1 Description of Tuning Device

Fig. 1 Tuning clamp, extended

A steel chain with 8 curved links is fitted with bronze jaws conforming to curvature of links on the outside and to form of cell of cavity on the inside(Fig.1).

There is a bronze jaw to each link. When curled up to a ring(Fig.2), the chain length can be adjusted with an M10 screw to produce change of diameter of assembly. Friction from relative circumferential motion between steel chain and jaws is reduced by needle bearings between steel and bronze parts. The bronze blocks are loosely attached to chain links, but left free to move circumferentially.

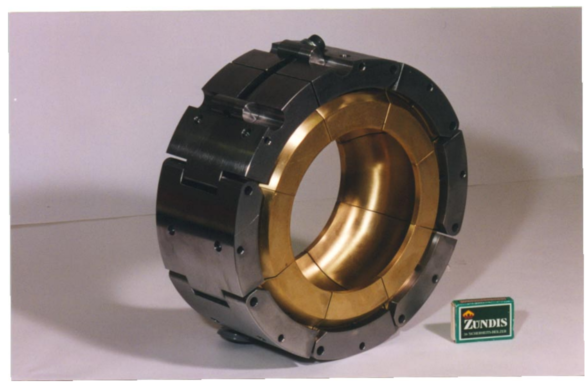

Fig. 2 Closed tuning clamp

1.2 Functioning Principle of Tuner

When placed over a TESLA cavity cell and tightened with the M10 screw, the tuner acts on diameter of cell much like a hose clamp. Since this "clamp" conforms to cell shape, confining it nearly down to the stiffening ring of cavity, the cell, where within bronze jaws, cannot grow in length and will largely maintain its original form during tuning.

To tune a cavity after frequency has been measured, the circumference U of tuning clamp is reduced in a controlled way, then the clamp is relaxed and the frequency measured again. This process is repeated until correct frequency is reached.

The tuning ring can, of course, only increase frequency. If one accidentally overshoots the desired value, the tune of cell affected can be corrected by reducing cell length in conventional tuning manner.

1.3 Test of Tuner and Results

The middle cell of a 9-cell TTF Cavity was placed into the tuning clamp(Fig.3) with the goal to raise cavity tune by 100kHz.

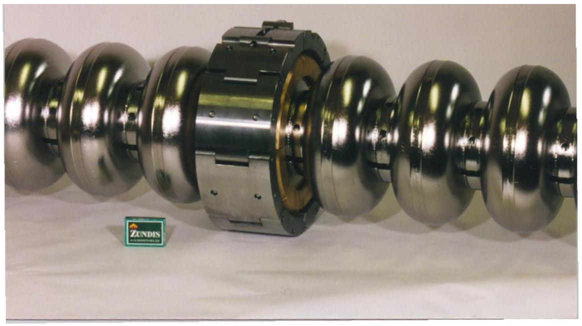

Fig. 3 Tuning clamp, closed over cavity

Change of clamp circumference and frequency shift Δf measured after again relaxing clamp, were measured and are recorded in Table 1 and plotted in Fig. 4. Total cavity length was also monitored and recorded. It is seen that ΔU must reach about 2mm before the cell will become plastic then df/dU rises sharply to , at around 3mm take on a constant value, allowing prediction of ΔU needed to produce desired frequency shift. The target of Δf =100kHz was hit exactly with fourth tuning step. The tune was then conventionally restored by reducing the cell length(actually, the frequency change was 110Hz). From the cavity length values, also recorded in Table 1, it follows that the tuning clamp for Δf=100kHz changed the cell length by only 0.15mm, which amounts to only 60% of length change of 0.25mm(corrected for overshooting targeted Δf) caused by conventional tuning.

ΔU[mm]	Δf[kHz]	Cav.Length[mm]
With tuning clamp. Δf measured after application of ΔU and subsequent relaxation of clamp		
0	0	1283.0
2.25	7	
3.00	25	
3.38	52	
4.13	100	1283.15
After restoration of original frequency by conventional tuning		
	-10	1282.87

Table 1. Experimental data of test of tuning clamp.

