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SRF CAVITY TUNERS FOR 3.9 GHz CRYOMODULES FOR LCLS-II PROJECT*

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Abstract

Fermilab conducted testing of three 3.9 GHz cryomodules for the LCLS-II project that will operate in continuous wave mode. A fast/fine tuning component was added to the LCLS-II 3.9 GHz tuner design due to the cavity bandwidth of 180 Hz which consists of two encapsulated piezos. Several cavities faced problems with fast-tuner operations after cooldown to 2 K and tuning the cavities to 3.9 GHz in cryomodule 2. All the piezo actuators were in working conditions, but the slow tuner ranges required to stretch some of the cavities to the operational 3.9 GHz frequency were too small to deliver the required preload on the piezos. This behavior can be attributed to several factors: setting the initial warm cavity frequency during production too high, pressure tests of the warm cryomodule could have changed cavity frequency; and the small bending and twisting of the cavity-tuner system during the cooldown and warmup of the cavities. A decision was made to inelastically retune the warm cavities to decrease the unrestrained frequency by 130-500 kHz, this was done via the slow tuner. The major challenge was to conduct this procedure without disassembling cryomodule and without any access to the tuner and cavities systems. The results for this retuning method of three 3.9GHz cryomodules will be discussed.

INTRODUCTION

The LCLS-II linac features a third harmonic section to generate an electron beam for the production of short-wavelength FEL operation. This section will have two cryomodules each consisting of eight 3.9 GHz elliptical cavities for the linearization of the beam phase space before the longitudinal bunch compression to increase the peak beam current [1]. The cavities and cryomodules designs were optimized from the Eu-XFEL linac and are discussed in [2]. The half-bandwidth of the cavity is 90 Hz, the peak frequency detuning (with resonance control) must be less than 30 Hz based on the design specifications [2]. Each cavity employs a slim blade tuner based on the INFN design for the Eu-XFEL 3.9 GHz cavities [3]. Two piezo actuator encapsulations were added to this design for fast/fine tuning. These tuners were tested on the cavities in the cryomodule setting at Fermilab. When moving the cavities to the nominal frequency after cooldown it was discovered that some of the piezo encapsulations were not engaging since no frequency change was observed when a voltage was applied to the piezos. This paper will detail the results of the tuner operation, unravel why the piezos were not engaging, and provide a solution to make the piezos engage with the tuner.

SLIM BLADE TUNER

The slim blade tuner is installed coaxially on the cavity helium vessel. The tuner can compress and stretch the cavity via the slow/coarse frequency component. Compression of the cavity decreases the frequency while stretching the cavity increases the frequency. The slow-coarse component consists of a Phytron stepper motor which is also used for the 1.3 GHz cavities [4, 5]. This component is used to tune the cavity to the nominal frequency after cooldown. The second frequency tuning component consists of two piezo actuator encapsulations used for fast-fine frequency compensation which can only stretch the cavity. The fast-fine component is used for resonance control of microphonics. The piezo encapsulations are made from two $10 \times 10 \times 18$ mm PICMA butted piezo stack manufactured by Physik Instrumente (PI) [5]. The slim blade tuner and the two components are shown installed on the 3.9 GHz cavity in Fig. 1. Kinematic model of the slim blade tuner presented in Fig. 2.

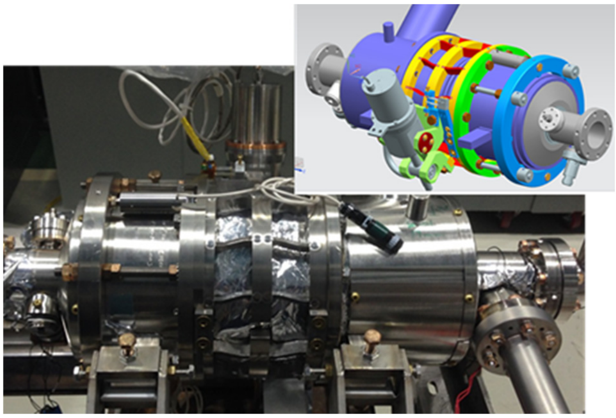

Figure 1 : Slim blade tuner installed on a 3.9 GHz cavity.

