PERFORMANCE OF THE 650MHZ SRF CAVITY TUNER FOR PIP II PROJECT

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Abstract
The PIP-II linac will include fifty seven 650MHz SRF cavities. Each cavity will be equipped with tuner for coarse and fine frequency tuning. Design and operations parameters will be discussed. Results from room temperature tests with prototype tuner installed on a 650MHz β_G=0.90 elliptical cavity will be presented.

INTRODUCTION

Design of the tuner for 650MHz elliptical cavities presented in previous publications [1]. Low $\beta_G = 0.61$ and high $\beta_G = 0.92$ cavities will be utilized for PIP-II project. Only the first 650MHz prototype cryomodule for the PIP-II project will employ four elliptical cavities with $\beta_G = 0.9$ that were designed several years ago [2] . The $\beta_G = 0.9$ cavity that was used for the tuner qualification test discussed in this paper has several design specifics: cavity has quite large stiffness ~20kN/mm; dressed cavity/He Vessel system has large diameter bellow from tuner side and required additional cavity/tuner interface element (split-ring).

The $\beta_G = 0.9$ dressed cavities/tuner system has limited operational range for the slow tuner. Limited operational range for cold cavity (ΔF~60kHz or ΔX~350um) dictated not by design of the slow tuner rather by maximum allowable load on the piezo-actuators. The 650MHz cavities with $\beta_G = 0.92$ and $\beta_G = 0.61$ will have stiffness ~4-5kN/mm and the slow tuner range will be expanded up to ΔF ~200kHz (or cavity compression ΔX >1mm).

In order to protect warm cavity from non-elastic deformation the maximum range of the cavity's compression/stretching must be limited to ΔX_{max}=0.3mm which is based on the ANSYS simulation of the $\beta_G = 0.9$ cavity. This was important factor that limited testing range of the slow tuner during our studies.

Picture of the tuner assembled on the dressed cavity presented on the Fig. 1. Details of the tuner design and ANSYS simulation results are presented in another paper [1]. As mentioned above $\beta_G = 0.9$ cavity/He Vessel/tuner system has special interface element "split-ring" that serves several purposes. The first role of the "split-ring" and safety brackets is to lock cavity to He Vessel to protect cavity from non-elastic deformation during pressurizing/leak check tests of the cavity during cryomodule assembly (Fig.2).

Large diameter of the bellow between He Vessel and $\beta_G = 0.9$ cavity end-group from the tuner side will lead to large forces, when dressed cavity will go through 3.3 bar pressure test.

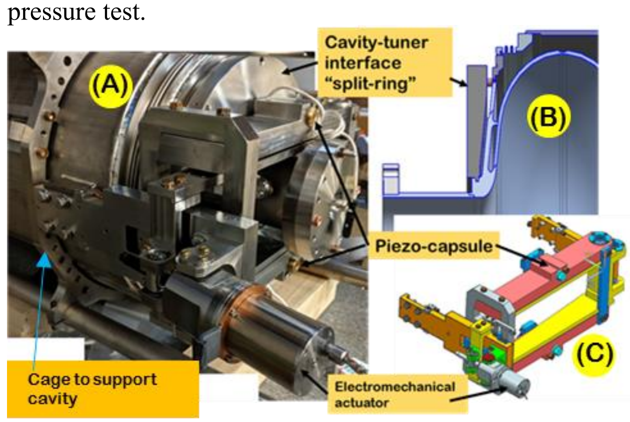

Figure 1: (A) Tuner assembled on the dressed cavity. (C) 3D model of the tuner. (B) Picture of the cross-section of the dressed cavity end-group from the tuner side.

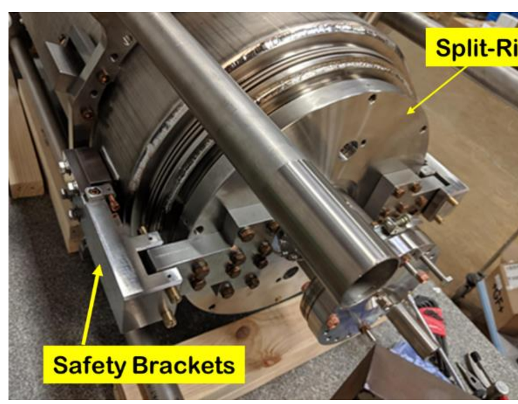

Figure 2. Split-ring and safety brackets installed on the dressed cavity.

