STUDY OF MICROPHONICS COMPENSATION FOR SRF CAVITY*

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Abstract

Microphonics and Lorentz Force detune the resonance frequency of a SRF cavity, leading to perturbations of the amplitude and phase of its accelerating field. Although this disturbance could be compensated by a piezo-electric tuner or with additional RF power, these two methods have conflicts, which is observed as unstable RF fields in a recent experiment. These conflicts could be explained by a model. Further experiments on ReA3 [1] cryomodule validates a conflict suggested by the model. Overall optimization of control algorithm is still needed to effectively combine the two methods.

INTRODUCTION

Microphonics and Lorentz Force Detuning are major disturbances to the accelerating field of an SRF cavity. Usually, people can invest more RF power into the cavity to compensate these effects. However, RF power is expensive, especially for high gradient SRF cavities. An economical substitute is piezo-electric tuner, which sense and compensate the vibration with a fast feedback system. But the compensation is relatively rough, compared with the RF power method. It seems natural to combine the rough and cheap tuner with fine RF power to get an effective and affordable compensation. As we expect a stable accelerating field by simultaneously applying both tuners, we did observe strong interference between them. Section 1 describes these observations.

To understand the conflict in the combo control, we have developed a model in MATLAB. The model reveals a conflict that is resulted from a time delay of piezo tuner control response. When high frequency modulation is induced by RF power modulation, such a time delay corresponds to a large phase difference, which could amplify the unwanted oscillations rather than suppress them.

We added a low pass filter to verify our speculation. The phase fluctuation has been suppressed from ±7° to ±4°, but not completely eliminated. Although the combo control uses two compensation methods simultaneously, their control algorithms are in fact separate. Apparently we need an overall optimization for the combo control algorithm that includes piezo's time delay into consideration.

In this paper, we also compared performance of ADRC algorithm on the piezo tuner with the common PI algorithm. Although ADRC appears to be more efficient than PI in simulation [2], their experimental performance are comparable. Section 2 describes our observation.

CONFLICTS IN THE COMBO CONTROL

To compensate microphonics, a piezo tuner was installed on the quarter-wave resonator (QWR) in ReA3. However, it was only used to suppress helium pressure fluctuations (<1 Hz), not microphonics (>1 Hz). A major source of the microphonics is the vibration of the QWR, with a resonate frequency ~38 Hz. To test the

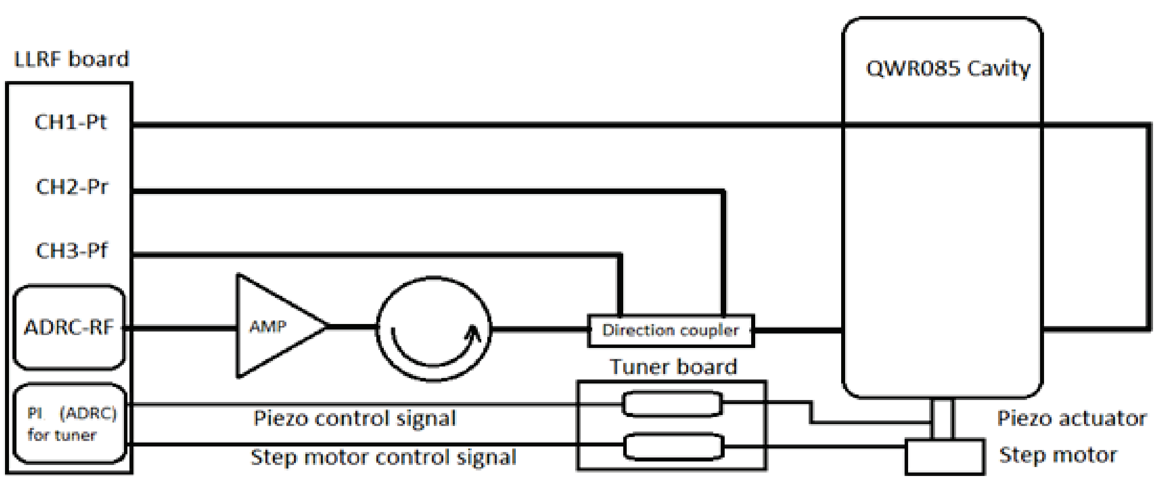

Figure 1: Test setup for a ReA3 cavity. CH1, CH2 and CH3 are three channels on the LLRF board receiving transmit (Pt), reflect (Pr) and forward power (Pf). RF power is controlled with ADRC. Piezo tuner is controlled by PI and later by ADRC.

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performance of combo control, we arranged a test as shown in Figure 1. Cavity accelerating gradient was set to be1.3 MV/m.

