ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-WEPLM66

MICROPHONICS STUDIES AT STC IN FERMILAB*

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Abstract

The spoke test cryostat is used to qualify the 325 MHz single spoke resonators at Fermilab (FNAL). During these tests a large detuning on the cavity was observed. The data acquisition for continuous captures were based on measurements from the piezoelectric actuators. A comparison of the cavity vibrations measured with RF signal from the cavity and piezoelectric actuator signals are shown. The effects of microphonics on the cavity are discussed.

INTRODUCTION

Fermilab's Proton Improvement Plan (PIP)-II is an 800 MeV superconducting H^- linac which will consist of 5 different types of radio frequency (RF) cavities [1]. One of these cavities is a 325 MHz single spoke resonator (SSR1) of $\beta_{opt} = 0.22$. These "dressed" cavities can be tested in a cryomodule-like environment at the spoke test cryostat (STC) facility located in Fermilab's meson detector building (MDB). This facility shown in Fig. 1 is used to test the performance of the cavities such as the cavity's accelerating gradient, Q_o, field emission, and other ancillaries such as the tuner system used for resonance control.

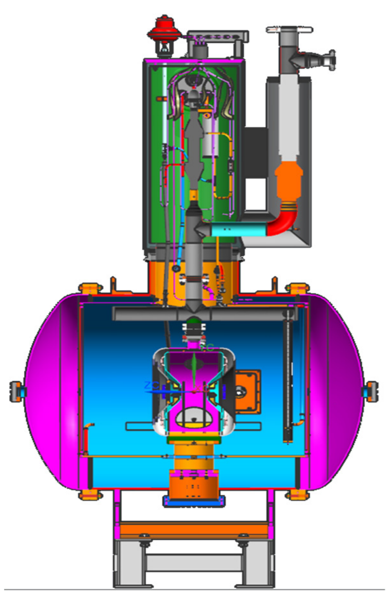

Figure 1: Schematic of SSR1 cavity inside the cryostat in STC.

Microphonics are vibrational noise that can couple to the cavity causing it to detune from its nominal frequency. These noise sources include pumps, internal and external vibration, pressure in the helium bath, and thermal acoustic oscillations (TAOs) in the helium supply lines. The calculated longitudinal frequency sensitivity of this cavity is 520 Hz/µm and the pressure sensitivity is 4.45 Hz/Torr [1]. A large detuning of the cavity will require more RF power to keep the desired accelerating gradient. Additionally, the RF power source has a limit, if the detuning is large enough the RF power source will not be able to provide sufficient power to the cavity and this will cause the cavity to trip.

In order to compensate for the detuning caused by microphonics a double lever tuner system is used. The design and figure of merit of the tuner are described elsewhere [2]. The slow/coarse frequency tuning component of the tuner is driven by a stepper motor with a tuning range of 135 kHz. This component is only used after cooldown to put the cavity at 325 MHz and is rarely used during the beam operation. The fast/fine tuner component uses piezoelectric (piezo) actuators which have a tuning range of 1 kHz. A control algorithm is used to drive the piezo actuators to compensate for microphonics [3].

For the control algorithm to reach the required PIP-II specifications of 20 Hz peak detuning for the 325 MHz SSR1 cavity the level of microphonics must be small. Fig. 2 shows a histogram for the detuning comparing the distribution when the active compensation algorithm is on versus when it's off. The level of observed microphonics noise is too high in order to compensate with the existing fast tuning system. This figure also compares the level of noise in the LCLS-II cryomodules to the one in the cryostat in this current study. The level of microphonics is 20 times larger than those in LCLS-II [4].

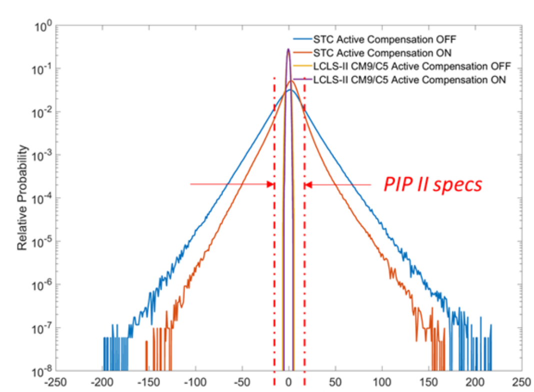

Figure 2: Histogram of detuning with active compensation on or off. For comparison the level of detuning in the LCLS-II is shown.

*This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics. Additional support provided by award number DE-SC0018362 and Michigan State University.
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This shows that this level of microphonics is on the extreme side and passive microphonics compensation must be done for the control algorithm to work. In this study the mechanical resonances of the cavity/tuner system were measured. The mechanical resonances were then compared to the vibration frequency of the microphonics to check if any of them were coupling to a fundamental (largest detuning) mechanical resonance.

