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DESIGN OF 650 MHz TUNER FOR PIP-II PROJECT

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Abstract

The Proton Improvement Plan (PIP) II project at Fermilab is a proton driver linac which will use of five different cavity geometries including a 650 MHz 5-cell elliptical cavities that will operate in RF-pulse mode. Detuning of these cavities by Lorentz Forces will be large and strongly depend of the stiffness of the cavity's tuner. First prototype tuner built and tested warm [1,2]. Measured stiffness of the prototype tuner was below 30kN/mm instead of expected from simulation 70kN/mm [2]. Significant effort has been invested into understanding discrepancy between simulation and experimental data that led to newest tuner design. Updated "dressed cavity-helium vessel-tuner" model provided consistent results between ANSYS simulations and experiment results. Modified tuner design and analysis in limitations for overall "cavity/tuner system" stiffness will be presented.

INTRODUCTION

The 650 MHz cavity will have a half-bandwidth (HBW) of 30Hz and will operate in RF-pulse mode. The cavity's resonance frequency needs to be controlled to the level of 20 Hz (peak). As seen from Fig. 1, the cavity's Lorentz Force detuning strongly depends on the tuner stiffness [3]. Cavity tuner stiffness is one of the key parameters that needs to be addressed during tuner design.

The first prototype was built and tested [2]. Based on the ANSYS simulations the tuner stiffness was expected to be 60kN/mm [1]. Measurements revealed that prototype stiffness is only 25-30kN. This will increase Lorentz Force Detuning (LFD) coefficient to ~1.4 times bringing the value of the parameter LFD/HBW to ~15-20.

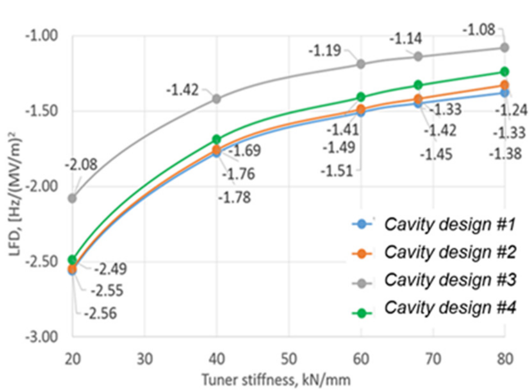

Figure 1: LFD coefficient vs. tuner stiffness.

Important to note that there are significant experience of LFD compensation for cavities operated in RF-pulse in the range of LFD/HBW up to ~5 [4], but there are no any experience in the range 15-20.

REVIEW OF THE TUNER PROTOTYPE

The difference (factor ~2) between calculated and measured prototype tuner stiffness led to review of the ANSYS model employed during design stage. An Updated model, with much more details, provided results that agreed with the experiment.

It is important to consider that LFD of the SRF cavity (as presented on Fig. 1) is not only dependent on the stiffness of the tuner as separate independent element. Instead it depends on the stiffness of a more complex system built from many elements such as the tuner frame, piezo-actuator, He vessel, cavity-He-vessel- tuner interface, etc.

The 3-D model of the double-lever tuner prototype is presented in Fig. 2. The tuner has been designed to serve the 650MHz cavities with range of cavity stiffness from 3kN/mm up to 20kN/mm. Due to the large forces on the fast tuner piezo-actuators when the stiff (20kN/mm) cavity will be tuned by slow tuner, we decided to build fast tuner with 4-piezos inside a cartridge mounted on the side of the tuner frame (Fig. 2). The complex design of the fast tuner was decided by several requirements. To deliver from piezos on the cavity stroke, not overloading piezo-actuators, and to have capability to replace piezo-elements without dis-assembly of the tuner.

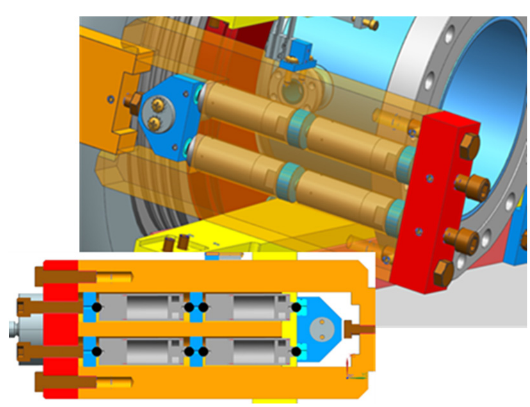

Figure 2: 3-D model of the fast tuner built from 4 piezo-actuators installed inside cartridge.

To keep stiffness of tuner higher, instead of flexible (as at Saclay-1 tuner) we are using solid arms (connection from tuner frame to the Helium Vessel. The same solution that was used in the design of the LCLS II 1.3GHz tuner [5]. Solid arms connections to the He vessel for double-lever tuner required "sliding" element between tuner arm and main lever (Fig. 3). ANSYS simulation indicated and

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detailed measurements confirmed that the major contribution of the overall tuner stiffness reduction came from cartridge with 4 piezo-capsules and the "sliding" joint between main lever and tuner's arm (Fig. 4).