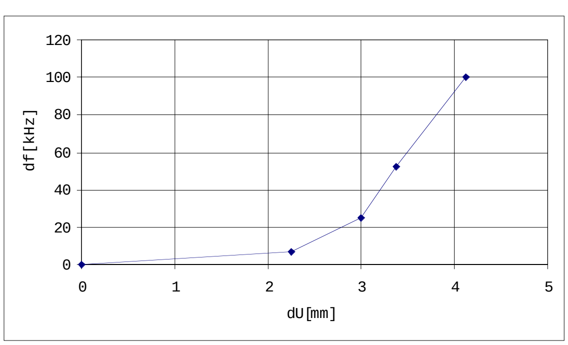

Fig.4 Frequency shift as function of change of tuning clamp circumference and subsequent relaxation.

1.4 *How to Tune Multi Cell Cavities with Tuning Clamp*

As many clamps, as the resonator has cells, will be mounted with link located near chain center, on axial guide system, leaving the clamps axially free but constrained to remain on common axis. The present M10 screw is replaced in all clamps by a more robust one that is driven by a stepper motor. The cavity, fabricated with assuredly too low resonance frequency in all cells is placed into the opened chains, which are then closed but left untightened. Tuning then proceeds as usual under computer control of stepper motors by change of *cell diameter* effecting frequency changes as in present conventional device. The latter, however, alters predominantly the *cell length.*

Since the cavity during tuning is confined straight by the clamps, no marked bending of axis during tuning need be expected. Straightness might even be improved by relaxation of possible bending stress when local plasticity occurs during tuning. The present device has no comparable feature.

1.5 *Summary*

The test results of the experimental tuner show improvement with respect to the present conventional tuner:

- Reduction of tuning induced relative change of cell length dl/df by 40%.
- Tuning induced distortion of cell form reduced by embedding cell in the bronze jaws during tuning.
- Straightness of cavity axis is expected to be maintained or even improved.
- Tuning principle can also be extended to tuning multi cell cavities.

2 NEW COLD TUNER FOR TESLA

Why bother to design a new tuner for TESLA? Both, the present TTF structure and a contemplated new one for several reasons call for design change[1]. The present tuner[2] is being used successfully in TTF. One major drawback is its occupying more than λ/2(λ=rf wavelength) of 3/2λ total space between cavities, or roughly 10% of cavity spacing module in TTF structure, i.e. of linac length. One would like to save the cost of building this unnecessary linac length by designing a tuner, not adding to length of structure.

Further, the proposed “Superstructure” for TESLA[3] can function only with λ/2 space between resonators in a superstructure. In this space must be located HOM-coupler, rf pick-up and joint in beam tube, leaving absolutely no room for tuner.

Finally, the *measured* compliance of present tuner of 25μm/kN leads with the Lorentz-force induced axial force of 31N at 25MV/m to tune shift of about 300Hz(p. 149of [2]). If total tune shift at 25MV/m due to Lorentz forces is set at 500Hz, only 200Hz would be left for the additive contribution from cell-form change, which actually is close to the more recently calculated value of 197 Hz[4]. Maintaining the permissible total tune shift at 500Hz, one could increase tune shift from cell form change by substantial decrease of wall thickness and, therefore, cavity price, by stiffening the tuner and thus reducing its contribution to the tune shift.

A *much stiffer* tuner, consuming *no length* in connection region between cavities, is therefore the outstanding design goal for the new tuner.

2.1 Description of Design of New Tuner

The He-vessel of the cavity is made the location of tuner by rigidly joining the cavities ends to those of the He-vessel and placing a bellows from titanium into a missing section of the vessel. The tuner bridges the bellows and acts on the tank sections to change total tank length and thereby also that of the cavity, thus tuning it. The design of the new tuner is shown in Fig.5.

