ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPML008

TUNER TESTING OF A DRESSED 3.9 GHz CAVITY FOR LCLS-II AT FERMILAB*

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Abstract

Fermilab is responsible for the design of the 3.9 GHz cryomodule for the LCLS-II that will operate in continuous wave (CW) mode. In the tuner design the Slim Blade slow tuner-mechanism was adopted from INFN for the European XFEL 3.9 GHz cavities [1]. The bandwidth of the SRF cavities for LCLS-II will be in the range of 130 Hz and fine/fast tuning of the cavity frequency is required. A fast/fine tuner made with 2 encapsulated piezos was also added to the design. As part of the Tuner Design Verification program the tuner prototype was installed on the dressed cavity and tested at the FNAL's Horizontal Test Stand (HTS). Summary of the tests are presented in this paper.

INTRODUCTION

Design of the 3.9 GHz tuner, technical specifications and results of the warm test measurements presented in the paper [2]. Tuner was mounted on the dressed cavity that has been installed at the Fermilab Horizontal Test Stand (HTS) [3] (Fig. 1).

TUNER TEST RESULTS

Slow/Coarse Tuner Test

The tuner was installed on the cavity as one of the last steps in preparation for cavity installation inside the HTS. Once the tuner was installed on the cavity the two-piezo actuators were uniformly preloaded by means of stretching cavity by 90 kHz corresponding to ~100 N preload on each piezo (or ~900 N including internal preload). To prevent non-elastic deformation of the warm cavity during several steps of assembly/pressure tests/cool-down the safety gap [2] on the tuner need to be set less than 150 um. Based on our previous experience with the Slim Blade tuner installed on the 1.3 GHz cavities [4] we learned that setting up a small safety gap can result in the locking of the piezo-actuators by the safety rods after cool-down to T=2K. We attributed this performance of the tuner to twisting and thermo-contractions of the different components of the dressed Slim Blade tuner/cavity system. We decided to set the safety gap during tuner assembly to 300um and back-up (squeeze) tuner ~150 um by running stepper motor 30,000 steps. The safety gaps on all 4-safety rods were remeasured after this procedure and were between 50 to 100 um.

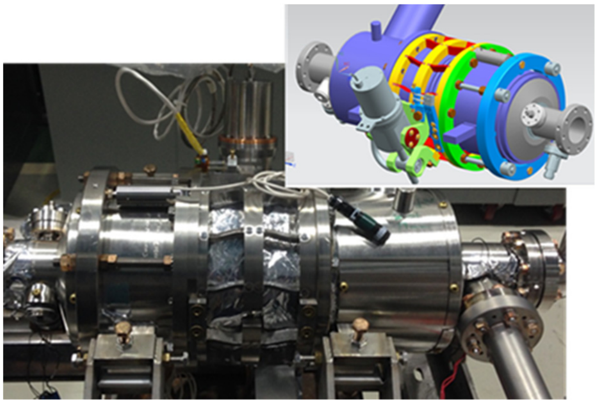

Figure 1: Slim Blade Tuner mounted on the dressed cavity before installed into HTS.

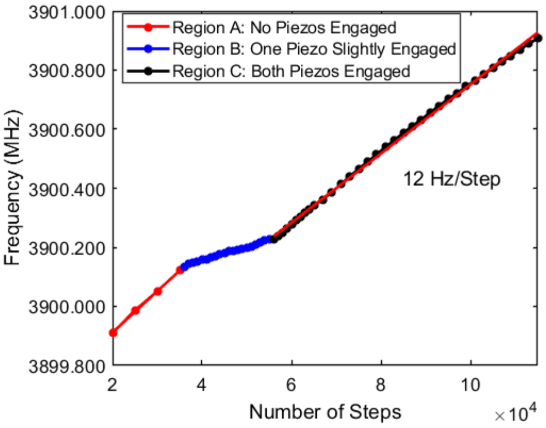

Figure 2: Detuning the cavity with stepper motor.

The tuner normally operates by stretching the cavity. For normal operation the frequency of the non-constrained cavity at 2K must be below 3,900 MHz with an offset of at least 100 kHz. For several reasons not related to tuner cold test the frequency of the non-constrained cavity at T=2K was 3,900.2 MHz, and frequency of the warm cavity during tuner installation (cavity beam line was under the vacuum) was 3,893.7 MHz. Measured cavity frequency shift ΔF = 6.5 MHz will be used to set target frequency for cavity tuning during manufacturing.

Results of the test of the slow/blade tuner are presented in Fig 2. Stepper motor runs in full step mode. Accuracy of the cavity frequency measurements with network analyzer was limited to quite significant microphonics on the cavity with an error was ~600 Hz. Three different ranges and sections of the slow tuner operation are presented in Fig. 2.