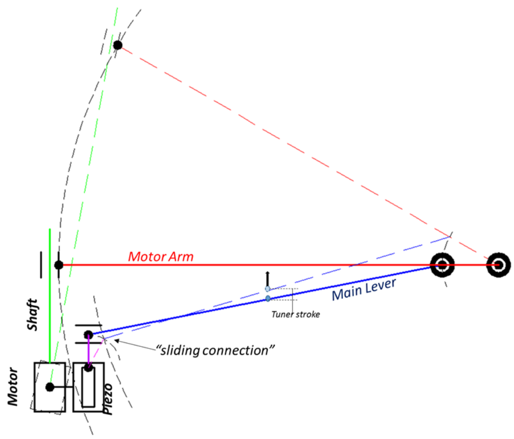

Figure 3: Kinematics scheme of the double lever tuner. Left end of the main lever required "sliding connection" for operation of the double lever scheme.

Calculations based on the updated ANSYS model provided stiffness of the prototype tuner mounted on the cavity's mock-up stand. Considering the effects of gravity force (Fig. 5) provided results of 32kN/mm that is very close to experimental results [2].

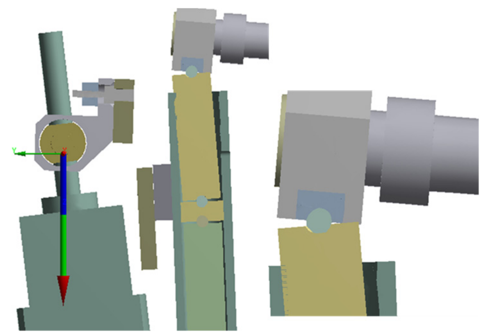

Figure 4: Displacement of the piezo tuner components with forces applied to the tuner.

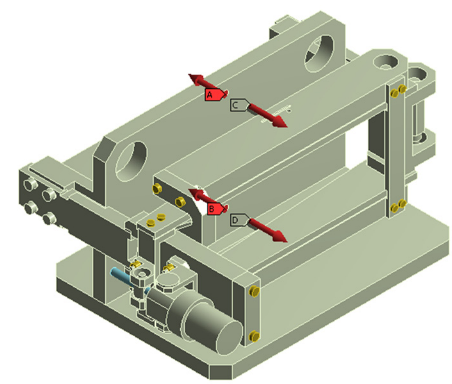

Figure 5: ANSYS model of the tuner, mounted on the test stand. Gravity forces considered during calculations o the stiffness Top & Bottom tuner arms.