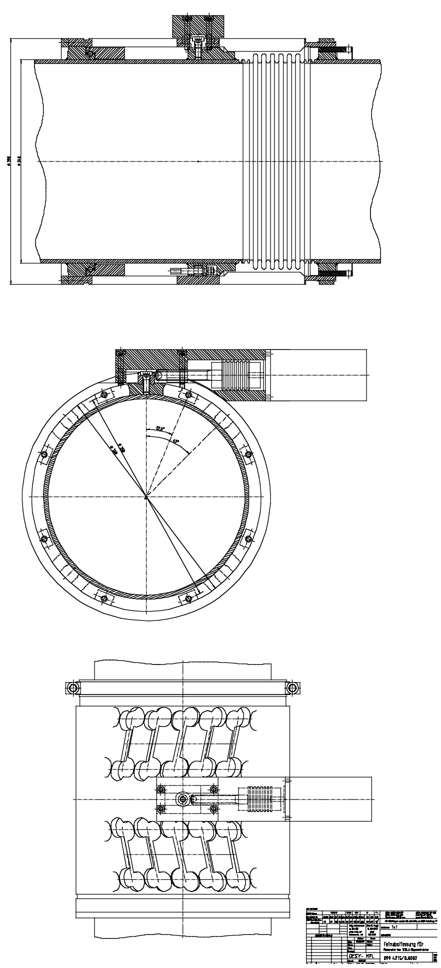

Fig. 5 Drawings of tuner: Axial section, cross section and top view (top to bottom)

The bellows in He vessel is bridged by a concentric “tuning tube”, fixed at its ends to the tank tube sections. The tuning tube’s length is variable, because rotating its short central section with respect to tank will change the angle of the two rows of links which join the central section of tuning tube with the end ones, thus changing tuning tube length. The links are generated by fabricating dog bone shaped breakthroughs leaving from the otherwise plain tube wall only the link bodies and the leaf-spring joints connecting them to the tuning tube sections. The central section of the tuning ring is rotated via screw, driven by 3:1 gear reduced stepper motor. To keep central section from being laterally offset by force of the screw, it is kept concentric with tank tube by 8 pre loaded rollers. The tuning tube is made from TiAL6V4 alloy for high yield strength needed in leaf- spring joints. All other parts are made from Ti II or Ti III. Axial adjustment of tuning tube relative to one of the tank sections is provided by connecting ring with right- and left hand threads. This adjustment serves to roughly set cavity length to produce the correct warm frequency. The thread-joints are made play-free by tightening the external clamping ring over whole joint. Some technical data are contained in Table 2. The cavity will axially always be under tension, since this provides greater stability against its becoming plastic, than under compression[5]

Angular range of links of tuning tube (relaxed: 12^0)	$12^0 \dots 8^0$
Tuning range, total	1.7mm
Stress in lever joints, max.	460N/mm^2
Yield strength of material of tuning tube	890N/mm^2
Compliance of tuning system	4.4 μm/kN
Transv. spring rate betw sections, He-tank	10.5kN/mm
Resolution of frequency adjustment	10Hz

Table 2 Selected Technical Characteristics of Tuner

2.2 Evaluation of Tuner Design and Summary

The tuner described, fulfills the design goals: It permits $\lambda/2$ distance between the 7-cell cavities and thus lays the ground for realization of Superstructure. It consumes no length, which would make longer the linac. Therefore, in present structure with 9-cell cavities about 10 % of linac length could be saved. It is by factor of 5.7 more rigid than present tuner. Its contribution to Lorentz force induced tune shift at 25MV/m will be only 53Hz, reducing frequency shift of present tuner by about 250Hz. This tune shift “gain” would permit either cheaper cavities with thinner wall or unchanged cavities with higher field. Its rigidity against lateral offset between tank section at bellows is probably adequate with 10500N/mm. The tuning tube is completely free from axial play and insensitive to possible thin layers of frozen gas forming on its surface. The stepper motor, concerning 1.8K operation, seems to be the most vulnerable part, but could also be placed in warmer regions of cryostat and drive the screw via a shaft. The only source of backlash in system will be the gear reduction.

The tuner OD is kept rather small to conserve radial spread of He-vessel and hence of the vacuum vessel. The relatively great length of tuner will very likely not obstruct other component.

3 REFERENCES

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