PIEZOELECTRIC TUNER COMPENSATION OF LORENTZ DETUNING IN SUPERCONDUCTING CAVITIES *

J. R. Delayen, G. K. Davis, Jefferson Lab, 12000 Jefferson Ave, Newport News, VA 23606, USA

Abstract

Pulsed operation of superconducting cavities can induce large variations of the resonant frequency through excitation of the mechanical modes by the radiation pressure. The phase and amplitude control system must be able to accommodate this frequency variation; this can be accomplished by increasing the capability of the rf power source. Alternatively, a piezo electric tuner can be activated at the same repetition rate as the rf to counteract the effect of the radiation pressure. We have demonstrated such a system on the prototype medium beta SNS cryomodule with a reduction of the dynamic Lorentz detuning during the rf pulse by a factor of 3. Piezo electric tuners can also be used to reduce the level of microphonics in low-current cw accelerators. We have measured the amplitude and phase of the transfer function of the piezo control system (from input voltage to cavity frequency) up to several kHz.

DYNAMIC LORENTZ DETUNING

SNS will be the first large-scale use of superconducting cavities in a pulsed accelerator. Although the cavities will be strongly beam-loaded the dynamic Lorentz detuning is expected to be a substantial fraction of the bandwidth and the phase and amplitude control under these conditions will require additional amounts of rf power. During tests of the SNS prototype cryomodule [1,2], the dynamic behavior of the frequencies of the three cavities was measured and the use of a piezo tuner for its compensation was evaluated.

The measurements were made with a cavity resonance monitor (CRM) [3]. The CRM has a 50 dB dynamic range, so it can measure the cavity frequency during the rise and decay of the fields, but we do not have, at present, the ability to measure the frequency between pulses. This would require maintaining a small, but finite, rf field in the cavity. Measurements of the static Lorentz detuning and of the Lorentz transfer functions are presented in another contribution to this conference [4].

A typical measurement of the dynamic Lorentz detuning for an "SNS" pulse is shown in Fig. 1. In that figure, and all similar ones, the transients at the beginning and the end are associated with the phase-lock loop acquiring and losing lock and are not significant.

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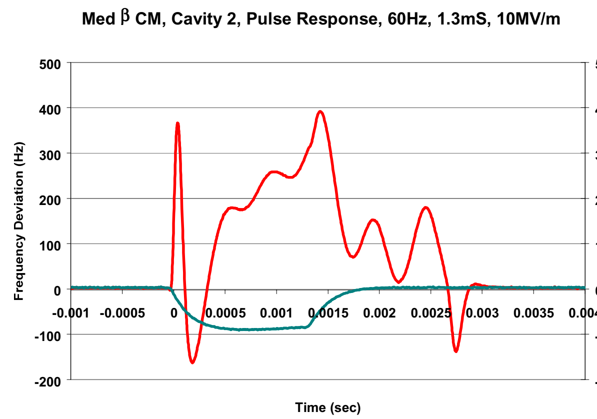

Figure 1: Dynamic Lorentz detuning during pulsed operation

PIEZO TUNER TRANSFER FUNCTION

The transfer function (phase and amplitude) from input voltage of the amplifier driving the piezo to cavity frequency was measured. This was done by sweeping the frequency of the drive modulation, and measuring simultaneously the phase and amplitude of the frequency modulation.

For cavity 2 we measured the transfer function for the two extreme positions of the slow mechanical tuner (Fig. 2). Subtle but real differences in the responses were observed.

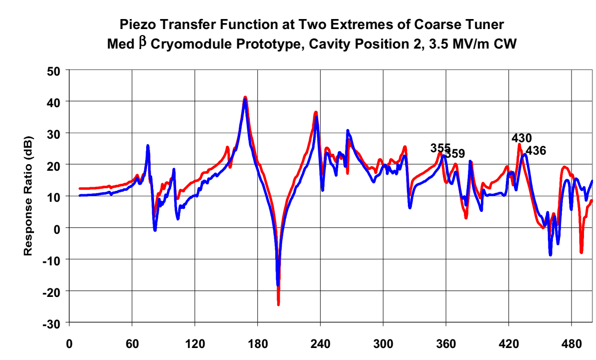

Figure 2: Amplitude of the PZT transfer function at two extremes of the mechanical tuner position

The behavior of the piezo tuner transfer function was somewhat unexpected and is not, at present, fully understood. First, the transfer functions of the 3 cavities were substantially different one from the other; some strong resonances that were present in one cavity were absent in others (Fig. 3). It should be pointed out that the transfer function includes the driver amplifier for the piezo, the piezo itself, and the mechanical modes of the cavity. Separation of the various contributions will require further testing.

