THE INFLUENCE OF TUNERS AND TEMPERATURE ON THE HIGHER ORDER MODE SPECTRUM FOR 1.3 GHz SCRF CAVITIES

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Abstract

Higher Order Modes (HOMs) are of concern for superconducting cavities as they can drive instabilities and so are usually damped and monitored. With special dedicated electronics, HOMs can provide information on the position on the beam. It has been proposed that piezo tuners used to keep the cavities operating at 1.3 GHz could alter the HOM spectrum altering the calibration constants used to read out the beam position affecting long term stability of the system. Also, of interest is how the cavity reacts to the slow tuner. Detuning and the retuning the cavity may alter the HOM spectrum. This is of particular interest for future machines not planning to use dedicated HOM damping as the tuning procedure may shift the frequency of HOMs onto dangerous resonances. The effect of temperature on the HOM spectrum is also investigated. An investigation of these effects has been performed at FLASH and the results are presented.

INTRODUCTION

Higher Order Modes (HOMs) are of concern for superconducting cavities as they can drive instabilities and so are usually damped and monitored. Simulations [1, 2] have shown that for future high power proton machines, HOM damping may not be required if the frequency of a mode is far enough away from a machine line and no complex chopping patterns are used.

Thus, it is important that cavities are designed such that their modes are far away from the machine lines. Of concern, is if a cavity is fabricated with a mode too close to a machine line. It has been suggested [3] that detuning and retuning the cavity, as well as warming up and cooling down the cavity could cause the HOM frequencies to shift slightly due to the cavity not being perfectly elastic.

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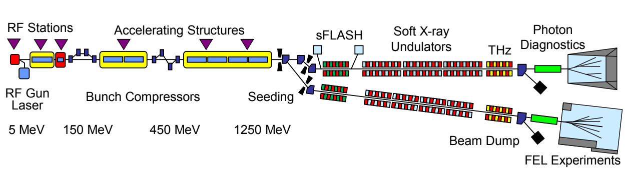

Figure 1: A schematic of the FLASH acclerator.

To investigate these effects, a study was performed at FLASH (Fig. 1). FLASH [4] is a Free Electron Laser facility generating short laser-like pulses with a wavelength between about 4 and 45 nm. It is also a test facility for the European X-ray FEL and the International Linear Collider. To accelerate the beam, seven cryomodules containing superconducting nine cell cavities operating at 1.3 GHz are used.

For the measurements presented here, cavities were measured in the fifth (ACC5) and seventh (ACC7) cryomodule.

SET-UP

The higher order mode spectra was measured using a Agilent 8753ES Network Analyser (NWA) connected to the HOM couplers of a cavity. For each cavity, the first two dipole passbands were measured from 1.6 GHz to 1.888 GHz along with the first quadrupole passband measured from 2.293 GHz to 2.32 GHz. The NWA was limited to a maximum data sample of 1601 points, therefore in order to get a good resolution of the modes, 500 data samples were taken for the dipole passbands and 50 data samples for the quadrupole passbands. The high number of data samples needed meant that the time to measure all three passbands was slow and on the order of 15 minutes.

Only eight out of the nine quadrupole modes were visible from the measurement.

The fundamental passband was not visible on the NWA. This possible due to the fact the HOM couplers reject the fundamental mode and thus coupler out.

The NWA had only 2 ports, therefore in order to prevent the need to continually plug and unplug cables, a Keithley S46 microwave switch system was used. The NWA and switch were both automated using LabView.

EFFECTS OF DETUNING THE CAVITIES

Before the superconducting linac was warmed up, the cavities were detuned to their relaxed state. Measurements were performed on cavity 1 and 2 from ACC7 before and after detuning in order to determine the frequency shift in the measured passbands. The accelerating mode in Cavity 1 was detuned by 305 kHz and in cavity 2 by 280 kHz. Figure 2 shows the shift in frequencies of the dipoles and quadrupoles for ACC7-C1. The shift is calculated by subtracting the detuned frequencies from the tuned frequen-

