DESIGN OF A COMPACT LEVER SLOW/FAST TUNER FOR 650 MHz CAVITIES FOR PROJECT X*

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Abstract

Fermilab is developing 5-cell elliptical 650 MHz β=0.6 and β=0.9 cavities for project X [1].

A compact fast/slow lever tuner intended for both types of cavities has been developed for final tuning of the resonance frequency of the cavity after cooling down and to compensate the resonance frequency variations of the cavity during operation coming from liquid helium pressure fluctuations. The updated helium vessel (presented at this conference) is equipped with the tuner located at one of the end of the cavity. The tuner design and results of ANSYS analysis of their properties are presented.

INTRODUCTION

One of the important parts of the mechanical design of a helium vessel-cavity assembly is a compact fast/slow tuner for final tuning of the resonance frequency of the cavity after cooling down and to compensate frequency detuning due to helium pressure fluctuations and Lorentz force detuning.

TUNER REQUIREMENTS

The cavity operational and test requirements are summarized in Tab. 1.

Table 1: Cavity Operational Requirements

Parameter	Value
Frequency	650MHz
Bandwidth	45Hz
Operating node	CW
Operating gain per cavity	17.7 MeV
Maximum Gain per cavity	> 21 MeV
Sensitivity to He pressure fluctuations	< 15 Hz/mbar
Field Flatness dressed	> 90%
Operating temperature	2.0 K
Operating Pressure	30 mbar
MAWP	2 bar (RT), 4 bar (2K)
RF power input per cavity	up to 100 kW (CW)
Cavity longitudinal stiffness	< 10^4 N/mm
Tuning sensitivity	> 180 kHz/mm

In order to accomplish the requirements for frequency range and resolution, the tuning systems for cavities of narrow bandwidths shall integrate a coarse/slow and a fine/fast mechanism engaged in series. The former normally utilizes a mechanical system which applies forces between the He vessel and cavity flange to squeeze or stretch the cavity. An electromechanical actuator is the system (stepper motor/gear box & spindle) to convert rotation from the stepper motor to linear stroke. An electromechanical system actuates the coarse tuner with large stroke capability but limited resolution. Fine/fast tuners usually contain piezo-electric actuators with limited stroke but virtually infinite resolution. The fine/fast tuning system allows integration of active compensation of cavity frequency detuning due to helium pressure fluctuations or by Lorentz forces or other external perturbations (microphonics).

The coarse tuner is predominantly used to consistently achieve the resonant frequency during cool-down operations and to take up mechanical lash in the tuner mechanism. The range necessary to compensate for the cool-down uncertainties is estimated to be 50 kHz. In the event that a cavity must be detuned as a result of a malfunction, the coarse tuning system must be able to shift the frequency away from resonance by at least 100 bandwidths (equal to ≈45 kHz) so that the beam is not disturbed. To take up mechanical lash in the tuner mechanism additional deformation of the cavity is needed, corresponding to a 20 kHz frequency shift. The total frequency shift is 70 kHz. The requirement on the tuning range considered a safety margin of 2.0. The cavity tuning sensitivity is 180 kHz/mm. The coarse tuner should be able to change the cavity length by ~0.8 mm.

The required accuracy of the frequency tuning is 4 Hz (or ~20 nm in cavity length). Based on the parameters of different manufactured SRF cavity tuning systems one can conclude that it will be a big challenge for any type of coarse mechanical tuning system to deliver this level of precision. Taking into account backlash & hysteresis of the cavity/slow tuner system, the requirement on the resolution of the coarse tuning system was set to 10 Hz. One can conclude that the coarse tuning system alone (without assistance from a fine/fast tuner) can't deliver the required cavity tuning accuracy (2Hz).
Also it is conservatively assumed that the coarse system cannot be operated during beam acceleration; it is thought

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that the vibration of a stepper motor may induce vibrations in the cavity severe enough to disrupt operation.

The expected limitations of the coarse tuning system outlined above stress the importance of a reliable fine/fast tuning system. The fine/fast tuner is designed to

- Assist the coarse tuning system to set the cavity frequency to the required 2 Hz accuracy
- Compensate the frequency shift of the cavity induced by fluctuations of the helium bath pressure
- Compensate cavity detuning induced by Lorentz forces
- Compensate cavity detuning induced by external vibrations (microphonics).

A particular design effort shall be dedicated to facilitating access to all actuating devices of the tuning system from access ports on the vacuum vessel. All actuating devices must be replaceable from the ports, either individually or as a whole cartridge.