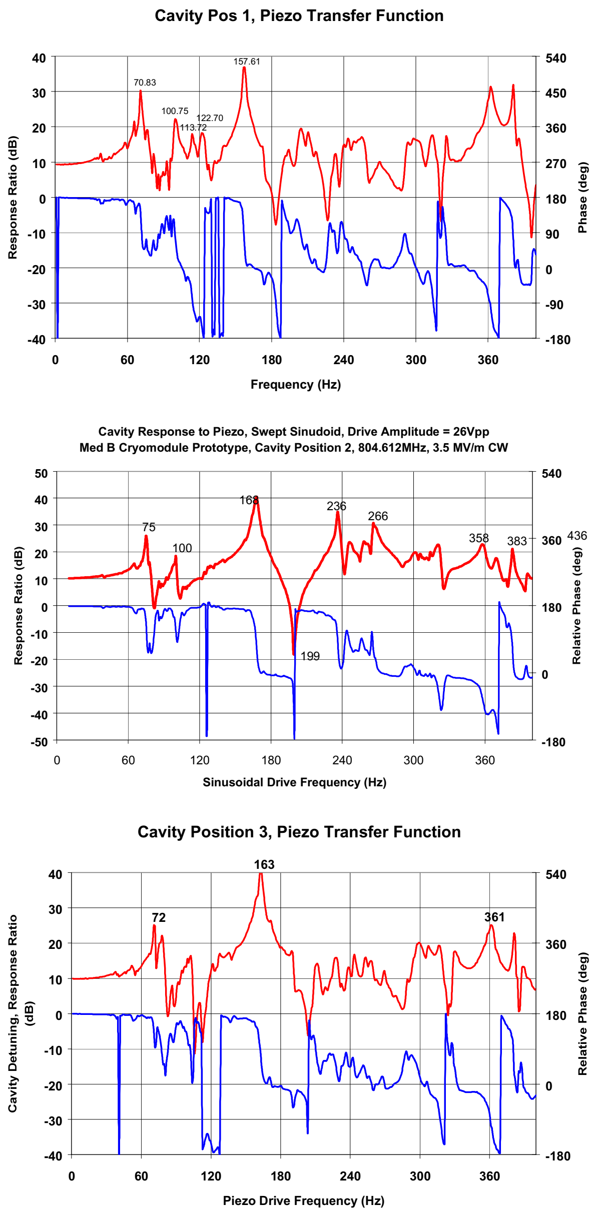

Figure 3: Phase and amplitude of the piezo transfer functions for the 3 cavities.

Phase Response Near Anti-Resonance

Frequency resolution was increased by sweeping the system from 185 Hz to 186 Hz in 400 equally spaced increments. Figure 4 clearly shows that the swept sine results in a -180° phase shift.

Next, the same cavity was retested using a dynamic signal analyzer to compute the frequency response function from an impulse. The impulse response was measured by driving the piezo with a 500msec pulse at a 1 second pulse repetition rate. Appropriate windowing is applied to the time domain signals. The analyzer then computes the ratio of the resulting FFTs. The resulting data shows a +180° phase shift, contrary to the previous swept sine measurement. Reasons for this apparent contradiction are under investigation. Identical tests on another cavity position produced a -180° phase shift for both tests.

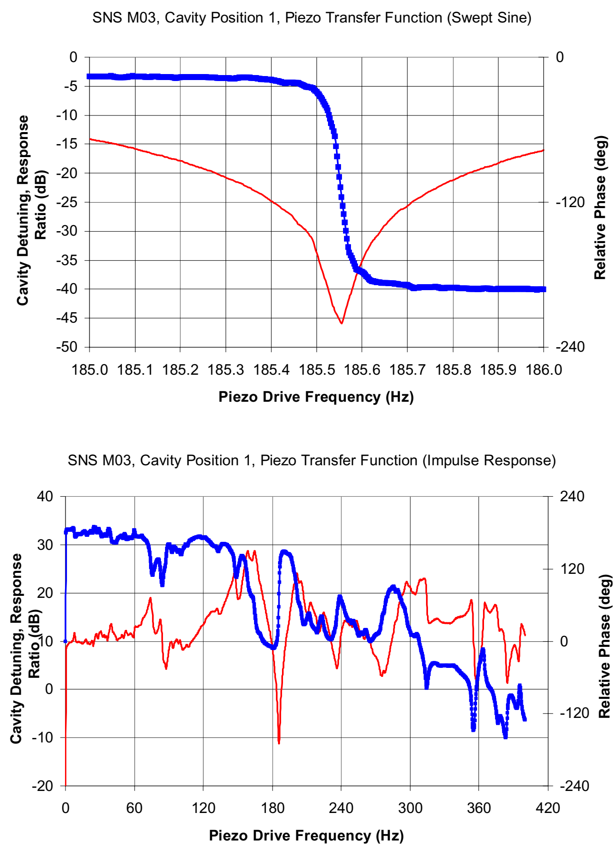

Figure 4: Phase response in the area near 180 Hz anti-resonance using two measurement techniques differs.

