Microphonics Measurement and Compensation

in Superconducting Radio Frequency Cavities

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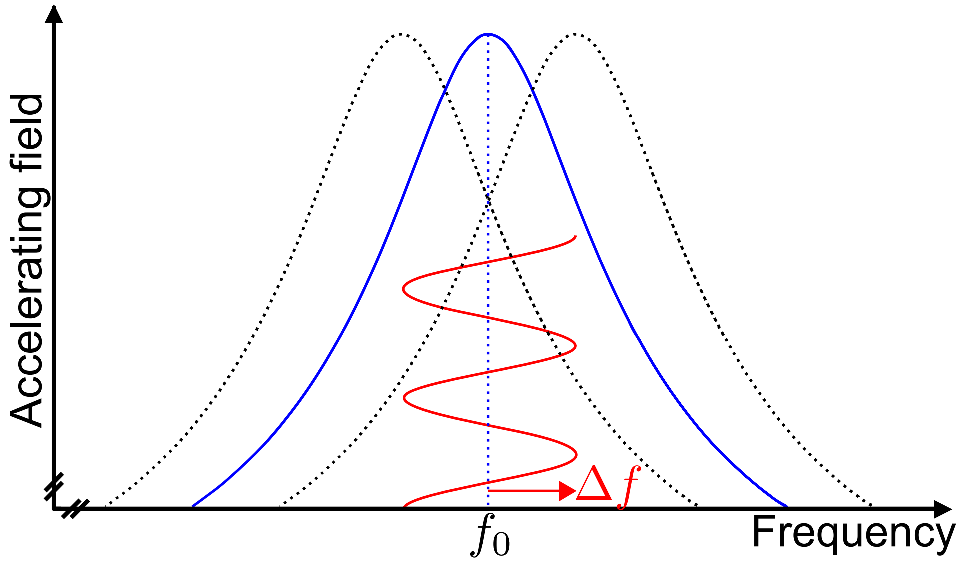
What are microphonics and why should we care?

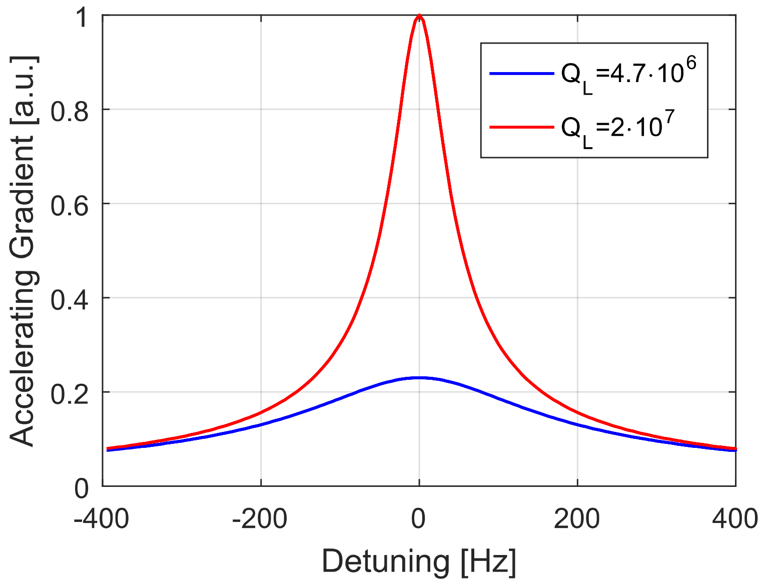
- Radio Frequency Cavities are resonators
- Geometry of cavities is affecting the resonance frequency
- Microphonics: external mechanical forces are changing shape of cavities
- Forces → deformation of a cavity → change in a resonance frequency → field instability
- Especially important in high Q_L operation



Microphonics in high Q_L operation

- Increasing Q_L improves a power efficiency
- Decreasing the bandwidth of cavities
- System becomes more sensitive to microphonics