Table 2: Tuning System Requirements

Parameter	Value
Coarse tuner frequency range	140 kHz
Coarse tuner frequency resolution	10 Hz
Fine tuner frequency range	1000 Hz
Fine tuner frequency resolution	0.1 Hz

650 MHZ TUNER DESIGN

The operation of the tuner is shown schematically in Fig. 1. The stepper motor drives a lead screw through a planetary gearbox. The lead screw in turn drives one end of a double lever with a ratio of 1:43. The proposed design is similar to the design of the SACLAY-I tuner [2]. Encapsulated piezo actuators are located on the same side as the stepper motor. The piezo actuator transmits forces (and stroke) through the long main arm to the clamp ring connected to the cavity. Half of the piezo stroke transmits to the cavity.

A CAD 3-D model of the tuner is presented in Fig. 2. The electromechanical actuator driving the slow tuner consists of an integrated stepper motor/gearbox/lead-screw. To be able to tune a quite stiff cavity (10kN/mm) this actuator must be capable of handling forces up to 300N (Figs. 1 and 2).

The fast tuner consists of two independent encapsulated piezo-actuators inserted inside special cartridges as shown in Fig. 2. The piezo-stacks are encapsulated to minimize shear forces, which might lead to damage. A special arm (red color on Fig. 2) and several screws were introduced into the piezo-holder design for the purpose of uniform loading of each piezo-actuator during assembly and for the capability to replace the piezo-capsule in case of failure. In the absence of a piezo drive voltage, the actuators simply transmit the forces from the slow tuner to the cavity. When voltage is applied to the actuators they exert additional force on the cavity to provide rapid precise control of the cavity frequency. The two actuators need to be driven simultaneously for uniform force distribution and optimal transfer of piezo stroke to the cavity. If only one of the piezo-actuators is used the fine/fast tuner frequency range will decrease by a factor of 2.

The manufacturer recommendation for the piezo's optimal preload for dynamic operation is 15MPa. The maximum force on each piezo delivered by tuning the cavity by 70 kHz can reach 2 kN and the minimum force (arising from the 20 kHz requirement) will be ~0.6 kN. With an initial preload of the piezo inside the capsule of ~0.4 kN the force on the piezo-stack will be in the range 1 kN-2.4 kN. A typical piezo-stack with a cross section of 10 x 10 mm^2 has a blocking force parameter of ~4 kN and will satisfy force requirements. To guarantee a tuning range for the cavity of 1kHz (or 5um) the piezo-stack needs to have a length in the range of 35-40mm. It will be beneficial to increase the length of the piezo-stack if it is practical. The piezo can be driven with lower voltage and it will drastically increase the lifetime of the fine/fast tuner.

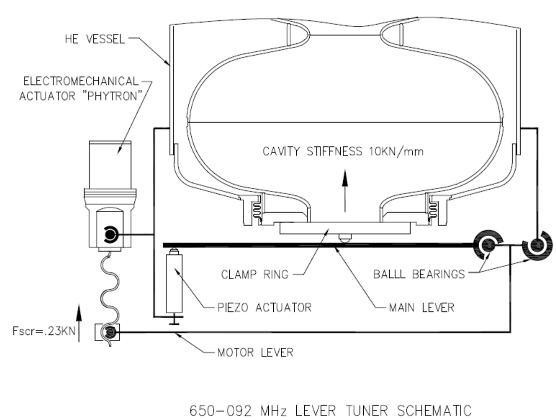

Figure 1: 650 MHz cavity lever tuner operating principle

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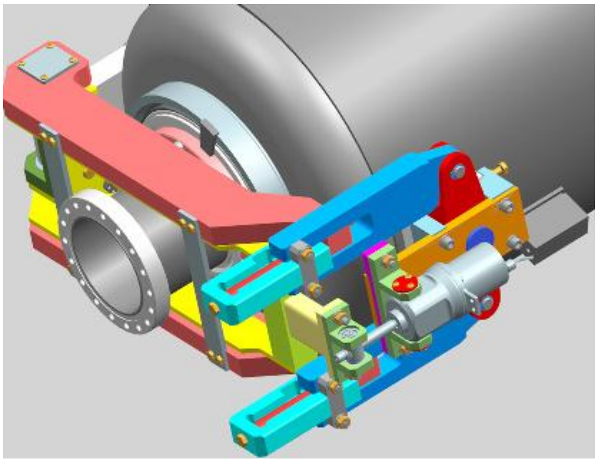

Figure 2: 3-D picture of the tuner. The electromechanical actuator is removable through a special port. The fine/fast tuner consists of two capsules with piezo-actuators installed inside special cartridges. Each of the encapsulated piezoactuators can be replaced through a special port.

