TESTS OF A TUNER FOR A 325 MHZ SRF SPOKE RESONATOR

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Abstract

Fermilab is developing 325 MHz SRF spoke cavities for the proposed Project X [1]. A compact fast/slow tuner has been developed for final tuning of the resonance frequency of the cavity after cooling down to operating temperature and to compensate microphonics and Lorentz force detuning [2]. The modified tuner design and results of 4.5K tests of the first prototype are presented.

INTRODUCTION

Several different types of superconducting spoke cavities are being developed for Project X. CW and pulsed tests of the first SSR1 tuner prototype have been conducted at the 325MHz Spoke Cavity Test Facility (SCTF) in Fermilab Meson Detector Building [3].

As shown in Figure 1, each end of the cavity was equipped with a lever tuner. The lever tuner was designed

- To re-tune cavity in the range of -250kHz/+25kHz;
- Able to deliver up to 15kN forces on the each of the cavity beam-pipe flanges;
- To fit inside 26mm space available between the end of He vessel and other beam line components.

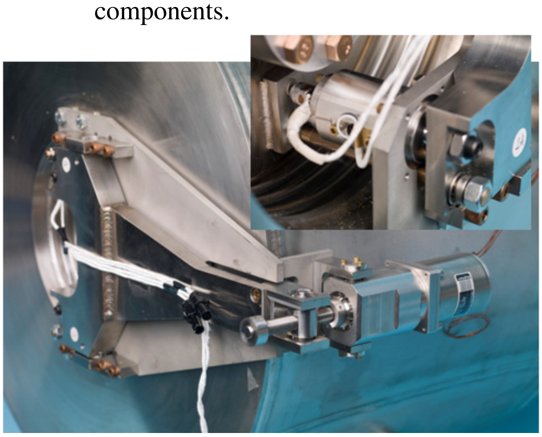

Figure 1: A lever tuner mounted on one end of the SSR1 prototype He vessel. The insert shows one of four encapsulated piezo actuators that push on the beam flange.

During the initial cool-down, the cavity was equipped with a narrow bandwidth (~1.5 Hz) coupler to allow Q_0 to be measured [3]. During the narrowband tests:

- Performance parameters of the slow tuner were measured.
- The sensitivity of the cavity to the pressure of liquid He bath (dF/dP) were measured.
- The static Lorentz force detuning coefficient was determined; and
- The fast tuner was used to compensate for detuning due to pressure variations in the 4.5K He bath.

Following the narrowband tests, the coupler was replaced with a wider bandwidth antenna (~100 Hz) [4]. With the wide bandwidth coupler:

- The fast tuner was used to compensate for dynamic Lorentz force detuning in pulsed mode at gradients up to E_{acc}~34 MV/m.
- The fast tuner was again used to reduce detuning due to variations the He pressure.

SLOW TUNER PERFORMANCE

Following initial cool down to ~4.5 K, the cavity resonance frequency was 217 kHz above operating frequency. The slow tuner was used to bring the cavity to the operating frequency by pushing on the cavity on the up-stream and down-stream beam-pipe flanges.

The tuner was designed always “to push” on the cavity to constrain the end-walls and to ensure adequate preload on the piezo-stacks [2]. As the cavity was tuned the forces on the cavity were measured by custom load cells installed on each of the four piezo actuators [5].

Figure 2 shows the cavity frequency as a function of the force on the beam flanges. The forces do not exceed the design bounds.

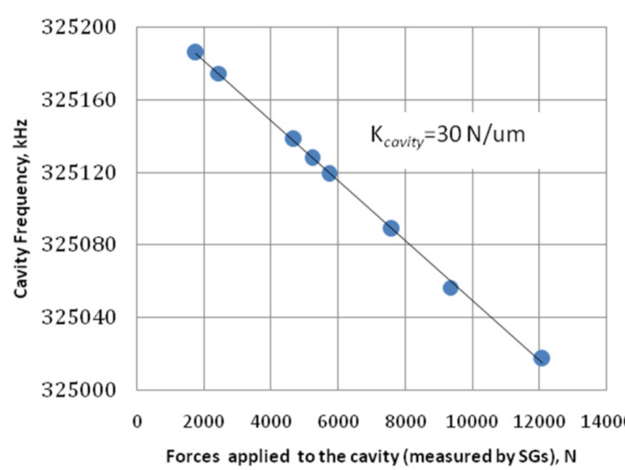

Figure 2: Cavity Frequency Shift as a Function of the Force on the Flanges

A summary of the measured slow tuner performance parameters along with comparisons to the design values is given in Table 1.