EXPERIMENTAL RESULTS

Data Acquisition and Setup

The measurements were done with the cavity in continuous wave (CW) mode at low gradient (5 MV/m). During the data acquisition all the vacuum pumps were turned off to exclude them from the noise source. The temperature during testing of the cavity was 2 K. The measurements for microphonics were done with the SSR1 detuning. Additionally, the piezo actuators were used as sensors. The piezo actuators work by producing a voltage when they are deformed. A schematic of the cavity and piezo configuration is shown in Fig. 3. Whenever the cavity is deformed longitudinally this deformation was transferred to the tuner arm which also deformed the piezo producing voltage. The voltage was digitized with NI-PXI-4472 14-bit ADC.

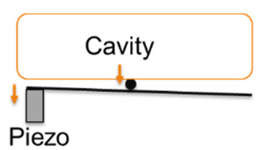

Figure 3: Cavity and piezo configuration.

The detuning of the cavity and the piezo actuator voltage was compared using FFT for both signals shown in Fig. 4. The main peaks of the vibration frequency of 22 Hz, 130 Hz, 150 Hz, and 196 Hz all line up with the signal from the piezo actuator. This shows that the piezo actuator is able to detect the same microphonic spectrum as the cavity. Although the shape of the spectrum is similar the intensity of the peaks is not the same. The piezo actuator is thus only used to find the frequencies of the microphonic sources but not intensity of each peak

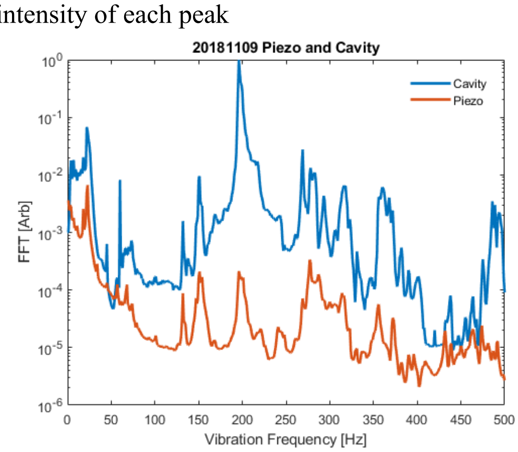

Figure 4: Comparison of cavity microphonics spectrum with that recorded via the piezo actuator.

Transfer Function

The mechanical resonances of the cavity-tuner system are measured with the piezo actuator. This is done by measuring the transfer function of the system. The transfer function correlates the amplitude and driving frequency of the piezo actuator to the cavity detuning. This was done by sweeping the driving frequency of the piezo actuator by 1 Hz increments and simultaneously recording the detuning of the cavity. The results are shown in Fig. 5 along with the microphonics spectrum for comparison.

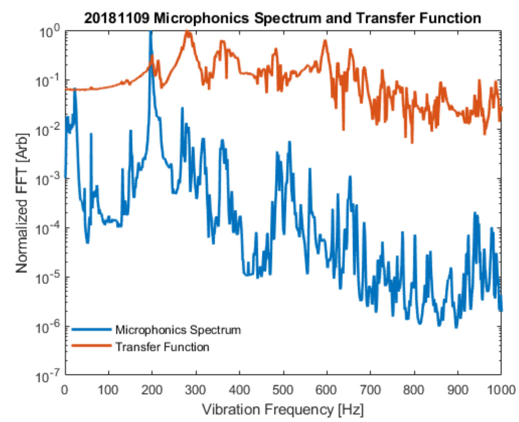

Figure 5: Comparison of the microphonics spectrum to the transfer function of the cavity-tuner system. The FFT spectrums have been normalized so that the main peaks are equal.

The transfer function shows that the dominant mechanical frequencies occur above 196 Hz. A vibration frequency around 300 Hz causes the largest detuning. This vibrational frequency can detune the cavity by 3 times compared to 196 Hz. The microphonics spectrum shows there is large peak around 196 Hz. This coincides with one of the mechanical resonances of the cavity-tuner system at 196 Hz.

This 196 Hz noise vibration is the main source of detuning on the cavity. The microphonics frequency contribution to the detuning is shown on Fig. 6, this figure shows the integrated RMS microphonics distribution for different dates. It was found that compared to previous dates the level of detuning had deteriorated. The 196 Hz vibration

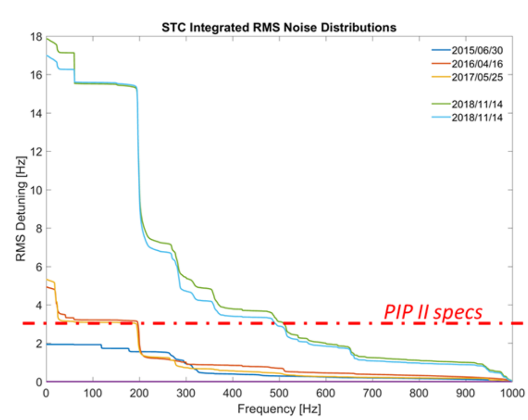

Figure 6: Integrated RMS detuning of the microphonics spectrum for different dates.

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frequency contributes the most to the overall detuning. But even if the 200 Hz source is found and mitigated the overall detuning is still above the PIP-II specifications. The microphonics spectrum is very broad and although the intensity at higher frequencies is small it can be seen from the transfer function that these higher frequencies contribute more to overall detuning if they are coupled to.

