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DYNAMIC TUNER DEVELOPTMENT FOR MEDIUM β SUPERCONDUCTING ELLIPTICAL CAVITIES *

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Abstract

The Facility for Rare Isotope Beams (FRIB) is developing a 5-cell 644 MHz $\beta_{opt} = 0.65$ elliptical cavity for a future linac energy upgrade to 400 MeV/u for the heaviest uranium ions. Superconducting elliptical cavities operated in continuous wave, such as the ones for FRIB, are prone to microphonics which can excite mechanical modes of the cavities. It has been shown that the detuning due to microphonics can be mitigated with the use of piezo actuators (fast tuner) as opposed to the costly option of increasing the input RF power. The FRIB slow/fast dynamic tuner will be based on the Fermilab experience with similar tuners like those developed for the linac coherent light source (LCLS) II and proton improvement plan (PIP) II. This paper will present the results of tuner properties on the bench.

INTRODUCTION

Superconducting (SC) linear accelerators (linacs) can provide high power proton, electron, and ion beams in continuous wave (CW) or pulsed mode operation. Two such examples of this are the FRIB energy upgrade project which will operate in CW mode and the PIP II project which will operate in pulsed mode. The FRIB energy upgrade will provide beam for nuclear physics experiments and the PIP II will provide beam for high energy physics experiments.

One of the main components of a linac are the SC cavities which accelerate particles via coupling to the RF power. Cavities in CW mode are operated at very high loaded Q_L which results in a small bandwidth making them susceptible to noise which results in detuning. In the case of cavities operated in the pulsed mode the main source of detuning is caused by the Lorentz force caused by radiation pressure. The latter can be much larger than microphonics. Figure 1 shows the RF power increase to compensate for microphonics, this increase in RF power can add up cost to the operation of the linac. Additionally if the power coupler can't provide enough power to compensate for the detuning the cavity will not be able to maintain the accelerating gradient which will result in operational downtime.

A passive approach to microphonics should be taken first such a building a stiffer cavity and having a design that limits vibrations. But even after this approach has been taken there is still a possibility of some detuning. A cost-effective approach to mitigating the detuning after the passive approach has been taken is to use piezo actuators for fast detuning [1, 2]. A collaboration between FRIB and Fermilab was started to work on a tuner for 650MHz [3] and 644 MHz [4] cavities.

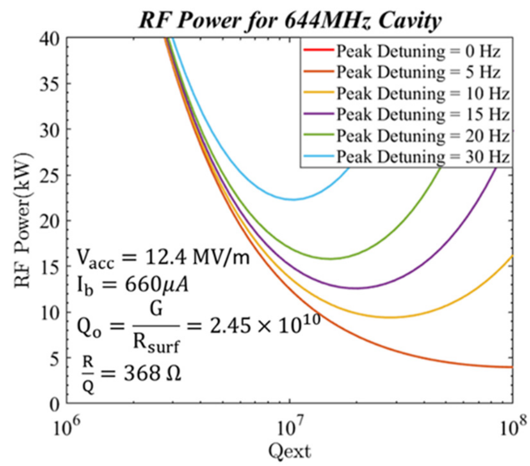

Figure 1: As the peak detuning goes up so does the RF power. Parameters are based on the FRIB cavity [4].

TUNER DESIGN

The tuner designed for the 650 MHz elliptical cavity is a lever tuner. It consists of encapsulated piezoelectric (piezo) actuators and an electromechanical actuator (stepper motor) similar to those used in the LCLS II tuner [5]. The piezo actuators are used for fast and fine tuning while the stepper motor is used for slow and coarse tuning of the frequency. The schematic model of the first prototype dynamic tuner for the 650 MHz cavity is shown in Fig. 3. The tuner will be mounted on the cavity's helium vessel and located inside the insulating vacuum space as shown in Fig. 2.

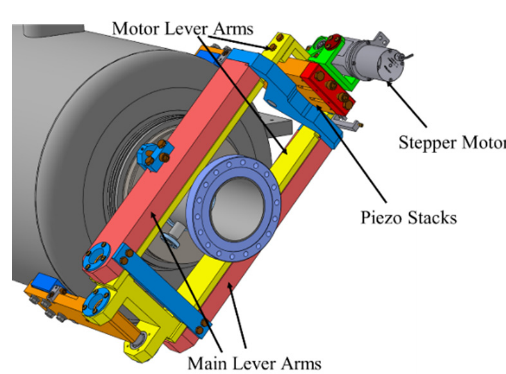

Figure 2: The jacketed 644MHz cavity with the tuner attached.