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* This manuscript has been authorized by Fermi Research Alliance, LLC under Contract N. DE-AC02-07CH11359 with U.S. Department of Energy

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First Section C is “normal operational” tuner range when cavity stretched by slow tuner through piezo-actuators. At Section C by running stepper motor on ~60 ksteps cavity has been tuned on 700 kHz with slow tuner sensitivity ~12 Hz/step.

The Section B (stepper motor range ~20 ksteps) is zone where cavity is non-constrained by tuner. If the cavity is totally non-constrained in Section B, cavity frequency must not change during operation of the stepper motor [4]. During our test in Section B, frequency of the cavity changed with a lower slope ~ 4 Hz/step. We attributed this behavior to two effects: tuner slightly twisting and at least one of the piezo being slightly engaged. At the stepper motor position 50 ksteps, DC voltage was applied to both piezos (one-by-one). When DC voltage was applied to top piezo, cavity frequency did not change. When DC voltage was applied to bottom piezo-actuator, the cavity frequency changed 60 Hz/V which confirms the bottom piezo engagement. Size of the Section B was 20 ksteps in motor rotations or 2 mm stroke in shaft, that is equivalent to tuner stroke ~100 um. This was direct measurements of tuner safety gap after cavity has been cooled down to 2K. Based on the results of this test we decided to keep safety gap ~300 um during tuner assembly in production cryomodules.

The Section A of the slow tuner curve (Fig 2) is tuner range when cavity compressed by tuner through safety rods/nuts. In the Section A piezo-actuators have been completely disengaged. There is no provision for operation of the cavity/tuner system in the range A. We operated tuner in the Section A only to establish cavity non-constrained frequency and the size of the safety gap.

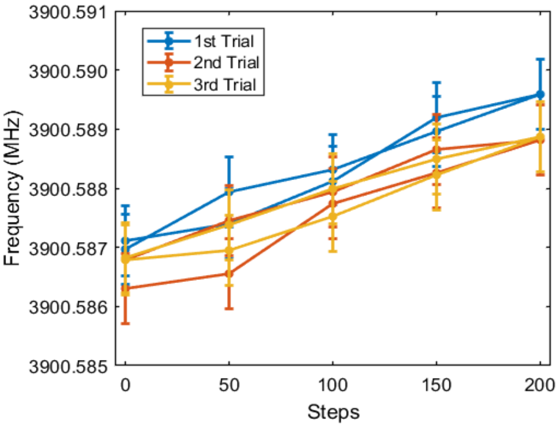

Figure 3: Short-range slow tuner performance.

Figure 3 shows that the slow tuner performance has a significant hysteresis which is approximately 600 Hz. As mentioned above, accuracy of the frequency measurements was limited to ~600 Hz which is reflected in Fig. 3. Estimation of the slow tuner hysteresis from data presented in Fig. 3 is consistent with measurements of the backlash for Phytron actuator [5] (~30 steps) and slow tuner sensitivity 12 Hz/step.

Fast/Fine Tuner Test

Another piezo test was performed when the tuner stretched cavity by 240 kHz from non-restrained position (from the end of Section B). The detuning of the cavity was measured when a DC voltage was applied to each piezo separately and on both piezos at the same time. For both piezo responses the sensitivity was ~120 Hz/V. When operated at 100 V the piezo actuator will detune cavity by 13 kHz with specifications of just 1 kHz. The piezo tuner response measured with cold cavity is consistent with measurements of the tuner mounted on the test stand at room temperature [2]. Results of the piezo tuner test are presented in Fig. 4. Taking into account cavity’s stiffness of ~5.4 kN/mm the preload is estimated on each piezo at ~300N (1.1 kN including internal preload).

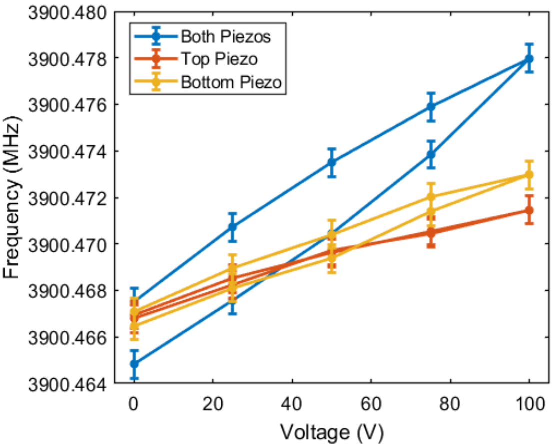

Figure 4: Detuning the cavity with fast/piezo tuner in region C.