The second role of the split ring is to transfer stroke from tuner to cavity. Range of the stroke transferred from tuner to the cavity from 0.3 mm (maximum stroke of the slow tuner) up to 5nm (to satisfy piezo tuner resolution

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~1Hz). Design of the "split-ring/safety brackets" system for HB650 $\beta_G = 0.9$ cavity is similar to the design of the same analogous system for 1.3GHz LCLS II cavities [3].

TUNER QUALIFICATION TESTS

Test Setup

Dressed cavity was secured with cage made from 4 rods and 2 spiders surrounding He Vessel and attached to vessel lugs (Fig. 1). During tests cavity was secured to granite table with straps.

Two dial indicators were installed from the tuner side of the cavity and one indicator from opposite (power coupler) side. Indicators measured stroke on the different elements of the dressed cavity/tuner system during operations of the tuner. In addition, a network analyzer (NWA) was connected to the cavity to monitor cavity frequency changes during tuner tests (Fig. 3).

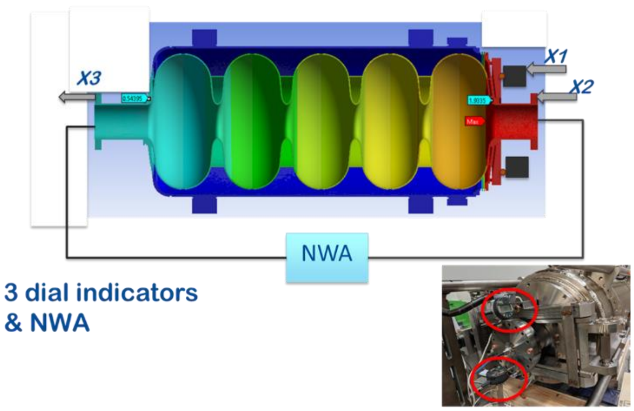

Figure 3. Schematics of the test-setup. Picture shows two (from three) dial indicators used to measure displacements of the main tuner arm and cavity beam flange.

Slow/Coarse Tuner Testing

During test of the tuner on the warm cavity the cavity compression limit was set to 300um. Considering the tuner's ratio 1:18, stroke on the motor arm was limited to 6 mm (or 6 full rotations of the electromechanical actuator spindle). It is required 60 kSteps from stepper motor to deliver 6 rotations of the spindle. Results of the cavity frequency change measured with the NWA versus the stepper motor rotations presented on the Fig. 4.

Exercising the stepper motor 60 kSteps caused a frequency shift of 29kHz on the cavity (or cavity compression on ~160um) instead of 60kHz as expected from kinematical model of the tuner. Measurements with dial indicators confirmed that cavity compression was ~156 um which is consistent with NWA measurements.

Slow tuner sensitivity is 0.5Hz/step that is ~2 times less than we expected and can be explained by limited stiffness of the dressed cavity/tuner system components: (1) split-ring interface, (2) conical flange interface between cavity end-group (from the power coupler side) and of the He vessel, and (3) tuner.

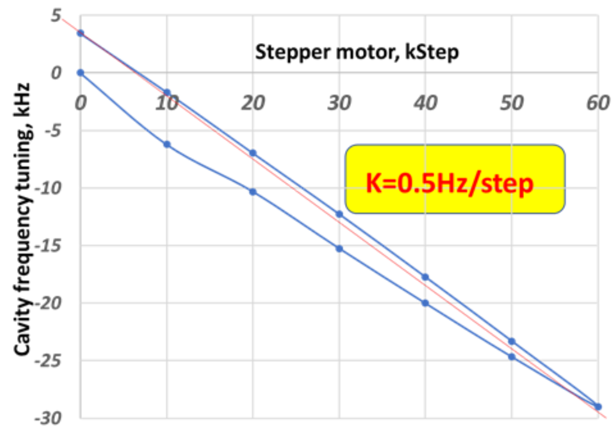

Figure 4. Cavity detuning with slow tuner.

Both system NWA and dial indicators don't have enough resolution to measure the warm dressed cavity slow tuner hysteresis value, which we are expecting will be less ΔF=100Hz (or ΔX=0,5um). Tuner hysteresis will be measured with cold cavity.

To estimate tuner stiffness, we replaced stepper motor with screw and load cell unit. Using the screw, we moved motor arms by $\Delta X_{Motor.Arm}$ and measured with load cell $F_{Motor.Arm}$. Using tuner kinematic ratio 1:18 we can estimate forces that applied from main tuner arms to cavity $F_{Main.Arm}$=18 x $F_{Motor.Arm}$. By measuring with dial indicator value of $\Delta X_{Main.Arm}$ we can estimate tuner stiffness by simple formula:

$K_{TUNER} = 18 \times F_{Motor.Arm} / [(\Delta X_{Motor.Arm}/18) - \Delta X_{Main.Arm}]$

K_{TUNER} estimated from simple measurements described above is near 40kN/mm that is in good agreement with our estimations from ANSYS simulations.