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The electromagnetic actuator consists a planetary gearbox and a leadscrew. The leadscrew moves the motor arm (yellow in Fig. 3) which pivots about bearing 1 and moves bearing 2 so that the main lever arm makes contact with the transition ring connected to the cavity. The 4 independent encapsulated piezo actuators transmit force to the long main arm (pink in Fig. 3) which pivots about bearing 2 until it makes contact with the transition ring connected to the cavity.

The forces on the stepper motor and the piezos can be estimated by analyzing the mechanical advantage of the system. The forces on the tuner components and the cavity are shown in Fig 3. The force from the stepper motor is given by F_M, the piezos F_P , and for the cavity F_C . The force on the cavity is inferred from the cavity stiffness and the amount of deformation that the tuner causes. From this a ratio between the force on the cavity and the tuner can be obtained as shown in Eqs. (1) and (2).

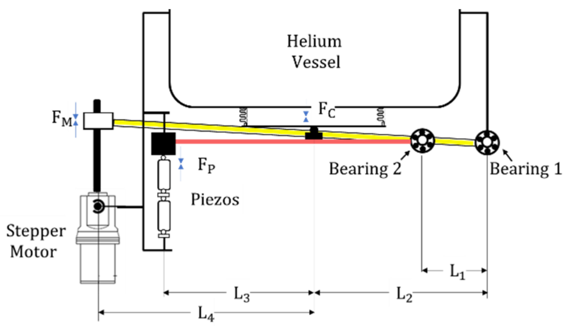

Figure 3: Schematic of 650MHz cavity lever tuner. Here $L_1 = 55$mm, $L_2 = 255$mm, $L_3 = 245$mm, and $L_4 = 310$mm.

$$\frac{F_P}{F_C} = \frac{L_2 - L_1}{L_3 + L_2 - L_1} \quad (1)$$

$$\frac{F_M}{F_C} = \frac{L_1}{L_4 + L_2} \cdot \frac{L_2 - L_1}{L_3 + L_2 - L_1} \quad (2)$$

The ratio obtained for Eq. (1) is $\frac{1}{2.2}$ and Eq. (2) the value is $\frac{1}{22.8}$.

The $\beta_G = 0.61$ PIP II cavities require a coarse tuning of 200 kHz and the cavity sensitivity is 240 kHz/mm [3]. Using the maximum required tuning of 200 kHz and the tuning sensitivity the deformation of the cavity is going to be 0.833 mm. Using this deformation, equations (1) and (2), and the cavity stiffness (4.9 kN/mm) the force on the motor and piezos can be obtained. The force on the motor is $F_M =$ 179 N and for all the piezos at this point $F_{piezo} = 1.85$ kN. Each piezo capsule then receives half the force, resulting in a force of 927 N since there are two capsules in parallel. Each piezo has an internal preload of 800 N and each piezo will experience 33.7 N when all of them are operated at 100V. The total force on a single piezo capsule is then 1.7 kN which is less than half of the blocking force (maximum force provided by the piezo, 4 kN). The coarse tuning for the FRIB cavity is the same as the PIP II cavity. The only difference is the cavity stiffness which is half of the PIP II cavities. Therefore, smaller forces are expected on the motor and piezos of the FRIB cavity.

TUNER TESTING

The detuning due to Lorentz force is dependent on the tuner stiffness [6]. For the case of PIP II a larger stiffness is required. The tuner was tested to check the stiffness as well as the piezo stroke. This was done with a stainless steel assembly which simulated the connection with cavity and the tuner. The cavity stiffness was simulated with a pair of Belleville washers. The Belleville washers were set to a stiffness of 4.9 kN/mm which is similar stiffness of the 650 MHz cavity. The force was generated by using the adjustment screw shown in Fig. 5 and recorded by a load cell. The displacements of the lever arms were recorded using dial indicators and for finer displacements such as the piezo stroke a laser was used. The setup is shown in Figures 4 and 5.

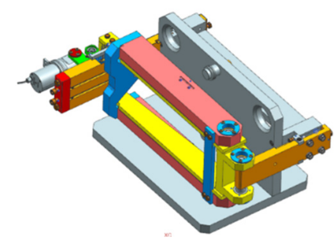

Figure 4: Schematic of tuner attached to test stand.

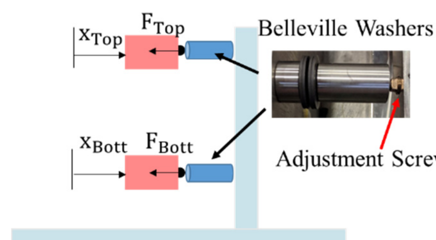

Figure 5: Tuner test stand setup, this shows the location of Belleville washers and where the displacement measurements take place.

The force and the displacement were recorded for both the top and bottom main lever arms, the results are shown in Fig. 6. Using the analogy of two springs in parallel, the stiffness is the slope from Fig. 6 and equal to ~30kN/mm. The stiffness is smaller than the simulated stiffness of 60 kN/mm in ANSYS. A large stiffness is required in order to mitigate the Lorentz detuning.