Impulse Time Response

The piezo impulse time response was recorded and time-averaged to remove uncorrelated noise such as background microphonics. Differences in the time response are notable in the detail of Fig 5. The same two cavities are compared in the frequency domain in Fig 6. These differences suggest that the low-level RF control system will have to be flexible enough to adapt to individual cavity characteristics.

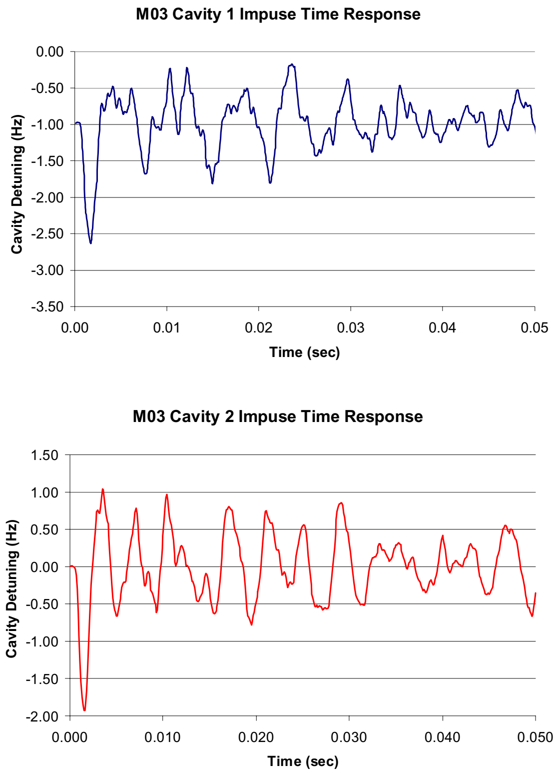

Figure 5: Impulse time response for different cavity position in the cryomodule.

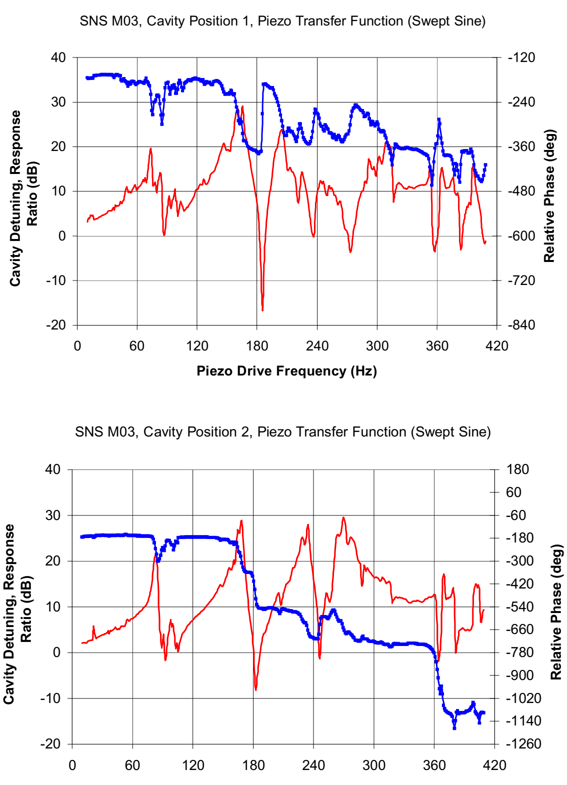

Figure 6: Frequency response for different cavity position in the cryomodule.

PULSED OPERATION OF THE PIEZO TUNER

The length of the rf and piezo pulses are much shorter than the period of the dominant mechanical modes, so it would be expected that the detail of the pulse shape would have relatively little effect on the dynamic behavior of the cavity frequency. Furthermore the decay time of the dominant modes is much larger than the spacing between the pulses, thus it would be expected that the cavities would be in a perpetual state of "ringing. This is demonstrated in Fig. 7. Cavity 2 was operated CW and the piezo tuner was activated at 60 Hz, in a similar fashion and amplitude that would be needed to compensate for the Lorentz detuning. The response of the cavity frequency was relatively insensitive to the rise time of the piezo pulse, but it was also essentially periodic. Consequenly, for the short duration of the rf pulse, the piezo pulse can be used to compensate for the Lorentz detuning which would have a similar complex, but periodic, behavior by carefully adjusting the timing between the two.