Single Control by Piezo-electric Tuner

We first would like to observe the performance of single control, i.e., RF control is open loop and piezo tuner is controlled by PI algorithm. A slow tuner, the step motor in Figure 1, is triggered to move when the cavity is detuned out of the frequency range of piezo tuner. The PI controller has a proportional gain (K_p) of 3 and an integral gain (K_i) of 1×10^{-4}. Those parameters were tuned to achieve the most stable response. The performance of piezo tuner is shown in Fig. 2 with a large microphonics and in Fig. 3 with a small microphonics.

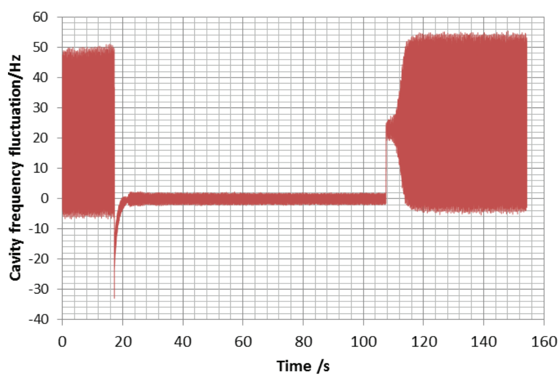

Figure 2: Performance of a piezo tuner with a large microphonics. The tuner was turned on at t=17 s and turned off at t=108 s.

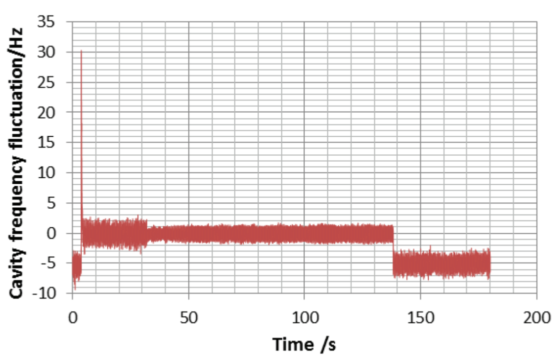

Figure 3: Performance of a piezo tuner with a small microphonics. Tuner was turned on at t=4 s with K_p=0 and $K_i=1\times10^{-4}$, K_p was changed to 3 at t=32 s, tuner was turned off at t=138 s.

It shows that a piezo tuner can reduce modulation of the cavity's resonance frequency to within ±2Hz for both large and small microphonics.

Performance of Combo Control

The motivation to use the combo control is to save the cost of RF power for compensation. But it turns out to be opposite result. Figure 4 shows the unstable phase of accelerating field with the combo control. It reveals conflicts between the RF power compensation and piezo tuner control, which drives a larger phase fluctuation.

To better understand the interference, we constructed a fundamental model, which should include fundamental parameters such as rise time of the piezo electric and basic components such as RF cavity, LLRF system, beam loading, microphonics and slow/fast tuner as Figure 1.

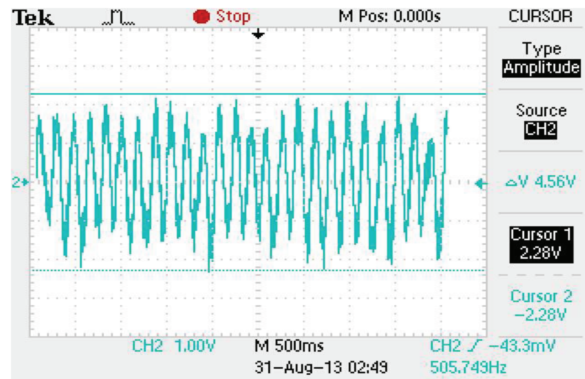

Figure 4: Unstable cavity phase with combo control. Phase fluctuation is up to ±41°.

Piezo tuner has a capacitance of ~36 uF, and an output resistance of 5 Ω. The rise time of charging T_{rc} thus is ~0.54ms (from 10% to 90%). In addition, piezo tuner also has a mechanical rise time. According to the data sheet provided by vendor, its mechanical resonant frequency (unloaded) is 5.5 kHz. Since the tuner is installed under the QWR bottom plate, which is weighed as ~2 kg compared with tuner's weight of 0.2 kg, the resonant frequency of the loaded case is

$$f = 5.5 * \sqrt{\frac{0.2}{2}} = 3 \text{ kHz}$$

The corresponding mechanical rise time is

$$T_{rm} = 1/(3f) = 0.1 \text{ ms.}$$

Since $T_{rm} < T_{rc}$, we use 0.54 ms in the model as the rise time, which is sufficiently fast considering the bandwidth of the ReA3 QWR (70 Hz).

With only rise time specified in the model, the combo control works well, as shown in Figure 5. It reduces the phase fluctuation to ±0.1˚. But it is not the case we observed.