Fast/Fine Tuner Testing

The DC Voltage from 0 to 100V (with increment of 20V) applied to both (top and bottom) piezo-actuators and cavity detuning was measured with NWA (Fig. 5). Measured response of the cavity detuning/compression versus applied piezo voltage is 36Hz/V or 0.2um/V. According to manufacture specifications at room temperature piezo must deliver ~ 38um stroke for nominal voltage 120V or ~ 0.3um/V. Based on our simple measurements and piezo specifications from vendor we can estimate fine/fast tuner efficiency ~0.2/0.3=66%.

When operated inside cold cryomodule piezo-stack will be cool-down to T=20K and stroke of the piezo-actuator will decrease ~5 times [4]. We are expecting maximum cold cavity detuning by fast tuner, when V=120V applied to piezo, will be up to ~ 850Hz.

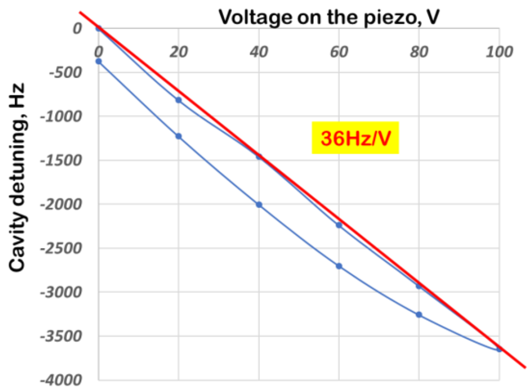

Figure 5. Cavity detuning with the piezo tuner.

Transfer Function of the Cavity/Tuner system

The PIP-II project specification on the level of the microphonics for 650MHz cavities is set to 20Hz peak detuning. It is crucial to design a dressed cavity/tuner system to minimize the sensitivity to external sources of vibration which can detune the cavity. Typically, frequencies of the external sources (cryo-flow induced vibrations, vacuum pumps and motor) are laying below 100Hz [5,6,7]. During the cavity design process efforts were made to shift the lowest mechanical resonance of the cavity to lie above 100Hz.

To measure transfer function of the cavity we assembled a simple RF system. An RF analog signal generator (Agilant CN5178) was used to produce the input signal which fed through splitter to produce two signals. One filled the cavity with the forward power $P_{forward}$ through an antenna installed on the one of the beampipe flange (Fig. 6). The second signal from the splitter was sent to input A of the AD8032 Analog Phase Detector (APD) [8]. A second cavity antenna on the opposite beampipe flange provided the transmitted power $P_{transmitted}$ which was sent to input B of APD. The output signal of the APD is proportional to the phase shift between $P_{forward}$ and $P_{transmitted}$ was digitized with NI-PXI-4472 14bit ADC [9]. Calibration of the APD detector was done by applying DC voltage to the piezo and measuring the response. The piezo voltage response was measured previously with a network analyzer with a sensitivity of 36 Hz/V on the cavity. This simple technique allowed us to establish a relation between APD output signal in mV to cavity detuning in Hz.

To measure transfer function, we applied to the piezo-actuators train of the sinewave stimulus pulses. A LabView program generate stimulus sine waveform with bias A=15V and amplitude peak-to-peak A=30V and frequency f_{piezo}. and with length of 3second followed 3 second interval when DC voltage with A=0V. Stimulus pulse generated by DAC (NI-6281) amplified with x15 by piezo-amplifier Jena ENT 400 and applied to piezo. Monitor signal from piezo amplifier (output signal/10) digitized by NI-4472 14 bit ADC simultaneously with APD signal. Test started with f_{piezo} =1Hz and with increment 1Hz run up to f_{piezo} =500Hz.

Cavity/tuner system transfer function presented on the figure 7. System has first resonance at 157Hz and strongest at 215 Hz, that is satisfied design requirements (no resonances below 100Hz).

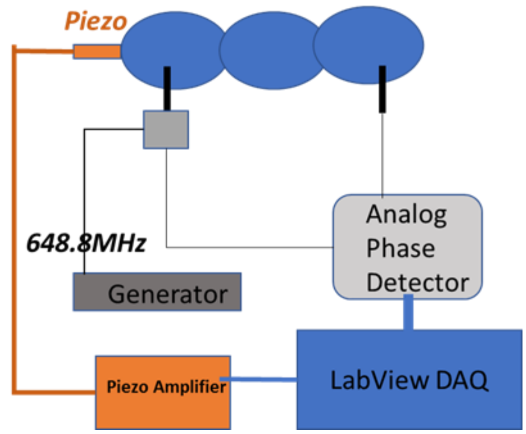

Figure 6: Setup to measure cavity transfer function.