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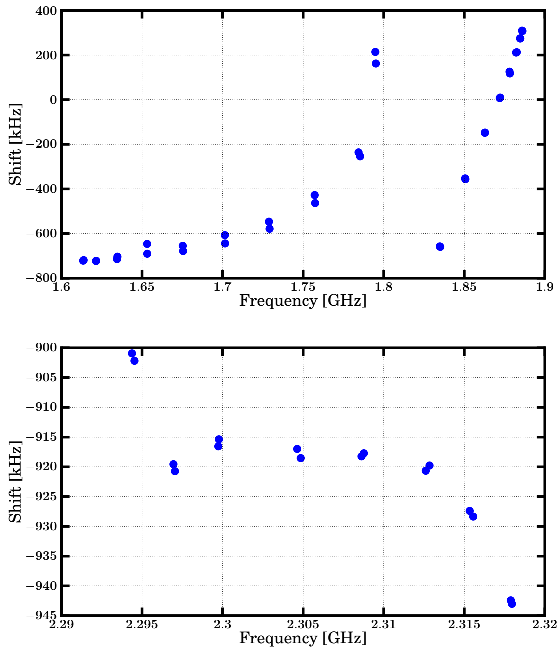

Figure 2: The shift in the dipole(top) and quadrupole(bottom) frequencies after the accelerating mode had been detuned by 305 kHz.

cies. Thus, a negative shift means the frequency has increased. The shift varies from -700 kHz to 200 kHz in the two dipole passbands however remains around 900 kHz for the quadrupole modes. Also of interest, is how the shift for the dipoles changes from negative to positive as the frequency increases in a smooth trend and then suddenly drops at the beginning of the new passband.

COOL-DOWN MEASUREMENTS

During the cool-down of the superconducting linac from 300K to 2K, the passbands were continually measured to observe how their frequencies shifted turing the temperature change. Cavity 1 from ACC5 and ACC7 were measured during the cool-down. The temperature as a function of time is shown in Figure 3. It can be seen that temperature drops at a relatively constant rate until around 60 K where the gradient increases. The right plot shows the temperature drop near and during the phase when the cavities become superconducting (T<9.2 K). Here the temperature has a very steep gradient from 10 K to 4.2 K where it remains constant until a final procedure is made to lower the temperature to 2 K.

The spectra of the passbands at temperatures of 300 K, 200 K, 100 K, 50 K, 10 K, 4.2 K and 2 K were then compared. It is important to note that at 10 K the temperature drop was very fast meaning that the modes could be at a temperatures below this. At high temperatures, it was extremely hard to detect the quadrupole modes and so only data from 10 K will be used in statistics.

Figure 4 shows the first dipole mode in ACC5-C1 as the

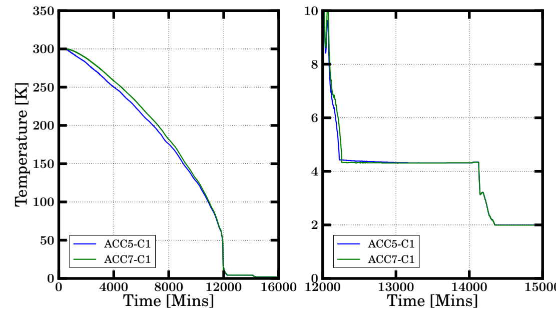

Figure 3: The temperature of the cavities measured as a function of time. The right plot shows a zoom in of the period when the cavities are superconducting.

temperature drops. It can be seen that as the temperature decreases, the frequency gradually increases as well as the quality factor. Between 10 K and 2 K, a very small frequency shift is observed however a massive increase in Q compared to 50 K due to cavity now being superconducting.

Figure 5 shows the fourth quadrupole mode in ACC7-C1 as the temperature drops. At temperatures above 50 k, the resonances are particularly hard to resolve, especially both polarisations.

Figure 6 shows how the dipole and the quadrupole frequencies have shifted after the cavity has been warmed up and re-cooled down to 4.2 K and 2K. The comparison is made with the detuned cavity frequencies. It can be seen that the frequency shift from 4.2 K to 2 K is quite large and is not thought to be just caused by the compression of the cavity due to cooling. After being warmed up and re-cooled, it is apparent that the frequencies have not returned to their initial state and have shifted which for the majority of modes is around 20 kHz. Once again, the dipole modes show a much greater variation in shift as compared to the quadrupole modes.

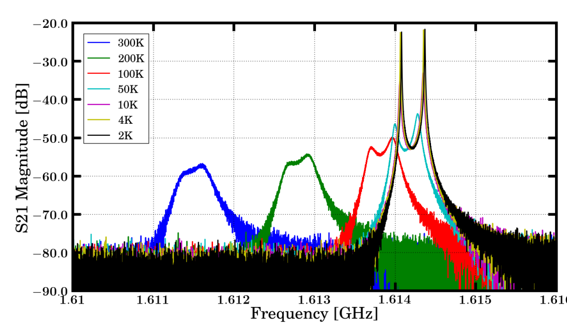

Figure 4: The first dipole mode in ACC5-Cav1 at different temperatures.