CAVITY TRANSFER FUNCTION AND BACKGROUND NOISE MEASUREMENTS

There were no efforts to conduct passive mitigation of the microphonics at Fermilab HTS facility during test of the 3.9 GHz cavity. Despite the expected large level of external noise to mounted SRF cavity, inside HTS measurements were made to determine the level of microphonics on the dressed 3.9 GHz cavity. Based on our previous experience [4] we expected significant level of the vibrations/microphonics at the Fermilab HTS facility. During test of 3.9 GHz cavity at HTS there were no available resources to perform identification or suppression of the external vibration sources and as results overall level of microphonics was ~400 Hz peak (Fig. 5). The LLRF system was used to capture on-line detuning continuously for several minutes. Spectrogram of the cavity microphonics (for 10 minutes) are presented in Fig. 6. For the reference the microphonics budget for 3.9 GHz cavity is just 30 Hz (peak).

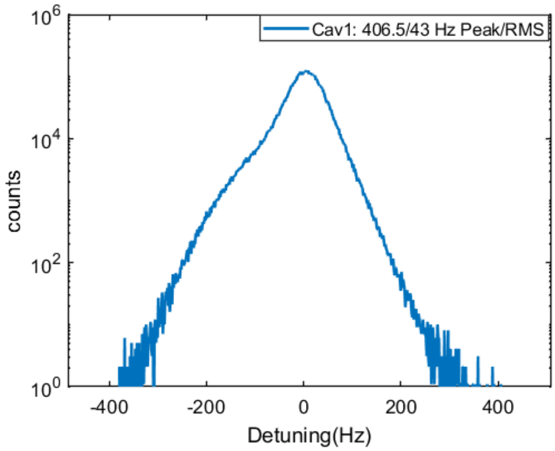

Figure 5: Histogram of the 3.9 GHz cavity microphonics.

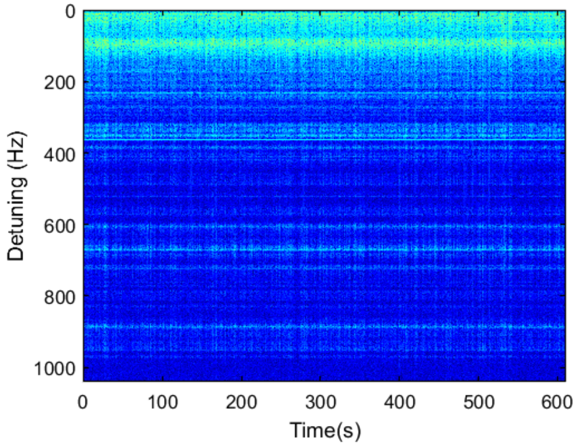

Figure 6: 3.9 GHz cavity detuning by external sources.

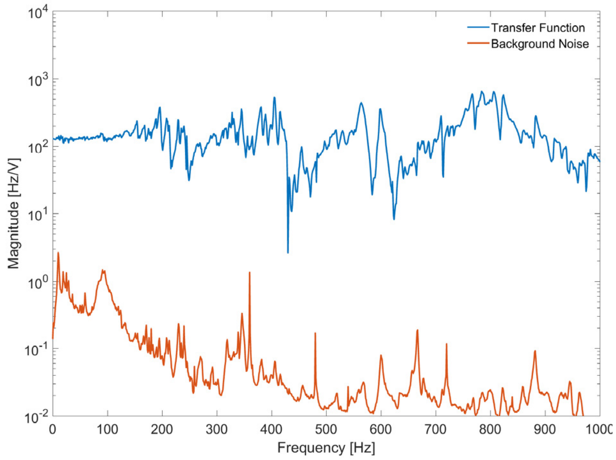

Figure 7: Cavity Transfer function (blue) and background noise (red).

The cavity/tuner system transfer function and background noise presented are in Fig. 7. Transfer function has been measured by sending on piezo sine-wave stimulus pulse (with 1 Hz increment) and measuring cavity detuning. This measurement shows that: (1) tuner/cavity system don't have internal mechanical resonances below 150 Hz; and (2) major contributions to microphonics spectrum came from sources with frequencies below 150 Hz. The 3.9 GHz cavity has internal (inside He vessel) magnetic shielding. Based on the resuls in Fig. 7 we can conclude that adding internal magnetic shielding does not cause strong mechanical resonances in the low (below 150 Hz) frequency range.

CONCLUSION

The tuner design verification tests of the 3.9 GHz tuner/cavity system at HTS facility confirmed that tuner met all specifications.

Several important aspects of the procedure for tuner assembly on the dressed cavity validated during cold tuner tests at HTS.

Lastly, initial microphonics measurements were made but no attempt was made to suppress them.

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