PRESSURE SENSITIVITY

The sensitivity of the cavity resonance frequency to changes in the pressure of the surrounding He bath (dF/dP) was also measured during the narrow bandwidth

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Table 1: A Comparison of the Measured Cavity and Tuner Performance Parameters to the Design Values

Parameter	Units	Measured	Design
Slow Tuning Range	kHz	-220kHz/ +20kHz	-250kHz/ +25kHz
Force on Cavity	kN	13	14
Force on each Piezo Actuator	kN	3	3.5
Fraction of Piezo Blocking Force	%	75	15-85
Cavity Spring Constant	(N/um)	30	20
Cavity Tuning Sensitivity	(Hz/um)	550	500
Unloaded dF/dP	Hz/torr	-280	-360
Loaded (13kN) dF/dP	Hz/torr	-137	-210
Unloaded K_{LF}	$Hz/(MV/m)^2$	2.0	----
Loaded (13kN) K_{LF}	$Hz/(MV/m)^2$	1.5	3.8

tests both while the cavity was loaded by the tuner and while it was unloaded. The measured values are again within acceptable bounds on the design values. To limit Lorentz force detuning, the accelerating gradient was maintained at a constant value during these measurements.

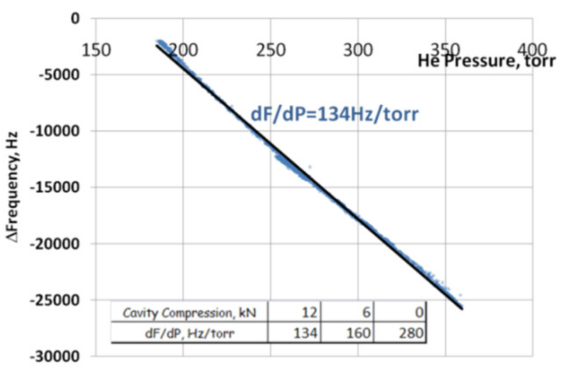

Figure 3: Cavity frequency sensitivity to He bath pressure (dF/dP). The inset shows the dF/dP value for different load applied by the tuner to the cavity beam flanges.

STATIC LORENTZ FORCE DETUNING

In addition to the forces of the tuner and the pressure of the surrounding He bath, radiation pressure (Lorentz force) on the cavity wall can change cavity frequency. The Lorentz force grows proportional to the square of the accelerating gradient:

$$\Delta F=-K_{LF}*E_{acc}^2.$$

The static LFD coefficient, K_{LF}, was measured by repeatedly changing the cavity gradient between E_{Acc}=3MV/m for 10 sec and E_{Acc}=20MV/m for 5sec and measuring the resulting change in the cavity resonant frequency. The results of this measurement are presented in the Figure 4. The changing heat load due to the changing gradient caused the He pressure to change. The measured dF/dP value was used to correct for the pressure changes. The measured values of K_{LF} while the cavity was both loaded and unloaded are included in the parameter summary of Table 1.

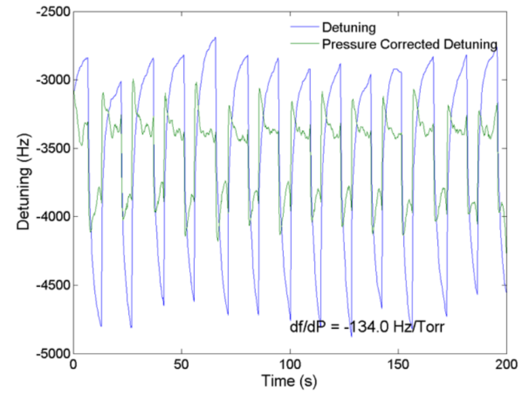

Figure 4: Static Lorentz Force Detuning in the SSR1 Prototype. The blue line shows the change of cavity frequency due to the combination of the static Lorentz Force and changes in the He pressure as the gradient was cycled between 3 and 20 MV/m. The green line shows the frequency shift following corrections for variations in the He pressure.

DYNAMIC LORENTZ FORCE COMPENSATION

In pulsed operation the predominant source of detuning is the Lorentz force. During tests using the wide bandwidth coupler, the fast tuner was used to compensate for LFD. The detuning of the cavity and response of the cavity operating mode F_π frequency to the piezo actuators was determine by exciting the fast tuner with a series of impulses while monitoring the cavity forward, reflected

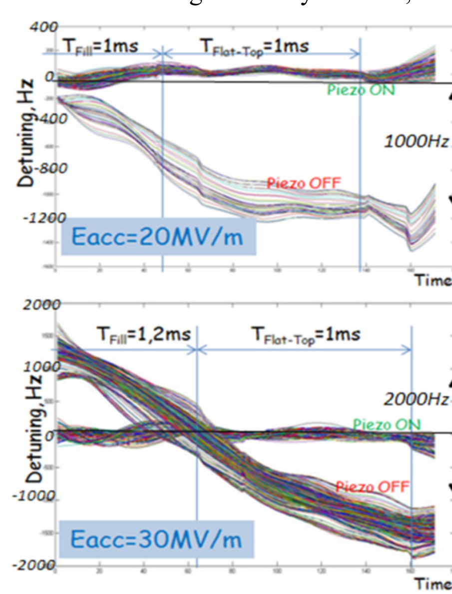

Figure 5: Lorentz Force Detuning compensation using the fast tuner during wide bandwidth RF-pulsed operation of the SSR1 cavity.

