RESONANCE CONTROL IN SRF CAVITIES AT FNAL

W. Schappert#, Y.Pischalnikov
FNAL, Batavia, IL 60510, USA
M. Scorrano
INFN-Pisa, Italy

Abstract

The Lorentz force can dynamically detune pulsed Superconducting RF cavities. Considerable additional RF power can be required to maintain the accelerating gradient if no effort is made to compensate for this detuning. Compensation systems using piezo actuators have been used successfully at DESY and elsewhere to control Lorentz Force Detuning (LFD) [1]. Recently, Fermilab has developed an adaptive compensation system for cavities in the Horizontal Test Stand [2,3], in the SRF Accelerator Test Facility [4], and for the proposed Project X [5].

INTRODUCTION

Superconducting RF cavities are in common use at accelerators around the world and cryomodules incorporating high-gradient (>30 MV/m) pulsed Tesla style 9-cell cavities are currently being constructed for the SCRF Test Area in NML at Fermilab as a part of the ILC Global Design Effort.

The walls of SCRF cavities are deliberately kept thin (<= several mm) to allow the cavities to be kept cool but the thin walls make the cavities susceptible to mechanical deformations induced by:

- The force of the accelerating electromagnetic field on the cavity walls (the Lorentz force);
- Fluctuations in the pressure of the surrounding helium bath;
- Mechanical vibrations induced by external mechanical noise sources (e.g. pumps, cranes, etc.).

These mechanical deformations can change the resonant frequency of the cavity. For high-gradient, pulsed cavities operating in super-fluid helium, the Lorentz force is the dominant source of cavity detuning. If no efforts are made to compensate for LFD, cavities can dynamically detune by several bandwidths. Maintaining the accelerating gradient under these conditions would require considerable excess RF power.

The use of piezo actuators to compensate for LFD was pioneered at DESY but has since been adopted widely [6]. Actuators connected to the beam flange are driven by a short unipolar drive signal prior to the arrival of the RF pulse. The timing, amplitude, width and bias level of the piezo drive signal are chosen such that the detuning of the cavity by the resulting acoustic impulse cancels the detuning of the cavity induced by the Lorentz force. This technique can successfully reduce the detuning of the cavity during the RF pulse from several hundreds of Hz to several tens of Hz.

While the standard approach can provide acceptable compensation for LFD, the mechanical response of individual cavities to the Lorentz force and to the piezo actuator can differ. Changes in cavity operating conditions, for example the changes in the gradient or bath pressure can require corresponding changes in the compensating waveform. At present, the compensation parameters for each cavity are selected manually. Operating multiple cavities for extended periods will require control systems that can automatically determine the best parameters for each cavity and adapt to changing operating conditions. Because the cavity detuning does not respond linearly to the changes in some parameters of the standard unipolar pulse, the adaptive capability that can be incorporated in LFD systems based on this approach may be limited. Furthermore while a single unipolar pulse can compensate cavities driven by short RF pulses, it may not be suitable for cavities where the length of the RF pulse is comparable to or greater than the period of the dominant mechanical resonance.

ADAPTIVE LFD COMPENSATION

The response of the cavity frequency to the piezo can be easily measured by driving the piezo with an impulse while the cavity is excited by a CW drive signal. Since it is often not convenient to connect a pulsed cavity to a CW source and alternative technique to measure this response was developed [7].

A procedure very similar to that used to optimize the pulse delay in the standard approach is employed at a gradient of several MV/m below the maximum. A series of low-amplitude unipolar drive pulses are sent to the actuator. The first pulse is timed to arrive in advance of the RF pulse. For each subsequent RF pulse, the delay between the piezo drive and the RF pulse is reduced in until the piezo pulse follows the arrival of the RF pulse. The forward, probe and reflected RF waveforms are recorded at each delay and used to determine the detuning. Least squares can be used to find the combination of delayed pulses that minimizes the detuning from this data.

As operating conditions vary, the RF waveforms can be used to measure any residual detuning. The response matrix can then be used to calculate the incremental waveform required to cancel that residual detuning.