Vibration Source

Typically, frequencies of the external sources such as cryogenic-flow induced vibrations (TAOs), vacuum pumps and motors are found to be below 100Hz [4-6]. The vacuum pumps were turned off during the data acquisition, this left open the possibility that the vibration source was from TAOs or from another mechanical vibration. During this study only the piezo actuators and cavity were used to measure the vibrations.

Two possible vibration sources can be expected, one which is deterministic and one which is stochastic. A deterministic vibration source has a fixed frequency and amplitude. A stochastic source changes frequency and amplitude with time. To study the frequency and amplitude change over time a spectrogram of the piezo actuator was used shown in Fig. 7. The spectrogram shows lines that are mostly below 100 Hz. The main source of detuning at 196 Hz shows a broad frequency but static in time. The lines below 100 Hz show variability in frequency with time. Additionally, some of the structure of the lines repeats as the frequency moves higher with the base frequency at 22 Hz. This behaviour can be attributed to the harmonics.

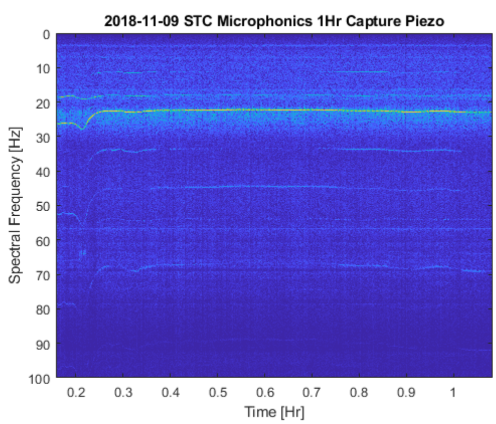

Figure 7: Spectrogram of the piezo signal over 1 hour.

Since there is a change in frequency of the 22 Hz line it's unlikely that this could be caused by a motor pump. Based on experience from mitigating LCLS-II microphonics another likely candidate would be due to the pressure inside the helium bath [4]. Inside the helium vessel of the SSR1 cavity there is a pressure transducer. The signal was recorded and an FFT was taken to compare to the signal from the piezo actuator shown in Fig. 8. From this data it can be concluded that the 22 Hz line is driven by a change in pressure of the liquid helium.

As mentioned earlier the spectrogram in Fig. 7 shows harmonic behaviour. Harmonics are an indication that a low frequency noise can be exciting higher frequencies. Fig. 9 shows the different harmonics with a fundamental frequency of 22 Hz. The 22nd harmonic happens at 198 Hz which is close to the main vibration source at 196 Hz. It is likely that the 22 Hz disturbance is exciting this 198 Hz which is close to 196 Hz vibration frequency. The source of this 22 Hz is likely coming from a TAO, the TAO frequencies are estimated to be between 10-100 Hz [7].

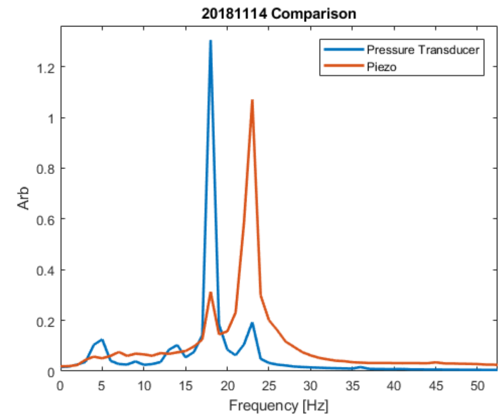

Figure 8: Comparison of FFT of signal from pressure transducer and piezo actuator.

Further studies are needed to reach a concise conclusion since the method applied in [7] were not applied during this study. These methods include changing the supply pressure and varying the helium flow. These methods will be done in a future study.

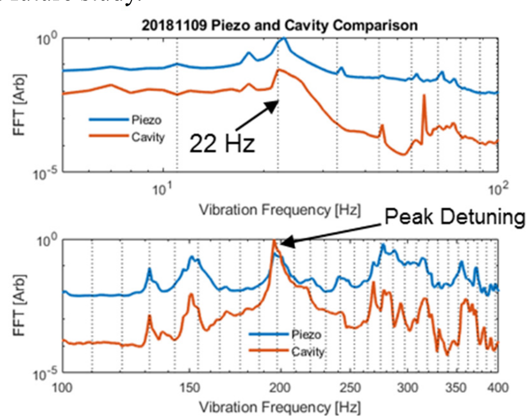

Figure 9: FFT of piezo signal with vertical lines showing the harmonics with f_o= 22 Hz.

CONCLUSION

The microphonics level was measured in the STC facility. The results show that there is a large detuning coming from a 196 Hz vibration source. Additionally, there are other noise sources which are coupling to mechanical resonances of high frequency. By analyzing the spectrogram of the signal from the piezo actuator it was shown that there are harmonics arising which are due to pressure variation likely caused by a TAO. Further studies are needed to verify whether the higher order harmonics are indeed causing the 196 Hz source and coupling to higher frequency mechanical resonances.

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