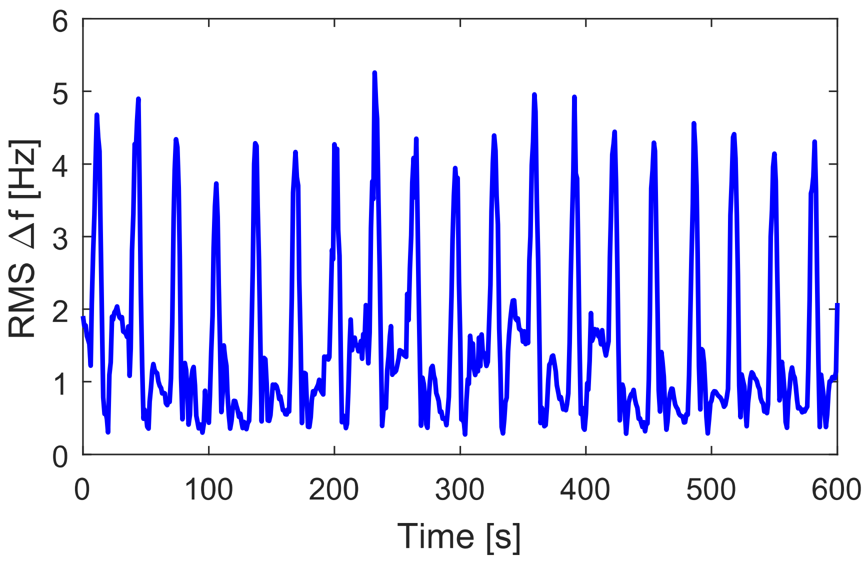
$$f_{1/2} = \frac{f_0}{2Q_L}$$

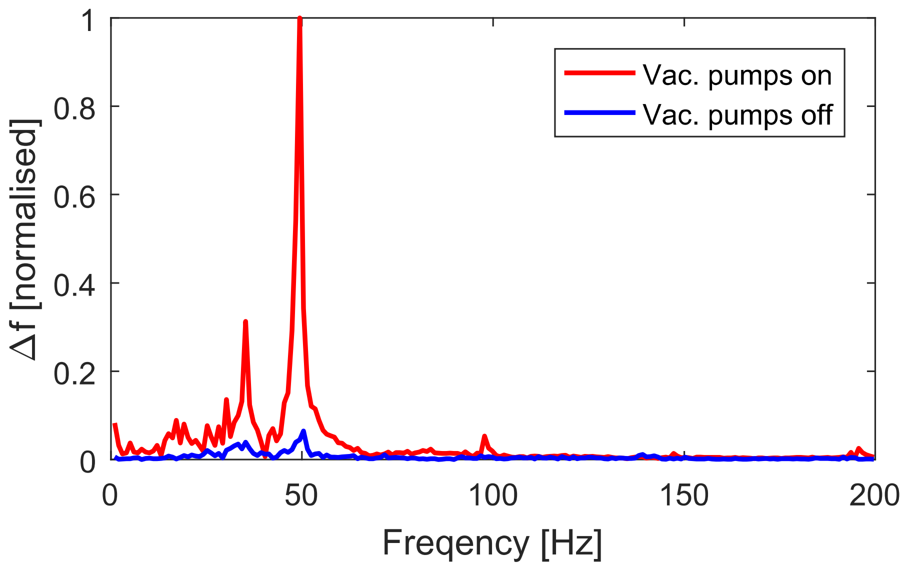


	XFEL	CMTB	
Q_L	4.6e6	2e7	6e7
Half BW [Hz]	142	32.5	10.8
Input power [kW] @20MV/m	21.2	4.9	1.6