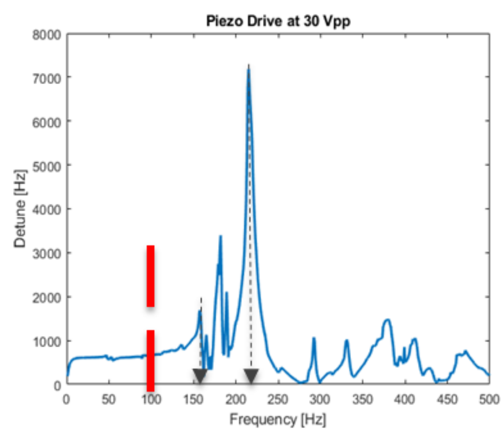

Figure 7: Transfer function as measured by APD when cavity excited by piezo.

At the next step in addition to APD we used piezo as a sensor to measure cavity vibrations. To generate vibration inside cavity we lightly tapped cavity's beampipe flange (opposite to tuner side) with rubber hammer. Fig 8 shows the responses as measured by APD and piezos when during interval of 10 second the cavity stricken 9 times. FFT of these signals presented on the Fig. 9.

By comparing transfer functions presented on the Fig. 7 and Fig. 9 we can make conclusion that both method of the exciting cavity (with short hit by hammer on the flange of the cavity or with piezo scan by sinewave stimulus pulses) provided the same results. On the spectrum measured by piezo sensors there is good correlation with peaks at the range of 150 to 250Hz. At the same time piezo measured some strong peaks below 100Hz (20; 45; 55; 85) that were not observed in spectrums measured with APD system. We contributed that low frequency resonances to the transversal rather than longitudinal motions of the cavity. APD system is sensitive to longitudinal motion and piezo was able to pick up both.

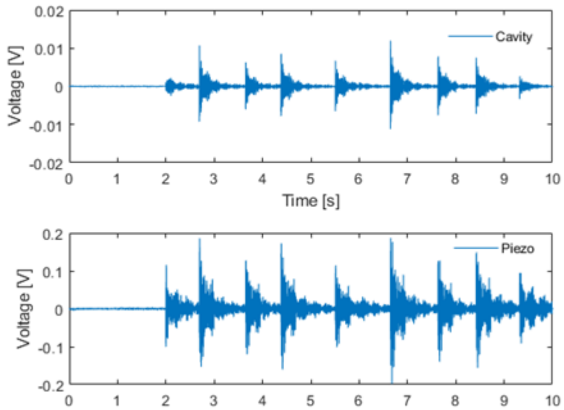

Figure 8: Amplitudes from APD and piezo (as a sensor) when cavity hit with hammer 9 times during 10 second time period.

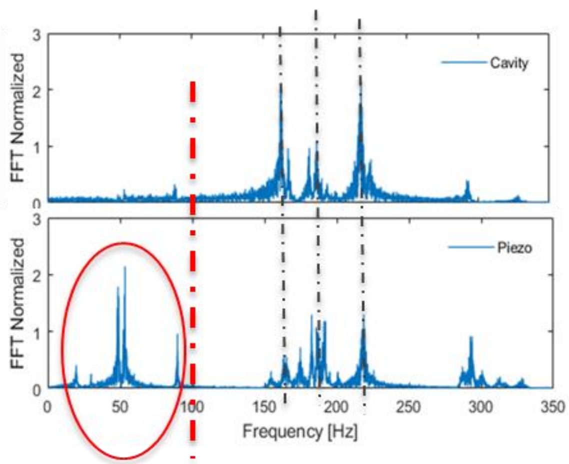

Figure 9: FFT of the signals when cavity hit with hammer (presented on the figure 3). Top: spectrum of the cavity vibrations as measured by APD. Bottom: spectrum as measured by piezo.

CONCLUSION

The first prototype tuner was fabricated and installed on the first dressed 650MHz (b=0.9) SRF cavity for the PIP-II project. Procedure of the tuner assembly was verified. This tuner was measured on the warm cavity. Tuner performance was found to meet specifications including, tuning sensitivity, mechanical stiffness, mechanical resonance of the warm dressed cavity/tuner system.

Some parameters, like tuner range, hysteresis, piezo tuner resolution, could not be assessed on the warm cavity and will be measured on the cold cavity.

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