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PROGRESS AT FNAL IN THE FIELD OF THE ACTIVE RESONANCE CONTROL FOR NARROW BANDWIDTH SRF CAVITIES*

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Abstract

Recent efforts at FNAL to actively compensate microphonics in narrow bandwidth cavities are discussed. Feed-forward compensation of Lorentz force detuning in combination with feedback of the forward/probe phase difference to a piezo actuator successfully stabilized the resonance of a 325 MHz spoke resonator to within 11 mHz of the frequency of the open-loop CW RF drive over a two hour interval.

INTRODUCTION

Many of the next generation of particle accelerators (ERLs, XFELs) are designed for relatively low beam loading. The cavities are designed to operate with narrow cavity bandwidths to minimize capital and operational costs of the RF plant. With such narrow bandwidths, cavity detuning from microphonics becomes a significant factor, and in some cases can drive the cost of the machine [1]. Piezo actuators have been successfully used to actively stabilize cavity resonant frequencies. This paper will present the results of ongoing detuning compensation efforts at FNAL using prototype 325 MHz SRF single spoke resonators designed for the PIP-II project at Fermilab [2].

PREVIOUS EFFORTS

Active compensation of both Lorentz force detuning and microphonics had been previously studied using an earlier SSR1 prototype with two different power couplers. An adaptive feedforward algorithm developed for pulsed 1.3 GHz 9-cell elliptical cavities [3] was able to reduce detuning in the spoke resonator from several kHz to 50 Hz or better during pulsed operation with a 150 Hz bandwidth power coupler (see Fig. 1). Feedback to the piezo actuator during CW operation at 4.3 K with a 0.5 Hz bandwidth coupler was able to limit detuning due to helium pressure variations to 0.4 Hz RMS. [4].

SECOND PROTOTYPE SSR1 SPOKE RESONATOR

A second SSR1 prototype was installed in the Spoke Test Cryostat (STC) in late 2014. The cavity was equipped with a matched coupler (0.6 Hz bandwidth) to allow quality factor measurements. The cavity was also equipped with two piezoelectric actuators that could provide dynamic tuning. The piezos were held in place by a dummy slow tuner that did not allow static tuning of the cavity. This cavity had been the focus on an active design effort to reduce and minimize pressure sensitivity [2]. During these tests the cavity was powered with CW at an operating temperature of 4.5 K. Despite the much lower measured value of df/dP (5 Hz/torr), the cavity would still not remain on resonance for any extended period without active stabilization.

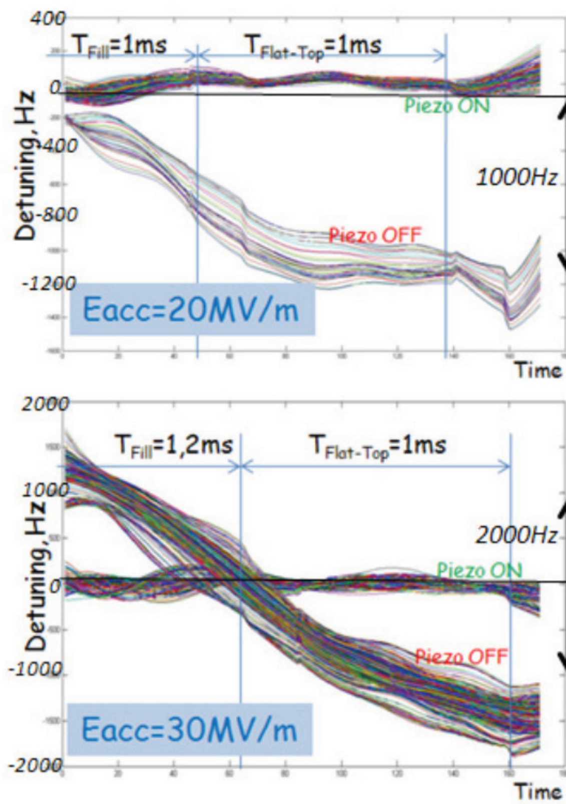

Figure 1: Pulsed compensation of Lorentz force detuning in an SSR1 cavity by adaptive algorithm.

FEED FORWARD COMPENSATION OF PONDEROMOTIVE EFFECTS

Radiation pressure from the EM fields in a powered resonator induces a mechanical deformation which in turn leads to shifts the cavity resonance frequency. The frequency shift is proportional to the square of the gradient as shown in Fig. 2.