The kinematics of the bladed tuner movement are described in Ref. [3]. Four safety rods are located downstream of the blades (see Fig. 2). These safety rods protect the cavity during transportation and from non-elastic deformation during cavity/helium vessel system pressure tests. A safety gap is set on all the safety rods so that the piezos do not lock when the cavity-tuner system is cooled down to 2 K.

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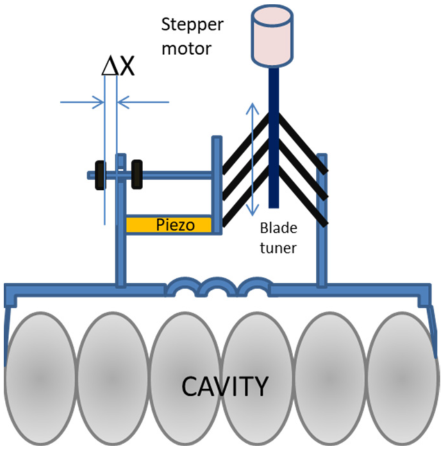

Figure 2: Slim blade tuner schematic.

OPERATION AT 2 K

The tuner operates by stretching the cavity only. For normal operation, the frequency of the unconstrained cavity at 2 K must be equal to or below 3,899.900 kHz. Four different sections of the slow tuner's normal operation are presented in Fig. 3. These sections are based on the results of testing of the tuner at HTS in Fermilab discussed in Ref. [6]. The frequency recorded for these trials was done with the network analyzer.

In region A the cavity the blades are being stretched thus releasing the initial compression by the safety rods of the cavity which causes an increase frequency. A frequency sensitivity of 10 Hz/step is observed in this region. The initial frequency in this region before moving the tuner is the cold-landing frequency. In region B the tuner blades continue being stretched and frequency sensitivity of 0.03 Hz is observed. This is the safety gap region and the frequency in this region will be called the unrestrained frequency. In region D, both piezos contact the outer ring. Once the piezos contact the ring further blade stretching will cause the piezos to stretch the cavity increase the frequency. The normal tuner operation shown in Fig. 3 can deviate due to bending of the tuner or cavity which will result in a piezo not contacting the tuner ring.

Testing of CM 2

The 3.9 GHz cryomodules were tested at the Cryomodule Testing Facility (CMTF) at Fermilab. The cryomodules consist of eight 3.9 GHz cavities each with a slim blade tuner installed. After the cooldown of the cavities to 2 K, the cavities are tuned to 3.9 GHz using the stepper motor. Once the cavities are tuned to 3.9 GHz the piezos are also