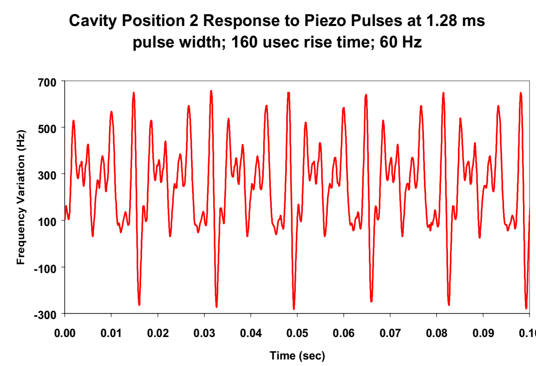

Figure 7: Cavity frequency variation induced by a 60 Hz excitation of the piezo tuner similar to that which would be needed to compensate for the rf-induced Lorentz detuning.

Of concern for use of the piezo tuner to control microphonics is the amount of microphonics that it can generate during activation. The frequency of cavity 2 was measured while activating the piezo tuner with a slow (1 or 2 Hz) trapezoidal signal with rise time of 0, 5, 10, and 20 msec. A square wave (0 rise time) generates microphonics of the same order of magnitude as the steady state displacement it induces; these microphonics then decay in about 400 msec (Fig. 8). In order for the microphonics to be less than 50 % of the steady state displacement, the ramp time of the trapezoidal drive must be at least 5 msec.

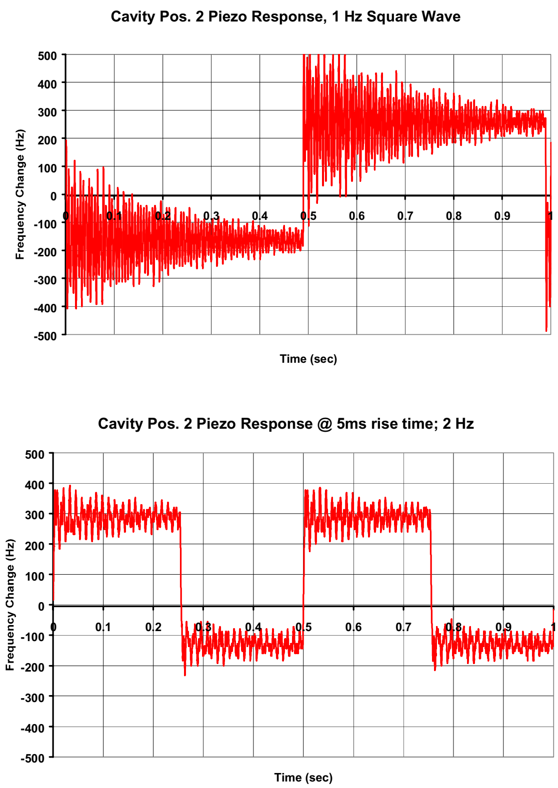

Figure 8: Cavity response to piezo square- and trapezoidal- wave (5 msec rise time) excitation

PIEZO TUNER COMPENSATION OF DYNAMIC LORENTZ DETUNING

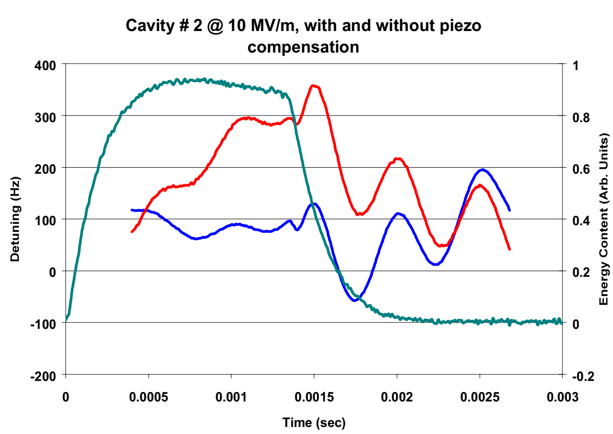

Figure 9: Cavity frequency without (red) and with (blue) piezo tuner compensation. Green: energy content.

The effectiveness of the piezo tuners in compensating for the Lorentz detuning is shown in Fig. 9. A reduction by a factor of 3 was easily achieved. The critical parameter was the timing between the rf pulse and the piezo pulse. Similar reduction was achieved by changing the polarity of the piezo drive signal by adjusting the timing. It should be noted that this compensation takes place only during the short rf pulse. Although we do not have the ability to measure it, it is likely that the cavity frequency undergoes large transients between the rf pulses.

REFERENCES

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[4] J. R. Delayen, G. K. Davis, "Microphonics and Lorentz Transfer Function Measurements on the SNS Cryomodules," these proceedings.