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TESTING OF THE SSR2 SRF CAVITY TUNER FOR PIP-II at 2 K*

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Abstract

The PIP-II linac will include thirty-five 325 MHz Single Spoke Resonators Type 2 (SSR2) cavities. Each cavity will be equipped with a tuner for resonance control. The tuner consists of mechanical frame with a motor for coarse frequency tuning and a piezoelectric actuator for fine frequency tuning. The tuner was tested for the first time at Fermilab on an SSR2 cavity. This dressed cavity-tuner system was tested at the single spoke testing cryostat (STC) in Fermilab at 2 K. The tuner performance was evaluated and is presented. Lastly, cavity-tuner mechanical modes were measured via the piezos.

INTRODUCTION

The SSR2 cavities are one of five classes of superconducting RF (SRF) cavities that will form part of the proton improvement plan (PIP)-II linac under construction at Fermilab. The cavities use an SRF tuner to keep them on resonance to accelerate the beam to the specified energy efficiently. The cavity will use a double lever tuner which is similar in design to the SSR1 tuner [1]. It can compensate for slow-coarse frequency detuning as well as fast-fine frequency detuning.

The tuner can only compress the cavity; therefore, the frequency of the warm cavity is set to have a positive frequency offset of ≤130 kHz (see Table 1) when cooled to 2 K. The slow-coarse frequency component of the tuner, composed of a stepper motor, is used to compensate for this deviation. Microphonics and helium pressure fluctuation require the use of a fast-fine frequency tuning component. The fast-fine tuner component consists of two piezoelectric actuator capsules. Accelerated lifetime and irradiation tests at Fermilab demonstrate that the stepper motor and piezo will survive prolonged operation far exceeding the typical linac lifetime of 25 years [2,3].

The frequency tuner performance was measured when the SSR2 cavity was cooled to 2 K. Additionally, the mechanical modes of the cavity-tuner system were measured via the piezos. The cavity was placed in the Spoke Resonator Test Cryostat (STC) facility at the Meson Detector Building (MDB) at Fermilab, pictured in Fig. 1. The results are compared to the project specifications [4] and to the results from the Irène Joliot-Curie laboratory (IJCLab) test in France [5].

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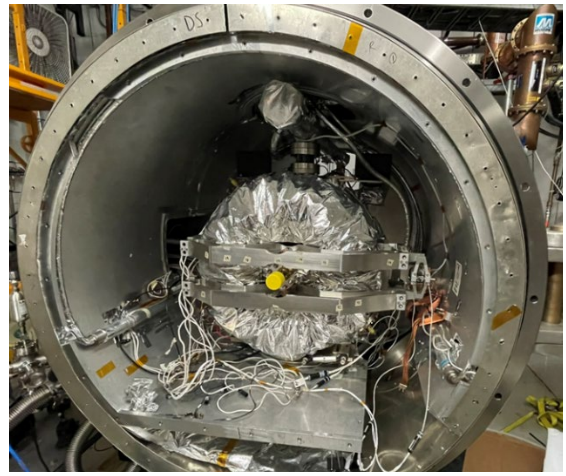

Figure 1: 325 MHz SSR2 cavity with tuner and other ancillaries installed at the MDB facility.

SLOW-COARSE TUNING COMPONENT

Pivoting Motor Lever Dislocation

After installing the tuner on the cavity the tuner probe gap was set to 1 mm. This gap is between the two probes on the tuner arms and cavity. The purpose of the gap is to avoid any excessive compression of the cavity by the tuner during cool down and measure the frequency change of the cavity solely due to cool down effects. The initial frequency (shown as 0 position in Fig. 2) is the frequency due to cool down effects (tuner was disengaged). An estimate of 60 k steps is needed to close the 1 mm gap between the probes and cavity (though due to cooldown effects it was expected to be less). During initial motor checks prior to closing the cryostat the shaft turning direction was checked. Applying negative steps to stepper motor will move the tuner probes to compress the cavity.

Once the cavity was cooled to 2 K the motor was actuated with minus 60 k steps and tuner probes must have moved by ~1 mm (see Fig. 2 named 1st movement). However, the cavity frequency did not change. After not seeing a response from minus 60 k steps doubt settled that the perhaps the wrong motor direction was applied. Positive steps were then used and after plus 60 k steps from 0 steps (see Fig. 2 second movement) no response was observed. The original direction (negative steps) was tried again.

After operating the stepper motor for minus 120 k steps from the 0th position the probes compressed the cavity (see Fig 2). The number of steps from the 0th position until first contact translates to 2 mm on the gap (See Fig. 2). After

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the cavity was warmed up and the cryostat was opened it was discovered that the motor pivot points were not inside the notch of the 2nd arm flexure (see Fig. 3). Pivot point A was still on the flexure arm but the other pivot point was not. This was likely caused by moving in the relax direction (positive steps) for more than 10 k steps, which eliminated the preload and allowed the pivot lever to rotate freely. This explains the discrepancy of the gap as well as why only one piezo capsule was making contact.