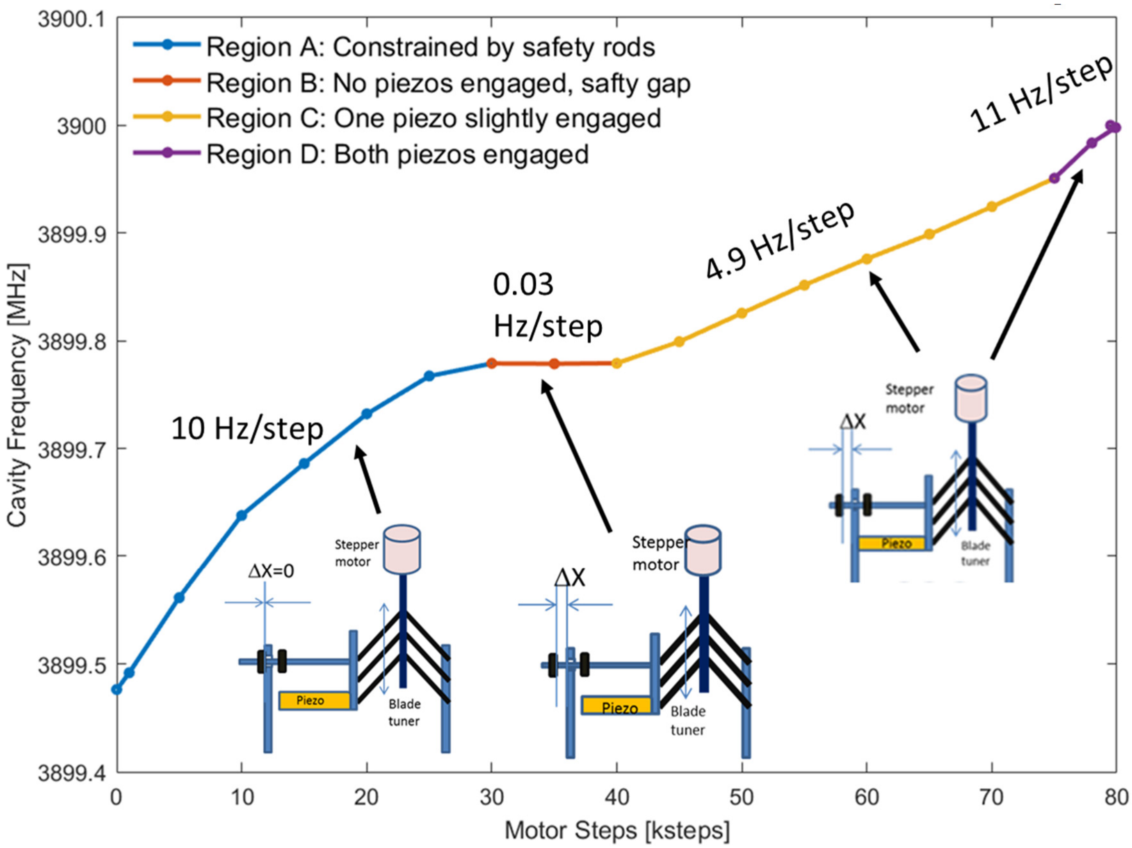

Figure 3: Frequency detuning the cavity with stepper motor tested at 2 K. Three regions are observed: region A has none of the piezo engaged and cavity frequency changes due to release of compression from the safety rods; region B is the position when cavity unrestrained with the tuner (both components: safety rod & piezo do not engage with cavity); region C is when one of the two piezo encapsulations is engaged; and region D is the position when cavity stretched by tuner through both piezo actuators.

tested to ensure that they are working. The expected frequency sensitivity for the piezos is 100 ±20 Hz/V if both piezos are engaged. During testing of cryomodule (CM) 2 cavity 6 had no response to the piezo stimulation. Additionally, cavities 2, 7, and 8 had only one piezo actuator engaged since their frequency sensitivity was below 100 Hz/V as shown in Fig 4. In all the cavities with low piezo frequency sensitivity, the wiring was checked by measuring the capacitance of all the stacks in the piezo encapsulations. The measurements all yielded a capacitance measurement of 1.9 μF for each stack. Therefore, the low-frequency sensitivity was not due to an electrical wiring fault.

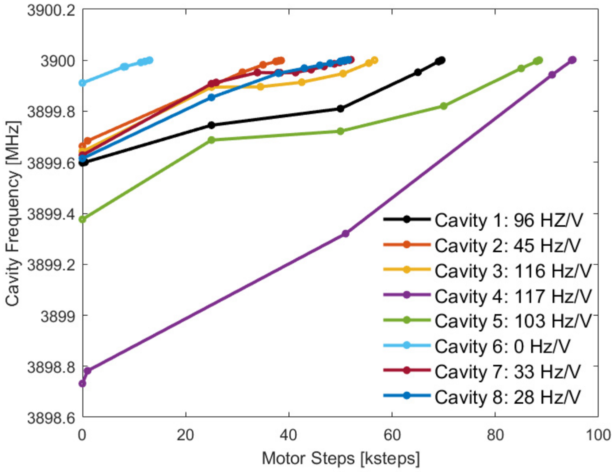

Figure 4: Slow tuner operation to set the cavity to the nominal frequency of 3.9 GHz in CM 2.