Microphonics sources at CMTB

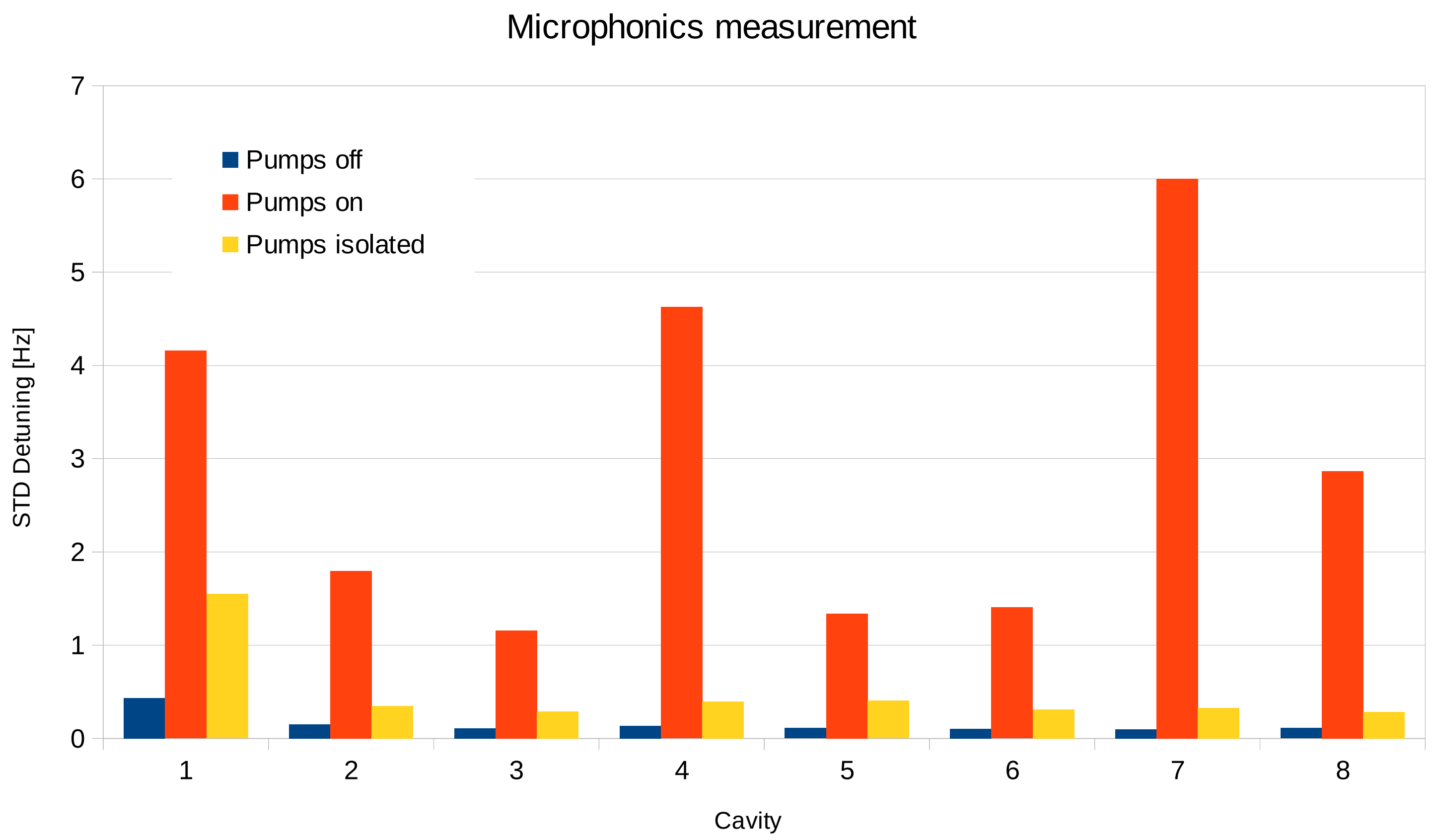
- DESY CryoModule Test Bench
  - XFEL type cryomodule, high QL tests (6e7) , CW, long pulse modes (200 ms, 1Hz)
  - IOT
- Helium pressure variations
- Other vibration sources
  - vacuum pumps identified as the major source
  - construction works, etc…
- Most disturbances are narrow-band





