INFLUENCE OF PIEZO-HYSTERESIS AND RESOLUTION ON CAVITY TUNING*

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Abstract

All mechanical tuning systems are subject to hysteresis effects: For coarse tuning with a stepper motor, the exercised forces lead to a visco-elastic deformation of the tuner body. In piezo-based fine tuning, even if the smaller deformations of tuner and cavity can be regarded as fully elastic, the piezo-actuators themselves suffer from remanent polarisation effects. The extent of these nonlinearities has been measured in three different tuning systems (Saclay I, Saclay II and Blade Tuner) utilizing high-voltage as well as low-voltage piezo actuators. An estimate of the resulting tuner-resolution and performance degradation with respect to microphonics compensation is given. Experiments were performed at the HoBiCaT facility at BESSY.

BACKGROUND

Future CW-LINAC driven light sources like the BESSY-FEL or ERL require an RF-phase stability better than 0.02°. At an external quality factor of 3.2×10^7 and an LLRF feedback gain of 100 this corresponds to a maximum allowable detuning of 0.7 Hz. RF control systems are limited in gain or by phase noise of the RF reference system. Thus, it is a viable option to minimize the main error source, i.e. microphonic detuning. Microphonics compensation in cw-operated narrow-bandwidth (20-40 Hz FWHM) superconducting cavities has been demonstrated [1] with various different tuning systems [2, 3]. The maximum achievable compensation is limited by the resolution of the tuner system and hysteresis issues. The microphonics spectrum may be composed of a variety of small scaled detuning amplitudes. In order to compensate such a detuning, a piezo based system needs to resolve down to the centi-hertz regime, see Figure 1.

PIEZO HYSTERESIS MEASUREMENT

Cavities were operated in a closed loop PLL, see Figure 2. In order to measure the dynamic hysteresis a piezo voltage history was imposed with a function generator (carrier signal). For simplicity, a periodic sawtooth wave with a small frequency was used. This signal was added to a low amplitude, high frequency sine-wave from a lock-in amplifier (modulator signal). The phase error signal from the cavity was measured with the lock-in amplifier yielding the true momentary piezo-voltage-history-dependent value of the transfer function at the modulator frequency.

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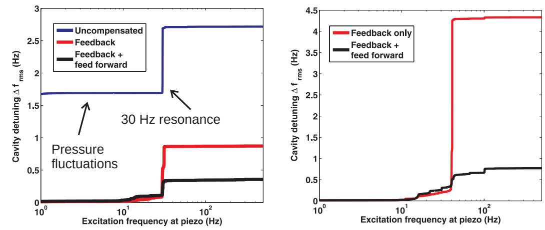

Figure 1: Microphonics compensation results: Integrated microphonics spectra of Saclay I (left) and Saclay II (right). By comparing feedback-only compensation with feedback/feedforward compensation, a resolution limit can be extracted: 0.1±0.05 Hz for the Saclay I tuner, and 0.2±0.05 Hz for the Saclay II tuner.

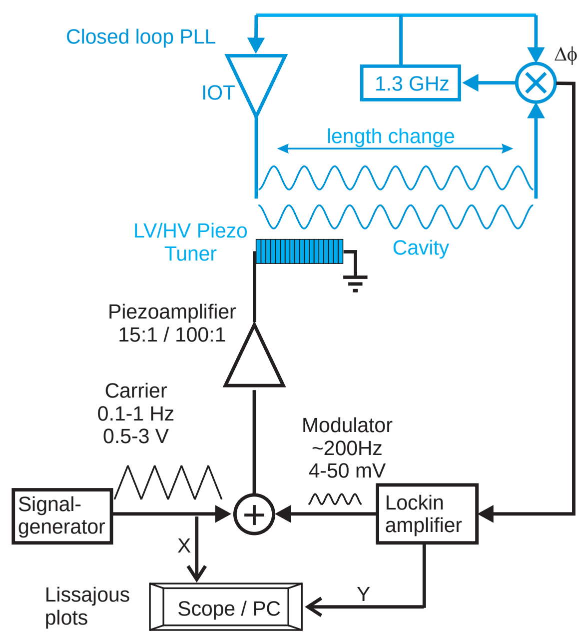

Figure 2: Experimental setup of the hysteresis measurements.

The dynamic response of the piezo to the controlling voltage is dependent on the history of the voltages, see Figure 3. The hysteresis effect can change the transfer function of the system: All resonances, or their Q-factors, respectively, are varied within an amplitude range defined by the maximum difference between the expanding and the contracting piezo. However, this viscoelastic nonlinearity of the piezo response is strongly deterministic, as can be seen from the shape of the hysteresis curves. With all the tuner modes mapped out properly, it can be incorporated into a feed forward based tuning algorithm.