Based on the results from Fig. 4 all the cavities except cavity 4 have a high unrestrained frequency. Cavity 4's unrestrained frequency was low compared to the other cavities due to an error during transportation and handling. For the rest of the cavities a high unrestrained frequency leads to the tuner not having enough space to transition to region D where both piezos are engaged. This can be resolved by inelastically tuning the cavities to shift the unrestrained frequency down so that enough space is left for both piezos to contact the tuner ring and reach the 3.9 GHz frequency. Since the cavities are inside the cryomodule a significant number of resources are required to take them out and tune them individually outside the cryomodule. To tune the cavity unrestrained frequency down the stepper motor on the tuner was used. This was an unconventional use of the tuner since it was designed to stretch the cavity. The following section presents the procedure.

Inelastic Retuning at Room Temperature

All the cavities were first warmed up to room temperature to be inelastically deformed to lower the unrestrained frequency. During this tuning, the pressure inside the beamline was 2×10^{-11} torr, the insulating vacuum of the cryomodule and the cavity helium vessel pressure was set to 1 atm with back filled nitrogen gas. The cavities were compressed iteratively to reach a lower frequency value. The cavities were first compressed with the tuner and the frequency was measured. The tuner was then used to go back to the previous frequency to ensure that the frequency was decreasing with each iteration. The results for retuning of cavity 6 are shown in Fig. 5. During this procedure, the motor temperatures were being monitored and all had temperature increases less than 20 K. During this inelastic compression of the cavity each of the 9 frequency modes of the cavity were also recorded to ensure the field flatness of the cavity would be within the project's specifications.

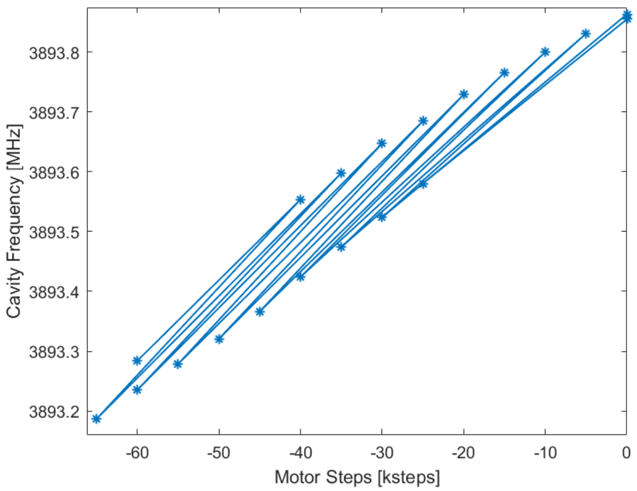

Figure 5: Inelastic tuning of cavity 6 with stepper motor.

The results after tuning the cavities for CM 2 are shown in Table 1. The warm frequency for all the cavities was lowered except for cavity 4. For cavity 4 the frequency was increased by 241 kHz. The shift in frequency depended on how close the unrestrained frequency was to 3.9 GHz. In the case of cavity 6 the frequency was 3899.911 MHz. The inelastic deformation of the cavity resulted in a shift of 469 kHz. After cooling down the cavity to 2 K, setting the insulating vacuum pressure to ~10^{-7} torr, and the pressure of the cavity helium vessel to 23 torr the cavity frequency will increase. This increase is on average 6 MHz ± 300 kHz from the warm frequency values shown in Table 1. The same inelastic deformation tuning was carried out for CM 3 cavities under similar conditions as CM 2.

Table 1: Cryomodule 2 warm cavity frequencies. The original frequency $f_{original}$ and the frequency f_{tuned} after tuning the cavities inelastically is given. The inelastic tuning is given by δf=($f_{original} - f_{tuned}$).