*This manuscript has been authorized by Fermi Research Alliance, LLC under Contract N. DE-AC02-07CH11359 with U.S. Department of Energy.

#warren@fnal.gov

COMPENSATION SYSTEM HARDWARE

A single-cavity system based on the procedure described here has been deployed in the Fermilab Horizontal Test Stand. The system down-converts 13 MHz IF signals from the HTS LLRF system to baseband using AD 8333-EVAL I/Q demodulator boards. The baseband signals are digitized by an NI-4472B DSA card. A Matlab implementation of the adaptive procedure described above is used to update the compensation waveform with each RF pulse. The compensation waveform is played through an arbitrary waveform generator implemented in VHDL driving one 16-bit 100kS/s DAC of an NI-7833R board. The output of the DAC drives a 10x10x40 mm Noliac SCMAP9 stack actuator installed in fast tuner through a 200V PiezoMaster™ driver [8]. A similar single-cavity systems have been deployed at the 325MHz Spoke Cavity Test Facility (SCTF) in Fermilab Meson Detector Building [9] and at the SRF Accelerator Test Facility in Fermilab NML for used during the commissioning of the first cryomodule installed there.

An integrated LLRF/Detuning Control system is being developed for the SCRF Test Facility. Digital RF waveforms captured by the LLRF system will be processed by a resonance control task running in the MVME5500 LLRF controller. The bulk of the C language source for the detuning control task will be translated automatically from code developed for the single cavity system using the Embedded Matlab Compiler.

EXPERIMENTAL RESULTS

Figure 1 shows the detuning with and without compensation of a nine-cell elliptical cavity equipped with a blade tuner operating in the Fermilab HTS at a gradient of 35 MV/m. Compensation reduces the detuning from 750 Hz to less than 20 Hz. Figure 2 shows the piezo drive waveform used to compensate this cavity.

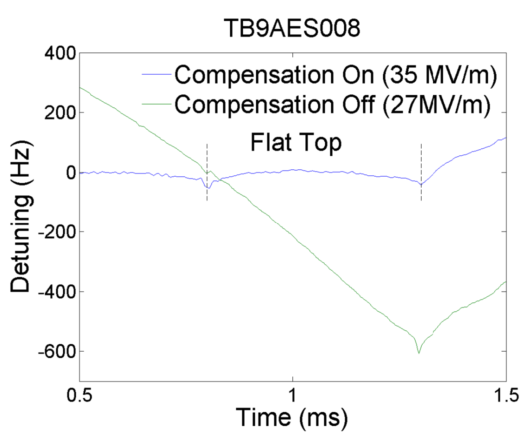

Figure 1: Lorentz force compensation in a nine-cell elliptical cavity at 35 MV/m.

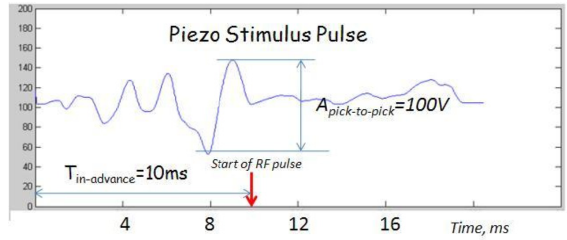

Figure 2: Compensation Piezo Wave Form for the Elliptical Cavity

Figure 6 shows the detuning of a 325 MHz spoke resonator at a gradient of 30 MV/m with and without compensation for multiple RF pulses.

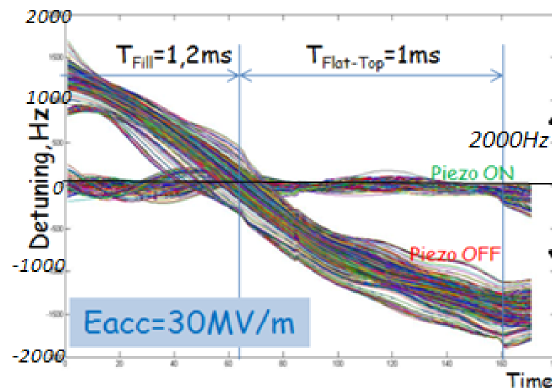

Figure 3: Detuning of a 325 MHz Spoke Resonator with and Without Compensation

Figure 4: shows the piezo waveforms used to compensate detuning in the spoke resonator. While the shape of the pulse changed little from pulse to pulse the bias adapted to compensate for pressure variations in the 4.5 K He bath. [10].