ANSYS SIMULATIONS

We use ANSYS Workbench software for mechanical analysis of the tuner system. The tuner stiffness and advantage factor has been calculated. Fig. 3 shows the simplified ANSYS solid model of the tuner, Fig. 4 shows the boundary conditions used in simulations. Advantages of symmetry are taken into account.

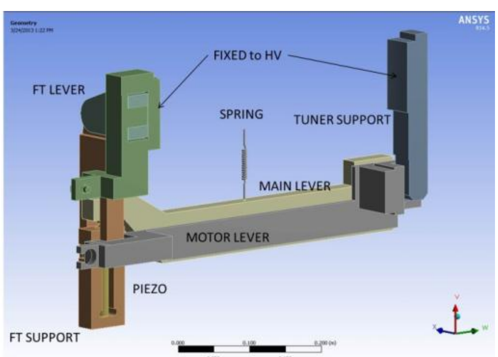

Figure 3: ANSYS model of tuner system.

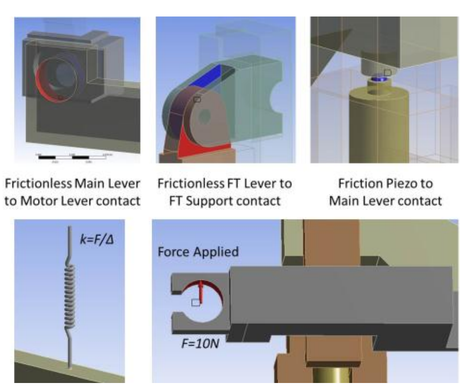

Figure 4: Boundary conditions used in ANSYS analysis.

Fig. 5-6 shows the total displacement and von Misses stress distribution. A simulation shows that the advantage factor is about 50. The tuner stiffness is ~34 kN/mm.

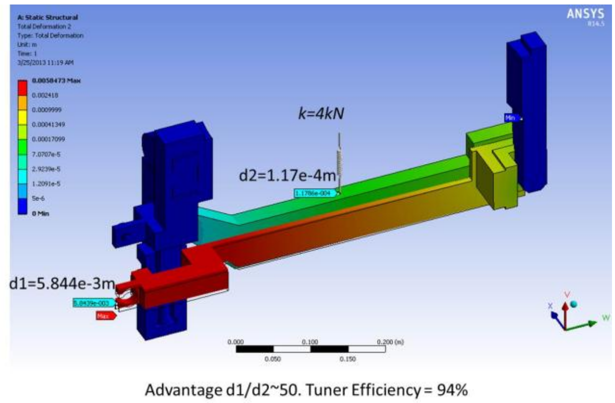

Figure 5: Total displacement in log scale.

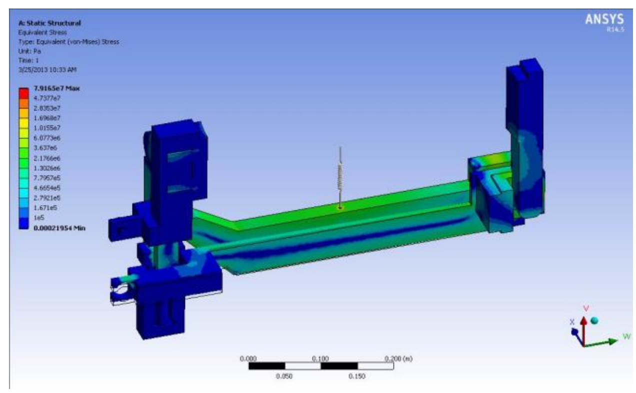

Figure 6: von Misses stresses.

CONCLUSION

A compact fast/slow lever tuner intended for 5-cell elliptical 650 MHz β=0.6 and β=0.9 cavities for Project X has been developed. The tuner met all design goals and will be able to:

- Bring the cold cavity to the operating frequency
- Compensate for frequency detuning of the cavity due to changes in the He bath pressure.

REFERENCE

[1] S. Nagaitsev, "Project X – New Multi Megawatt Proton Source at Fermilab.", PAC2011, New York.

[2] Bosland, P.; Wu, B., "Mechanical study of the Saclay piezo tuner PTS, CARE-SRF-WP8

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