CM 2	$f_{original}$ [MHz]	f_{tuned} [MHz]	δf [kHz]
Cav. 1	3893.434	3893.299	135
Cav. 2	3893.531	3893.271	260
Cav. 3	3893.457	3893.287	170
Cav. 4	3892.573	3892.814	-241
Cav. 5	3893.191	3893.22	-29
Cav. 6	3893.743	3893.274	469
Cav. 7	3893.491	3893.297	194
Cav. 8	3893.454	3893.245	209

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Results of Tuning

The results of tuner operation in CM 2 after tuning are shown in Fig. 6. Note that all the unrestrained frequencies of the cavities are lower compared to those measured before the inelastic tuning (see Fig. 4). The number of steps needed to reach 3.9 GHz is also greater for all cavities. A piezo frequency sensitivity improvement was observed for cavities 2, 6, 7, and 8. Cavities 2, 7, and 7 all reached both piezo engagements with the tuner. Cavity 6 was inelastically deformed the most compared to the other cavities, but it only has one piezo engaged. Despite only having one piezo engaged cavity 6 can still tune the cavity by 5 kHz at 120 V. Note that not all the cavities exhibit the same shape as shown in Fig. 3. It is possible that during this large deformation the tuner or cavity was also deformed which caused only one piezo to engage.

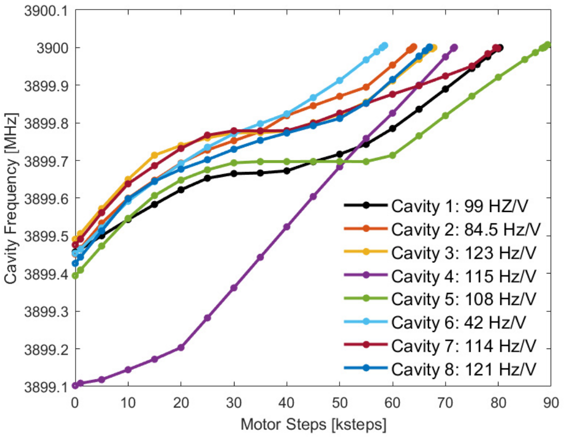

Figure 6: CM 2 cavity tuner operation after retuning cavity frequency of cavities 1, 2, 6, 7, and 8. The piezo frequency sensitivities are given next to the cavity.

The compression of the cavities for CM 3 was larger and the results of the tuner operation are shown in Fig. 7. In this case, only cavities 1, 3, and 5 have both piezos engaging. The other cavities have only one piezo engaging. All the cavities have a low unrestrained frequency. Therefore, it can be assumed that the cavities with only one piezo engaged were due to the deformation of the tuner or cavity.

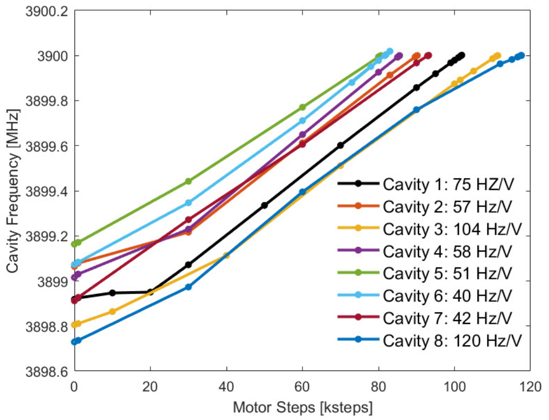

Figure 7: CM 3 cavity tuner operation after retuning.

CONCLUSION

During the operation of the 3.9 GHz cryomodule, it was discovered that one of the cavities had no piezo engagement after 100 V were applied. This was attributed to the initial frequency after cooldown being too close to 3.9 GHz. This was resolved by inelastically deforming the cavities with the slim blade tuner inside the cryomodule. This retuning of the cavities successfully engaged at least one of the two piezo actuators. For the cavities that only one actuator was engaged this can be attributed to deformations of the tuner or the cavity.

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