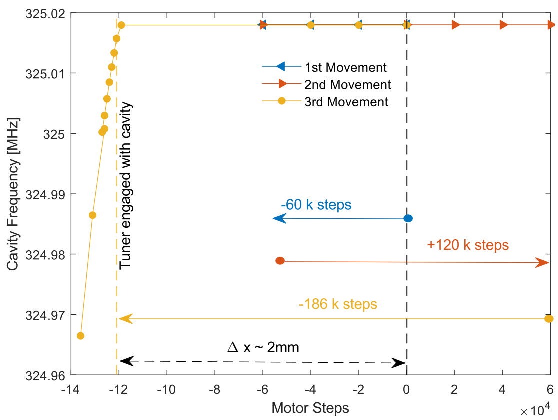

Figure 2: Frequency shift of the cavity due to compression from the motor. The flat region is the gap.

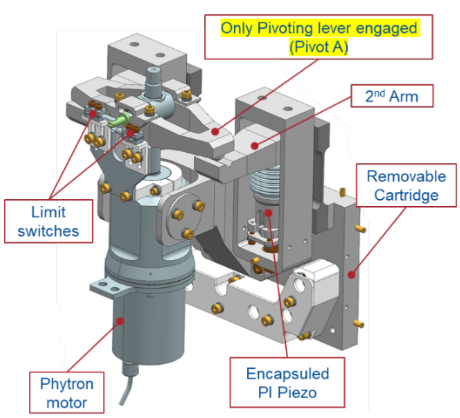

Figure 3: Model of the motor and piezo cartridge of the SSR2 tuner. Only pivot A was in contact with the 2nd flexure arm. The other pivot was not in contact.

In the future careful measurements of the direction and gap of the tuner will be done to prevent this. Additionally, the gap size can be reduced, and preload increased to eliminate the disengagement of the pivot arm in case the wrong direction is taken. Lastly, during assembly of the cryomodule the tuner will have limit switches installed which will prevent movement in the opposite direction.

Slow Tuner Test Results

A total of 7000 steps were required to tune the cavity to 325 MHz from 325.018 MHz once the tuner was engaged with the cavity (Fig. 2) The frequency to motor step sensitivity was measured at 2.58 Hz/step which satisfies the project requirements (see Table 1). The value obtained in the IJCLab results was 3.1 Hz /step. Note that only Pivot point A was engaged (see Fig. 3), which could explain the difference in the sensitivity. The full range of the tuner was not measured in order to avoid damage. A range of 56 kHz was measured.

The motor hysteresis was measured when the cavity was set to 325 MHz. The results are shown in Fig. 4, the motor was actuated with 50 step increments before returning to the original position. The hysteresis measured was about 800 Hz, versus IJCLab's measurement of 330 Hz. This significant difference could be due to only Pivot A making contact. Additionally, microphonics was on the order of ~50 Hz which adds uncertainty to the measurement. Another test is needed to verify the hysteresis.

Table 1: SSR2 Cavity-Tuner System Parameters [4].

	Value
Cavity Stiffness [kN/mm]	15.7
Cavity Tuning Sensitivity [Hz/μm]	520
Slow Tuner Frequency Range [kHz]	≤ 130
Stepper Motor Resolution [Hz/step]	≤ 9.5
Slow Tuner Hysteresis [Hz]	≤ 300
Piezo Tuner Frequency Range [Hz]	≥ 700

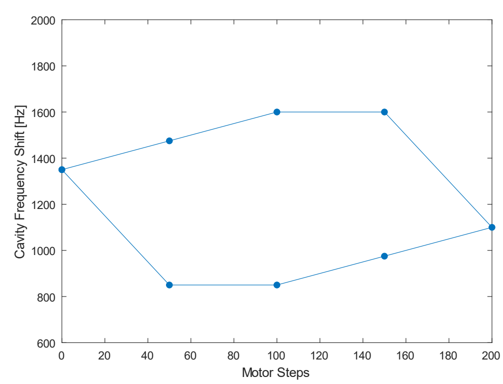

Figure 4: Measurement of motor hysteresis. Fifty step increments were done during this measurement.

FINE-FAST TUNING COMPONENT

During the test both piezo were driven by DC voltage and then a test for each individual piezo was done. When the individual test was done it was discovered that only one piezo was in contact with the cavity since only Pivot A was engaged.