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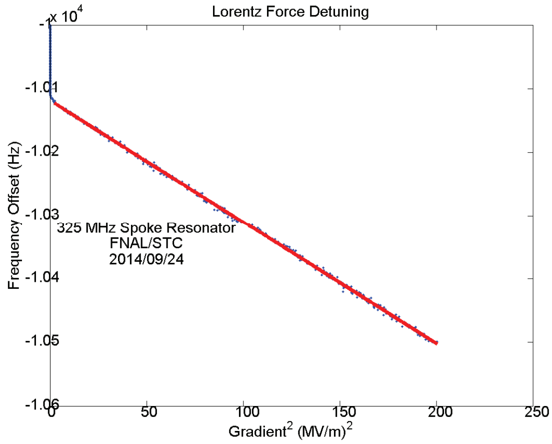

Figure 2: Measurement of LFD coefficient in SSR1. Cavity run to high field, then the stored energy was modulated down to zero while frequency tracking continued. The linear correlation between field-squared and detuning can be seen.

When frequency shift induced by the Lorentz force is larger than the cavity bandwidth ponderomotive effects can either stabilize or destabilize the cavity gradient depending on whether the drive frequency is above or below the resonance [6].

If the drive frequency is above the cavity resonance the Lorentz force shifts the cavity resonance frequency lower as the cavity gradient increases. The frequency shift acts reduce the cavity gradient. This negative feedback leads to stable operation above resonance.

In contrast, below the resonance the Lorentz force detuning leads to an increase in the gradient which results in even higher Lorentz force. This positive feedback makes stable operation on the lower frequency side of the resonance extremely difficult if not impossible.

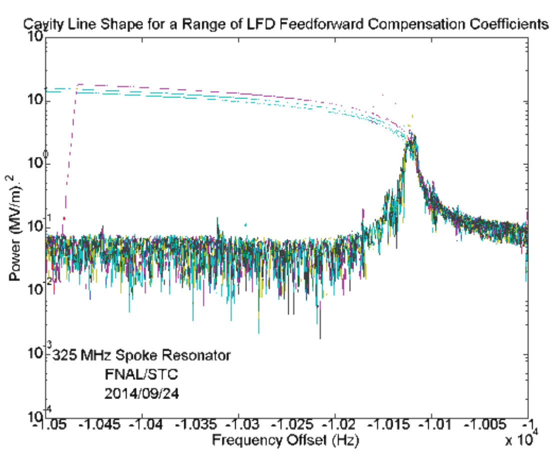

Figure 3: Resonance maps for three different LFD compensation coefficients. Purple and cyan show the heavily tilted resonance of a cavity with significant LFD while the peak on the right is the resonance map once proper compensation is achieved.

To counteract Lorentz force detuning a feedforward compensation voltage proportional to the square of the cavity gradient was applied to the piezo. The incident, reflected and transmitted signals were down-converted from 325 MHz to 13 MHz, digitized at 104 Ms/s with 14 bit precision, and processed in an FPGA to generate a piezo drive waveform using a 104 MS/s, 14-bit DAC connected to a high voltage amplifier. When feedforward compensation was active the cavity responded over a much narrower band as the drive frequency was swept as shown in Fig. 3 and the cavity did not exhibit any sign of instability on the lower frequency side of the resonance.

ACTIVE RESONANCE STABILIZATION USING FEEDBACK

Once ponderomotive effects had been suppressed using feedforward Lorentz force compensation, feedback proportional to the phase difference between the incident and transmitted signals was added to the piezo drive waveform generated by the FPGA. The combination of feedforward and fast feedback compensation successfully locked the cavity resonance to a fixed frequency open-loop RF drive signal but some long term drift was evident. A second slow feedback loop that adjusted to the piezo DC bias was implemented on the host computer to reduce such drift. The combination of feedforward, fast feedback and slow feedback was able to stabilize the cavity resonance to with 11 mHz RMS of the drive frequency over a two hour interval.