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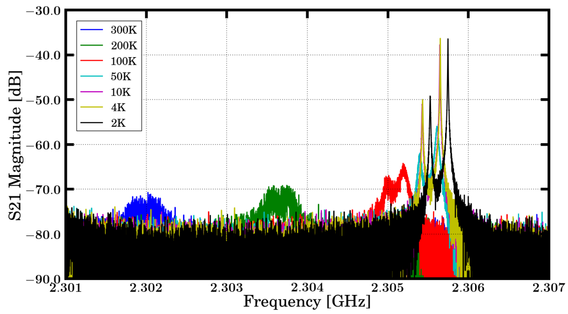

Figure 5: The first quadrupole mode in ACC7-Cav1 at different temperatures.

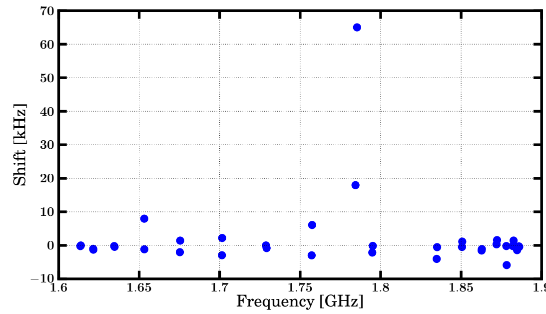

Figure 7: The shift in frequency after the cavity has been detuned, warmed up, cooled down and then retuned.

EFFECTS OF RETUNING THE CAVITIES

After the cool-down was complete, the cavities were then retuned to return the accelerating mode to 1.3 GHz. The final shift in dipole frequencies between the original tuned cavity and the final cavity after being detuned, warmed up, cooled down and retuned is shown in Figure 7.

The total shift is in most cases less than 5 kHz with some exceptions of much higher shifts. The biggest being close to 65 kHz. On-going analysis of the other cavity data is expected to determine if this shift is an anomaly.

SUMMARY

The shift on the modes in the first two dipole passbands and first quadrupole passband is observed while the cavity undergoes external effects. The cavity was first detuned before being warmed to 300 K. The cavity was then cooled down to 2 K and retuned. The cavity spectra was measured at various stages.

Analysis of the results of one cavity suggest that the whole cycle will result in frequencies shifts on the order of several kHz, thus this shift should be accounted for in cavity designs when avoiding dangerous resonances.

The tuning effects measured in this paper made use of the slow tuners. Of future interest, is the effect of the fast piezo tuners used to keep the cavity operating close to resonance during operation. It is of interest to see how the HOM spectrum responds to the fast tuners and whether this has an effect on diagnostic systems that make use of the HOMs.

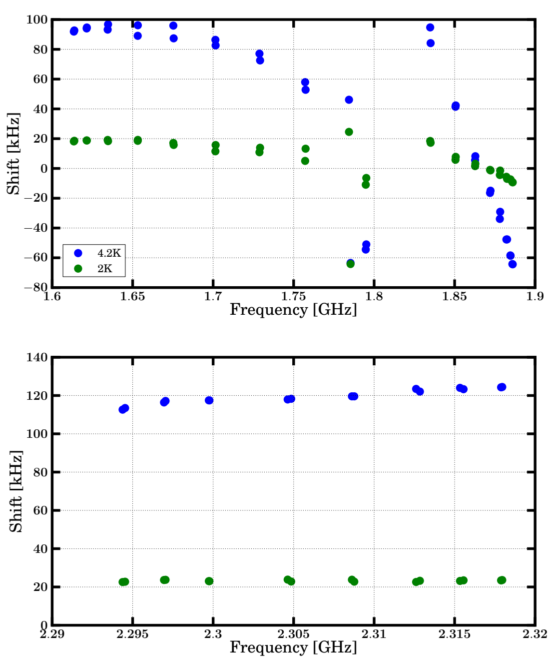

Figure 6: The shift between the detuned cavity before the warmup and the cavity at 4.2 K and 2 K during the cool-down. Dipole(top) and Quadrupoles(bottom) are shown.

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