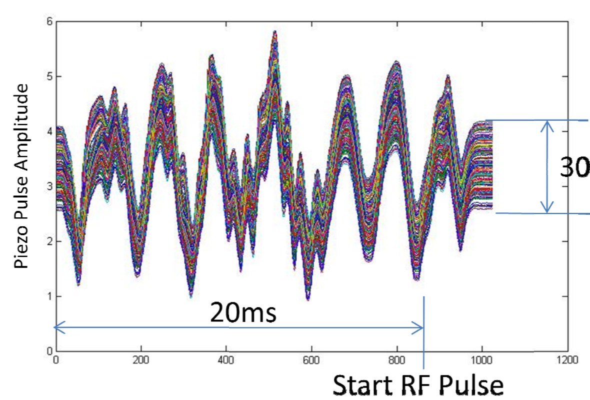

Figure 4: Compensation waveforms for the Spoke resonator.

Figure 5 shows the detuning of a nine-cell elliptical cavity driven by an 8 ms pulse with gradient E_{acc}=22MV/m. Cavity detuning without piezo compensation was several KHz. This was sufficient to drive the cavity completely off resonance.

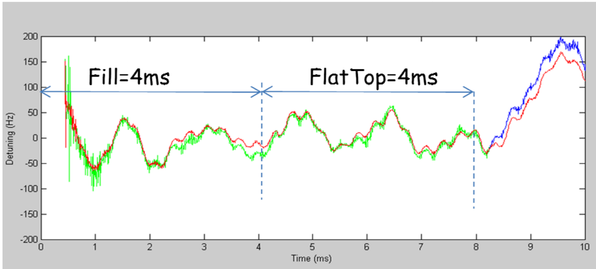

Figure 5: Detuning in a Nine-Cell Elliptical Cavity Driven by an 8 ms RF Pulse.

Figure 6 shows the detuning compensation for of a nine-cell elliptical equipped with a blade tuner at a gradient of E_{acc}=27MV/m. Detuning prior to compensation was ~300Hz. This cavity was built at Fermilab and sent to KEK for installation in the S1-G cryomodule. As part of the S1-G effort a single-cavity detuning control system was also deployed at KEK for several weeks. During that interval the system was able to successfully limit LFD detuning in of cavities of built to several different designs to better than 20 Hz.

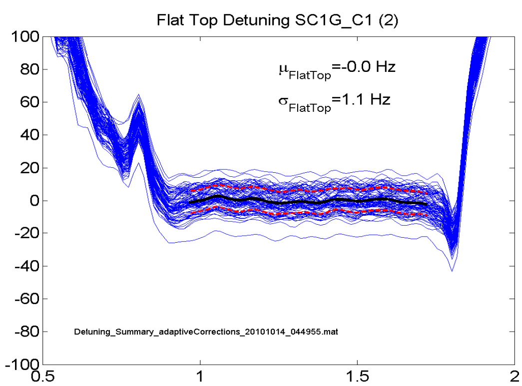

Figure 6: Detuning a Blade Tuner Equipped Cavity Installed in the S1-G Cryomodule at KEK

CONCLUSION

An adaptive procedure has been developed at Fermilab to compensate for Lorentz force detuning in SRF cavities. The procedure can automatically characterize the response of individual cavities to the Lorentz force and to the compensation actuator. The measured response is used to automatically calculate an appropriate compensation waveform and adapt that waveform to changing cavity operating conditions. The procedure has been successfully used to compensate a variety of cavities at Fermilab and elsewhere. Single cavity compensations system based on this procedure are routinely used to limit Lorentz force detuning during operations in the Fermilab Horizontal Test Stand. A multi-cavity system is being developed for the Fermilab SCRF Test Facility in NML.

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