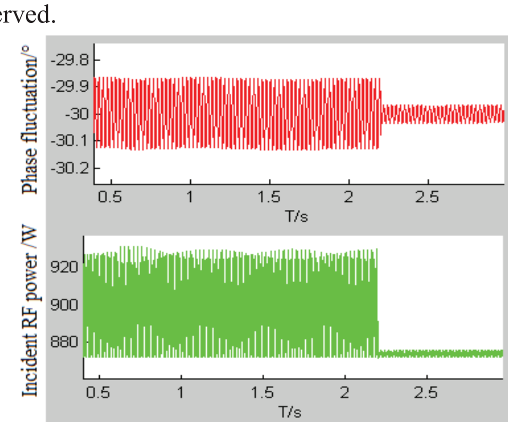

Figure 5: Simulation without piezo's time delay. RF control is on all the time, while piezo tuner is turned on at t=2.2 s.

We adjust the model by including piezo's delay. The combo control becomes unstable when we add a time delay (≥0.16 ms) to the piezo, i.e., piezo tuner responses ≥0.16 ms later after receiving control signal. That delay could actually happen due to: 1) hysteresis and backlash of the piezo; 2) transport of mechanical wave; 3) loop delay of the electronic circuits, where hysteresis could be the most important contribution to the 0.16 ms delay.

Experiment Validation and Suppression

Delay of piezo tuner could cause an additional phase shift between tuner control and RF control. This phase shift is much larger for high frequency signal than low frequency, which enhances the high frequency fluctuation brought by RF compensation. To validate this concept of interference, we add a low pass filter before the tuner control. In simulation, it eliminates the unstable fluctuation when the delay is set to be 0.16 ms.

Experimentally, the low pass filter is added in the DSP code of the tuner control. The original microphonics is measured as ±7°.

To use the combo control, we closed the RF phase control loop and tuner control loop, while kept RF amplitude control loop open. When the low pass filter is bypassed, phase of the cavity acceleration field became unstable (±41°) as in Figure 4. After we applied the low pass filter as in the simulation, the phase fluctuation is reduced to ±4°, as shown in Figure 6.

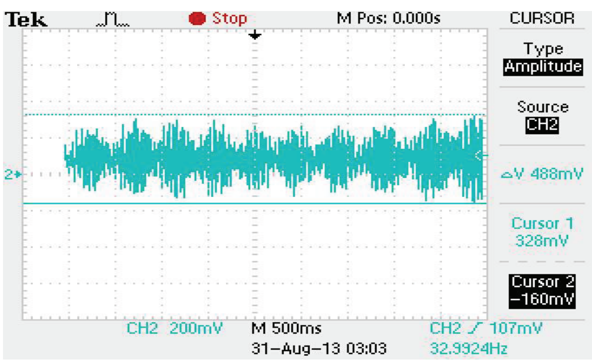

Figure 6: With low pass filter added before piezo tuner control, the phase fluctuation is reduced to ±4° for combo control.

Comparing with the background microphonics, the combo control reduces the phase fluctuations from ±7° to ±4°. The combo control works to some extent, but not as well as signal control. It did validate the conflict in the model, although a low pass filter cannot thoroughly mitigated the interference in the combo control. Since the cavity operated at a low gradient (1.3 MV/m) during experiment, no obvious reduction of RF power was observed in this experiment.

To optimize the performance of combo control, multi parameter optimization is needed for its control algorithm. There is no easy solution to use single parameter optimization approach in the combo control.

ADRC BASED PIEZO ELECTRIC TUNER

Besides the combo control test, we also applied ADRC algorithm on the piezo tuner to compare with PI controller. Different from what we expected in the simulation [2], the performance of ADRC (Fig. 7) is comparable with PI (Fig. 3), no obvious improvement. Both PI and ADRC performances are likely to be compromised by the hysteresis of the piezo tuner.

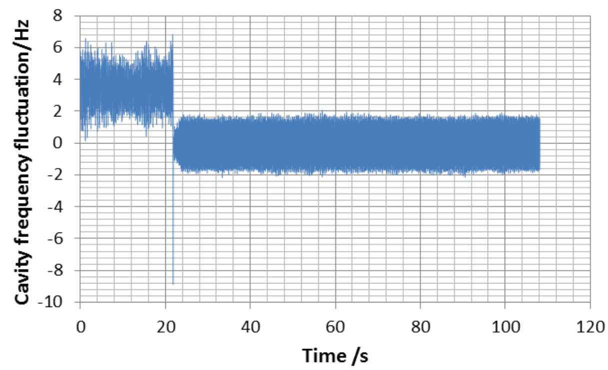

Figure 7: The performance of ADRC based piezo electric tuner. This is single control by piezo electric tuner. Tuner was turned on at t=22 s.

CONCLUSION

We did a series of experiments to benchmark the proposed combo control for microphonics compensation. It reveals that hysteresis induced time delay creates conflicts between piezo tuner and RF power control. A low pass filter before the piezo tuner control could suppress some interferences but not all of them. To achieve a good performance of combo control, a multi parameter control algorithm is needed.

We also compared ADRC and PI algorithms for the piezo tuner control, but found little difference.

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