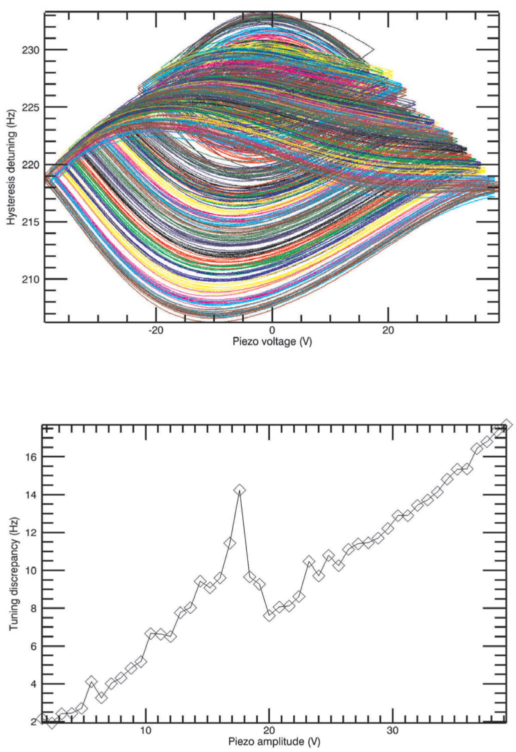

Figure 3: Dynamic hysteresis of piezo tuner. The measurement was done with the blade tuner at a modulator frequency of 205 Hz, a modulator amplitude of 1 V and a carrier frequency of 0.5 Hz. The carrier amplitude was varied from 1 V to 40 V. In the vertical direction, the variation of the phase-error signal in terms of detuning is plotted. The detuning obviously shows a hysteresis behavior. The asymmetrical shape of the hysteresis curve is caused by imperfect phase match of the PLL. In the lower plot, the maximum difference is plotted. The peak in the lower plot is due to manual phase correction during the measurement.

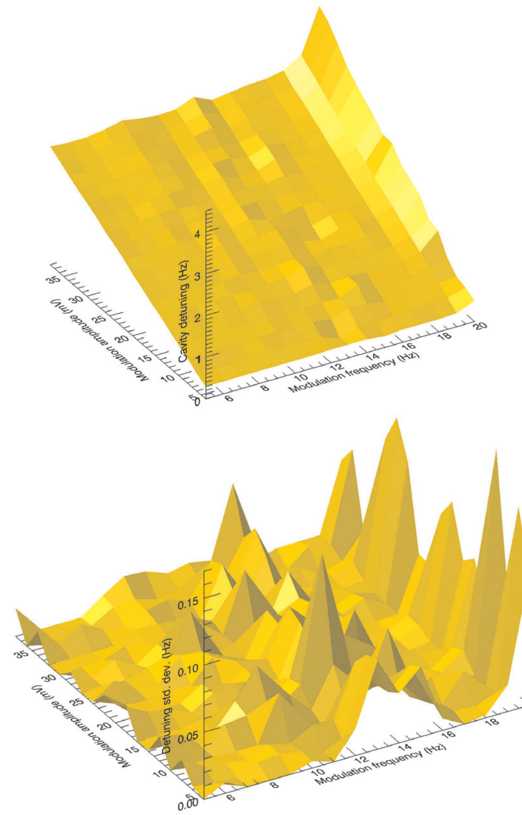

Figure 4: Measurement of piezo resolution without carrier (blade tuner, LV piezos). Upper picture: Low-frequency transfer function with amplitude scan. Lower picture: Standard deviation of the same measurement yielding estimates for the achievable piezo resolution. The measurement is overlapped by (very small scale) microphonics at 14 Hz and 20 Hz.

PIEZO RESOLUTION

The piezo resolution was measured by taking regular transfer functions at low excitation frequencies. A series of those transfer functions was taken at different amplitudes. The average value from the lock-in amplifier yields the strength of the mechanical resonance. It is depicted in the upper part of Figure 4. In addition the standard deviation of lock-in amplifier value over time was recorded, see the lower part of Figure 4. We have identified this value as the piezo resolution, or rather the resolution including noise from all involved electronic components. The reason for this indirect approach was to minimize the impact of the ubiquitous microphonics.

We can extract a medium standard deviation of 0.016 Hz and a maximum value of 0.17 Hz from the data, which sets the limits for a successful detuning compensation of lines in the microphonics spectrum. These values are much lower than what would be expected from the curves in Figure 1 if the compensation limit was purely given by the piezo resolution. This observation suggests that it should in principle be possible to further optimize the compensation algorithm.

OUTLOOK

In a next step we will attempt to incorporate the hysteresis into the feed forward tuning algorithm.

REFERENCES

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