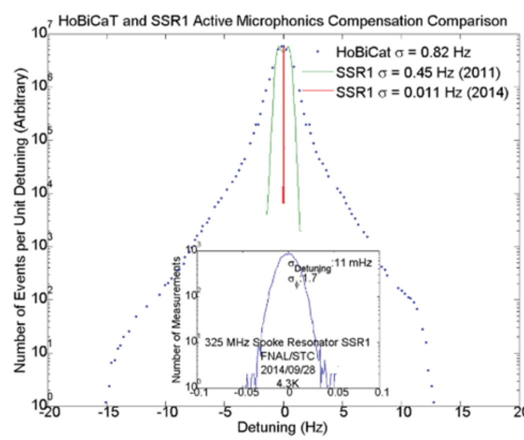

Figure 4: A comparison detuning distributions following active compensation at HoBiCaT and FNAL.

Figure 4 compares the distribution of detuning measured using the current SSR1 prototype to microphonics measurements made in the HoBiCaT test stand at BESSY and to measurements made using the earlier SSR1 prototype.

The distributions measured at FNAL show no sign of the large tails observed in the published BESSY data. Those tails are now believed to be due to instabilities in the cryogenic system. The detuning distribution measured at FNAL showed a double peak which may have been due

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to some signal other than the cavity baseband signals leaking through the digital filters in the FPGA firmware.

The most recent measurement employed synchronous down-conversion. The same clock was used to generate the cavity drive signal and to down-convert the cavity IF signals from 13 MHz to baseband. The detuning distribution shows only a single, narrow peak with a width of 11 mHz.

Figure 5 compares the measured magnitude of the transmitted/incident and transmitted/reflected transfer functions during active compensation to the expected resonance curves for a cavity coupling factor of β=1.4.

The feedforward compensation for Lorentz force detuning provides stabile operation on both sides of the cavity resonance.

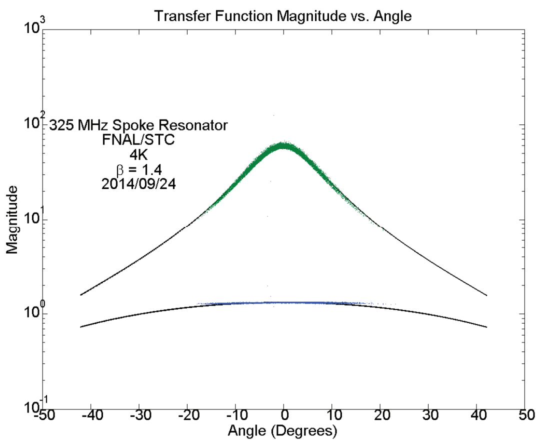

Figure 5: Magnitude of the probe/forward (blue dots) and probe/reflected (green dots) Transfer functions vs. forward/probe phase during active compensation.

FUTURE WORK

While the results of this work are promising, further effort will be required to bring active compensation to a point where it can be integrated into a control system capable of adequately stabilizing the resonance frequency of all cavities in an operational accelerator over the lifetime of that machine.

Stabilizing the resonances of the PIP-II cavities presents additional challenges because current plans call for pulsed operation of the machine. Further work will be required to demonstrate that Lorentz force detuning during can be controlled to the required levels.

CONCLUSION

Great strides have been made toward active piezo compensation of Lorentz force detuning and microphonics in SSR1 style cavities for PIP-II. Feedforward LFD compensation successfully suppressed ponderomotive instabilities during CW operation. Active feedback of the forward/probe phase difference to the piezo actuator was then able to limit cavity detuning to 11 mHz RMS over a two hour period.

REFERENCES

[1] S. Nagaitsev, “Project X, new multi megawatt proton source at Fermilab”, Invited talk, PAC’11, New York, USA (2011).
[2] D. Passarelli, L.Ristori, “SSR1 Tuner Mechanism: Passive and Active Device”, LINAC2014, Geneva, Switzerland (2014).
[3] Y. Pischalnikov, W.Schappert, “Adaptive LFD Compensation”, Fermilab-Conf-11-100-TD.
[4] Y. Pischalnikov, W.Schappert, “Adaptive LFD Compensation”, Fermilab Preprint-TM2476-TD.
[5] W.Schappert et. al.,” Resonance Control in SRF Cavities at FNAL”, PAC’11, New York, USA (2011).
[6] J. R. Delayen, “Phase and Amplitude Stabilization of Superconducting Resonators”, Ph.D. thesis, California Institute of Technology (1978).