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and probe RF signals. A Least Squares algorithm was used to determine an appropriate compensation waveform [6].

Figure 5 shows the uncompensated and compensated detuning of the cavity at gradients of 20 MV/m and 35 MV/m for pulses with "fill" times of up to 1.2 ms and "flat-tops" of 1 ms. The LFD compensation system reduces the detuning of the cavity during the fill and flat-top from 3 kHz to less than 100 Hz. The dynamic LFD coefficient, K_{LF}, measured during 1ms "flat-top" is ~1.2Hz/(MV/m)^2.

The LFD control system also tracked and compensated for pressure related changes in the cavity frequency. As a result, the pulse-to-pulse variation in detuning in Figure 7 is noticeably larger when the compensation is off.

MICROPHONICS COMPENSATION

In CW operation at 4.5K the major source of detuning is changes in the He bath pressure. During CW operation with the narrow bandwidth coupler pressure changes could detune the operating frequency F_π cavity by many bandwidths. To maintain a constant gradient, the RF drive frequency was locked to the cavity resonant frequency [7]. The fast tuner was successfully used to stabilize the resonant frequency using a frequency locked loop. The control loop measured the cavity frequency and fed the result back the piezo actuators. When it was active, the control loop limited pressure related detuning of the cavity from several hundreds of Hz or to 1.3 Hz RMS.

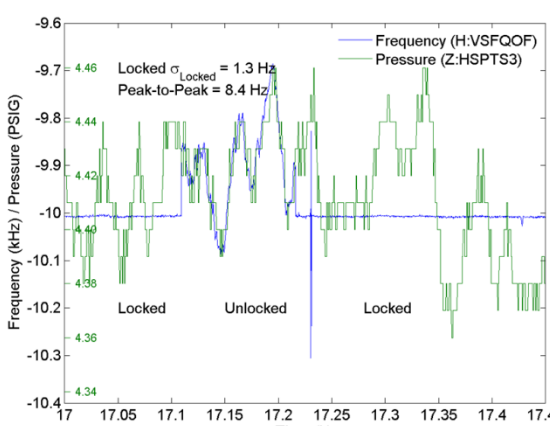

Figure 6: Microphonics compensation during narrow band CW operation of the SSR1. The blue curve shows the frequency offset of the cavity while both locked and unlocked. When the cavity is not locked the resonant frequency closely tracks the He bath pressure (green). The spike between 17.2 and 17.25 hours is due to changes in the cavity operating conditions unrelated to pressure.

Following installation of the wide bandwidth coupler these measurements were repeated with a fixed drive frequency and a phase-locked loop controlling the piezo actuators. Again the fast tuner was able to limit pressure related changes in the cavity frequency from several hundreds of Hz to 1.3 Hz.

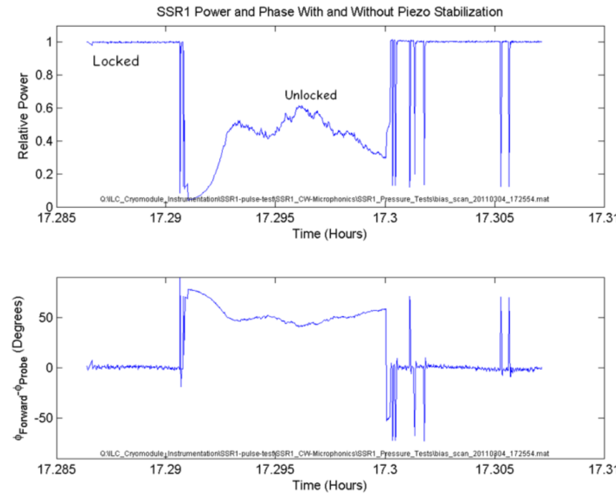

Figure 7: Microphonics compensation using the fast tuner during wide bandwidth CW operation of the SSR1. The blue curves show the relative power and forward-probe phase difference cavity both locked and unlocked. The spikes are due to changes in the cavity operating conditions unrelated to pressure.

CONCLUSION

The performance of lever tuners for the SSR1 spoke resonator prototype has been measured during recent CW and pulsed tests in the Fermilab SCTF.

The tuner met or exceeded all design goals and has been used to successfully

- Bring the cold cavity to the operating frequency;
- Compensate for dynamic Lorentz force detuning; and
- Compensate for frequency detuning of the cavity due to changes in the He bath pressure.

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