The lower measured stiffness can be caused partially by the small stiffness of the tuner stand. The top part of the stand is more likely to bend as opposed to the bottom part. This can be seen from the geometry of the stand, the standing plate is bolted to the bottom plate, see Fig. 5. Measurements made on the back of the standing plate show that it was being deformed. Therefore the results shown don't reflect the tuner stiffness but also the stiffness of the stand too. From now on will reflect only the displacement of the tuner arm. This will be treated as the displacement on the cavity. The piezo stroke was measured next.

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Results

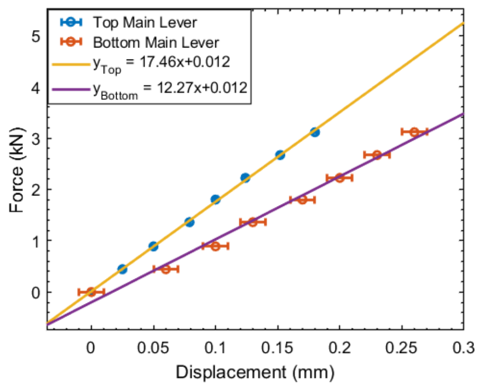

Figure 6: Force generated by adjustment screw and displacement in the main top and bottom lever arms.

The piezo stroke measurements were done in the setup shown in Fig. 5. In total there are four piezo encapsulations. To measure the lever arm displacement a laser was used since the piezo strokes are small. The configuration of the piezo encapsulations is shown in Fig. 7, a single piezo encapsulation (piezo number 3) was first tested. Figure 7 shows the maximum stroke of a single piezo is 9µm on the top lever arm at 100 V and under the 4.9 kN/mm load. The top piezos, 1 and 2, provide a stroke of 18.4 µm and the bottom piezos, 3 and 4, 17.8µm.

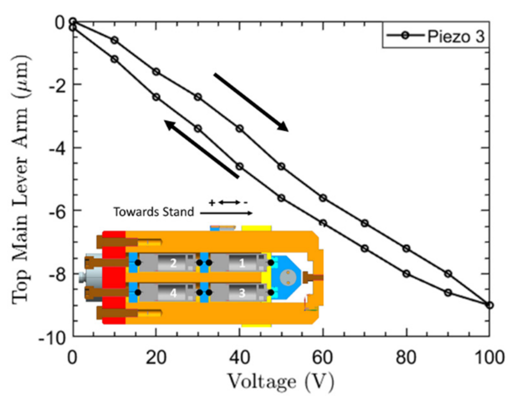

Figure 7: Configuration of the piezo encapsulations is shown. The displacement caused by piezo number 3.

The results are shown in Fig. 8. The top and bottom results provided twice the stroke as a single piezo encapsulation. Lastly when all the piezos were engaged at 100V the total stroke was 33.4 µm. These are the results at room temperature and when the cavity is cool down to 2 K the piezo stroke will decrease. Previous results show that the piezo stroke is 20% of the room temperature stroke. Using the 20% of the displacements obtained earlier and the cavity sensitivity the detuning of the piezos can be obtained during 2 K operation. For a single piezo encapsulation the detuning will be ~430 Hz at 100 V and for all four piezo encapsulations it will be ~1.6 kHz at 100 V. The values given are under the assumption that the level arm displacement is the same as the cavity deformation which is not true. The level of detuning will be much smaller than the one calculated due to the small stiffness of the tuner stand. A new tuner is being developed and was designed to provide a large stiffness and piezo stroke [7].

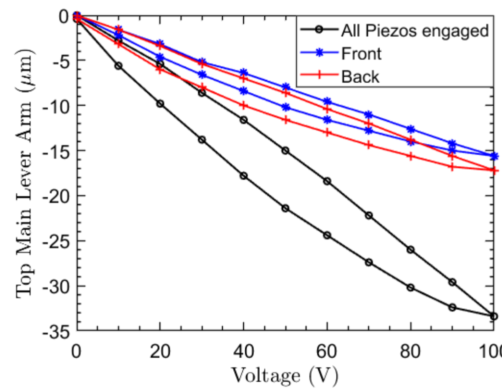

Figure 8: Top main lever arm displacement with the respect to the piezo voltage.

CONCLUSION

The stiffness of the tuner was measured as well as the stroke of the piezos. The results show that the stiffness was smaller than the value from the simulations. Since the deformation of the tuner stand was not considered the value is not accurate, this can be resolved by measuring the deformation of the stand as well as the displacement of the lever arm. The same must be done for the piezo stroke since the value being measured is being overestimated. This is the first tuner prototype and a new one is being developed with a larger stiffness.

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