The hysteresis measurement of the single piezo was done after cycling the piezo with voltage from 0 to 100 V to "burn-in" the piezo. The maximum piezo frequency shift from 0 to 100 V is 800 Hz (see Fig 5). The frequency shift of the piezo measured at IJCLab was 896 Hz for both piezos at 100 V. Note that the piezo temperature during IJCLab test was 2 K but during FNAL test piezo temperature was around 77K. The results agree when considering that the test at Fermilab has only one piezo with full contact

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and considering the temperature difference. The results also meet the project specification listed in Table 1.

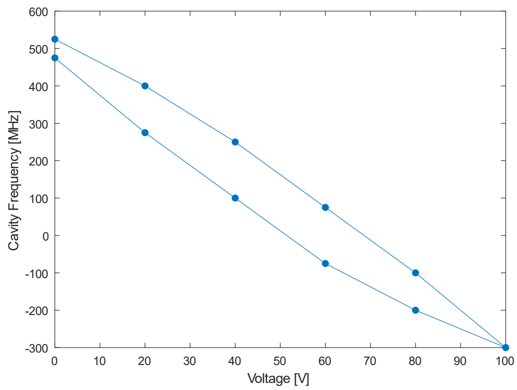

Figure 5: Piezo hysteresis of a single capsule.

CAVITY-TUNER SYSTEM MECHANCAL RESONACES AT STC

The piezo was used as a sensor to characterize the cavity mechanical modes. When pressure is applied to the piezo it will generate a voltage which can be measured with an ADC. The transfer function measurement was done with an impulse hammer which also has a piezo to measure the force applied on it. The hammer was used to hit the side of the cryostat exciting different mechanical frequencies on the system. The result from one hit and the effect on the cavity piezo is shown in Fig. 6. Measurements were done at different cavity compressions. One was done when the piezo is not engaged, the other with 18 kHz compression on the cavity, and the last one with a 56 kHz compression on the cavity. The purpose of these different compressions is to see if the compression affects the mechanical modes of the cavity-tuner system.

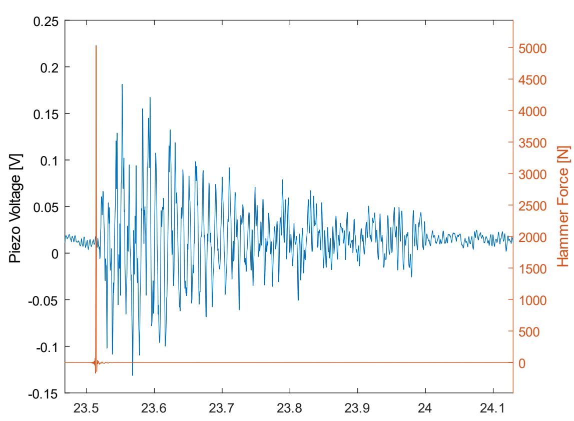

Figure 6: Voltage of the piezo on the cavity (blue) due the impulse of the hammer (orange).

The signal from these three different compressions were then analysed with an FFT to check for the cavity mechanical modes. Figure 7 shows that in all three cases, a 20 Hz vibration is present. This was previously correlated to a cryogenic line. One clear mechanical vibration occurs at 100 Hz when the cavity was compressed by 56 kHz but this does not occur at the other compressions. In the region of 250 Hz to 300 Hz the spectrum changes depending on if it's compressed by 56 kHz or 18 kHz. More measurements are needed to verify these vibrations with RF on the cavity.

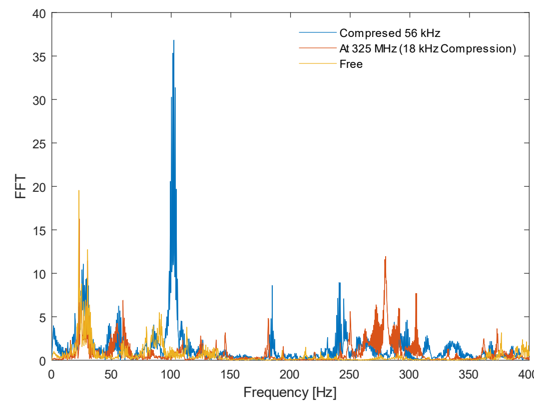

Figure 7: FFT of the signal of the piezo caused by the impulse hammer. The FFT for each compression is shown.

CONCLUSION

The SSR2 tuner was installed on the cavity and tested at 2 K. The slow coarse component shows that a tuner sensitivity of 2.6 Hz/step is achieved. During measurement it was found that only one piezo was engaged and later it was confirmed once the system was warmed up. A frequency shift of 800 Hz at 100 V was measured due to only one piezo capsule. A larger frequency response was measured since the piezo-motor cartridge is connected to 77 K. Despite the pivoting motor lever dislocation, the tuner meets some but not all the project's specifications. Future test will involve more preventive measures to avoid the motor pivot arm dislocation and to verify the tuner performance.

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