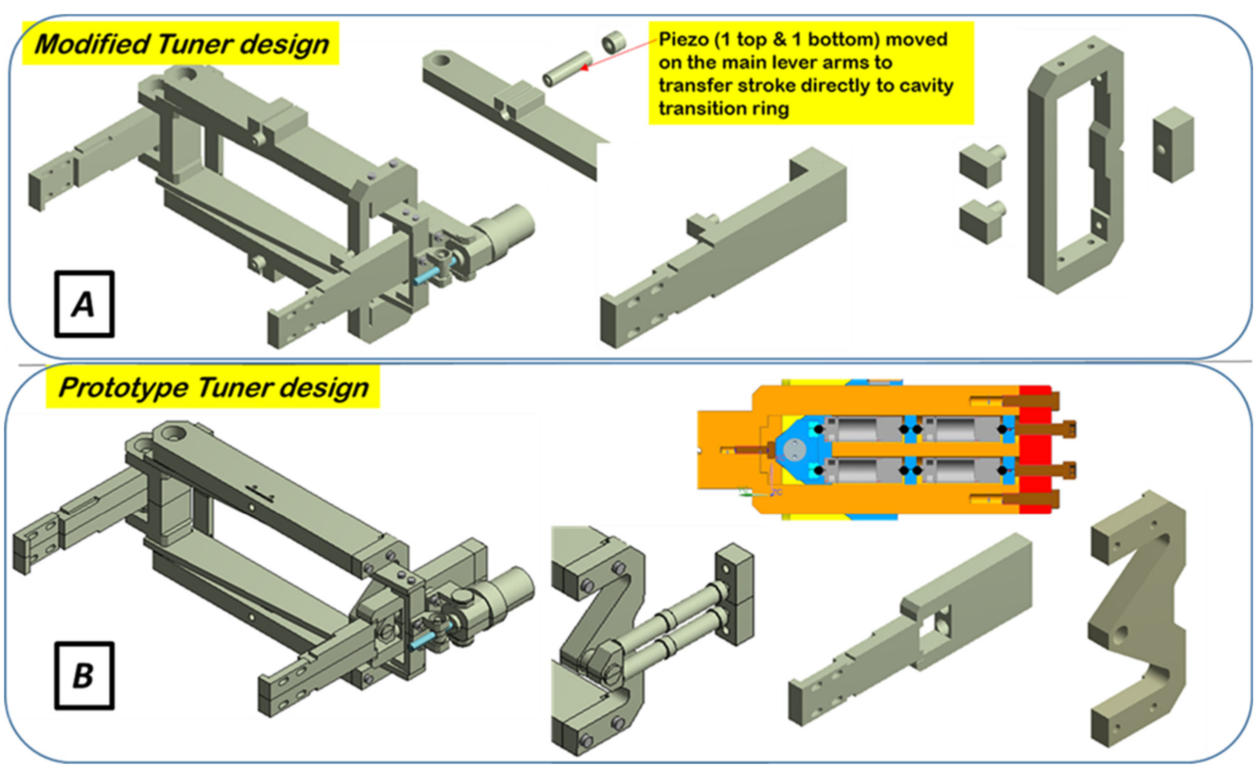

Figure 6: New vs Modified Tuner Design.

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MODIFIED TUNER DESIGN

Figure 6 shows the major modifications from the prototype to new tuner design. Analysis of the prototype tuner led to decision to modify fast tuner design and interface between left arm and main tuner arm.

Instead of a 4 piezo-actuator cartridge we decided to use a design similar to LCSL II 1.3GHz tuner where the piezo-capsule is installed between main arms and cavity interface ring [5]. Because of the limited space piezo- actuators installed into designated packets machined into the main tuner arms. New 650MHz tuner adopted from LCLS II 1.3GHz tuner several design solutions, like ceramics balls, piezo-adjustment screws, safety rods (Fig. 7). ANSYS simulation helped to conduct optimization studies by varying dimensions of the different components of the tuner. Calculated stiffness of the slow tuner frame (insert A, Fig. 7), with electromechanical actuator, was ~140kN/mm. Calculated stiffness of the dressed cavity/tuner system that included piezo-capsules (with stiffness ~100kN/m [6]) and Nb-Ti cavity-tuner transition ring (Fig. 8) decreased to the level of the 42kN/mm. As one of the proposals we considered slow tuner frame design with stiffness up to 600kN/mm. Disadvantage of the 600kN/mm design that it will required significant modification of the dressed cavity He vessel design and will be difficult to assemble. As soon as piezo and transition ring introduced into calculations, stiffness of the system dropped to just 55kN/mm.

Simulations illustrated that slow tuner frame is not limited factor for the stiffness of dressed cavity/tuner system. Stiffness could be increased only with significant modification of the dressed cavity design that included He Vessel and transition ring, and using piezo-actuators with much larger cross-section (and stiffness).

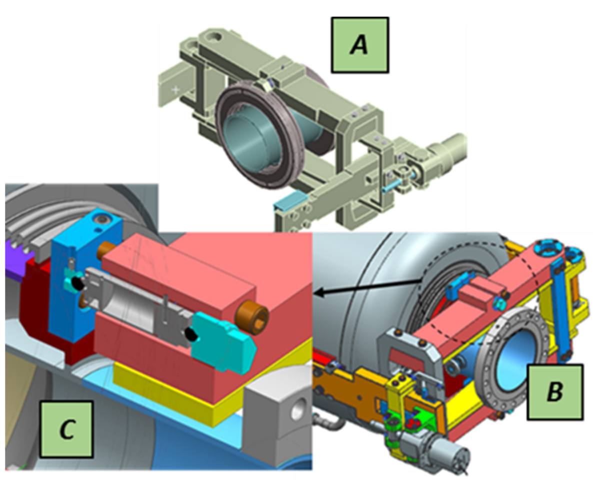

Figure 7: 3-D model of the modified tuner (A&B). (C) - Piezo-actuator inserted into main tuner arm and interfaced cavity through Nb-Ti ring.

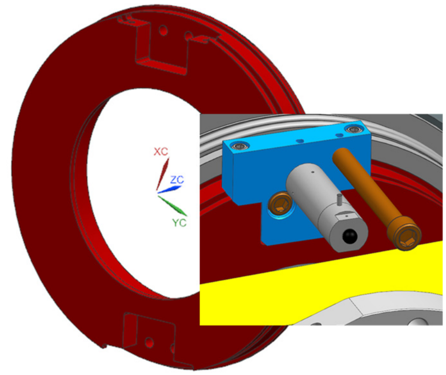

Figure 8: Nb-Ti interface ring that welded to cavity beam-pipe. Insert: Piezo-capsule, safety rod and interface plate that attached to Nb-Ti ring.

CONCLUSION

The expected stiffness of the updated cavity/tuner system will be close to 42kN/mm. At least two major tasks need to be accomplished to reach stiffness of the dressed cavity/tuner system to the level of 60-70kN/mm: redesign of the dressed cavity system (He Vessel and cavity-tuner interface) and develop new reliable piezo-actuator with larger cross-section/high stiffness.

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