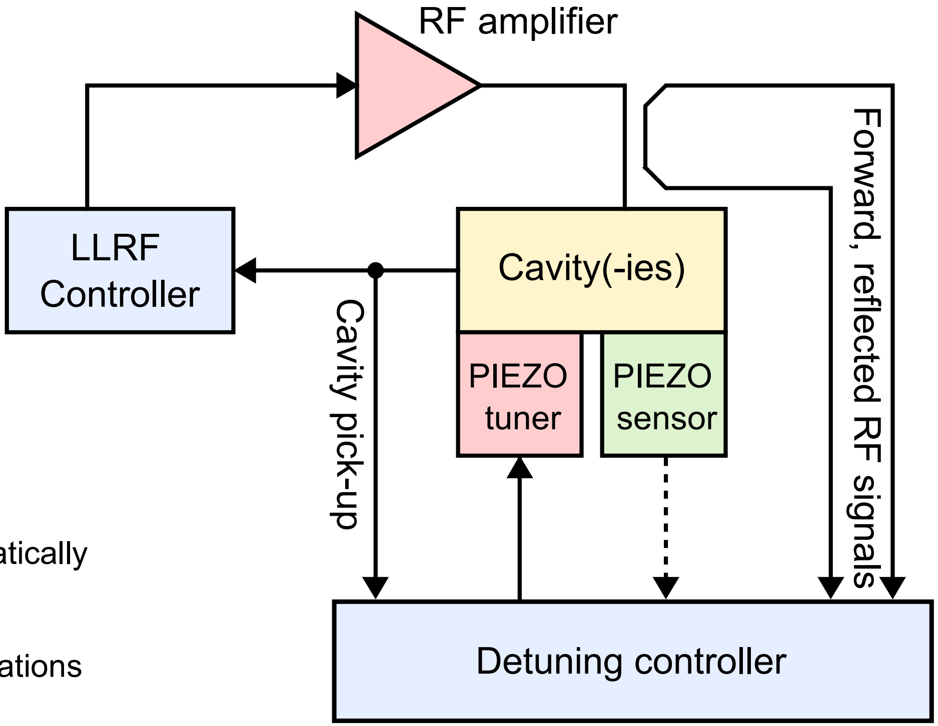
Passive detuning control

- Great outcome using simple measures
- Mechanics very important!
- Passive vibration isolation is a cost effective method



Active detuning control – design considerations

- **>** Employing fast tuners
  - piezo tuners
- **>** Detuning information
  - phase difference
  - model based estimation
  - piezo sensor
- **>** Detuning controller design
  - PID control
  - model based approach
    - > very hard to identify model automatically
  - Active Noise Control
    - > suitable for narrow-bandwidth vibrations

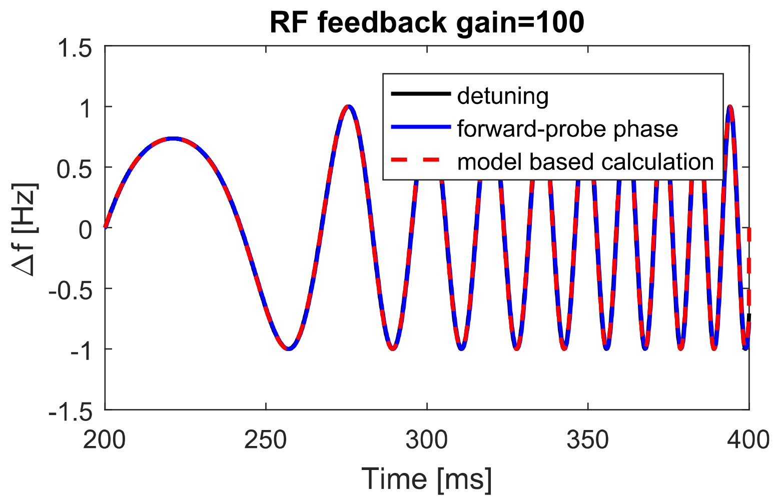


Detuning estimation

> Phase difference method

- simple
- depended on RF regulation
- VS?
- beam?

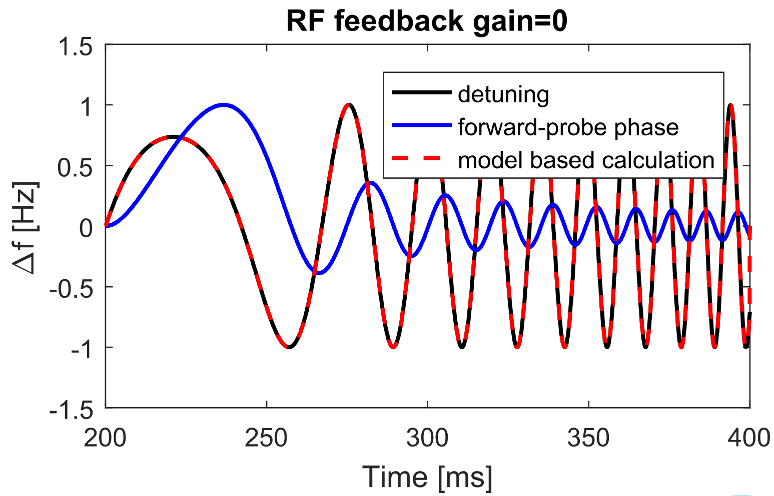
$$\Delta\omega = \mathrm{tg}(\angle\mathbf{V_{for}} - \angle\mathbf{V_C})\frac{\omega_0}{2Q_L}$$



> Model based approach

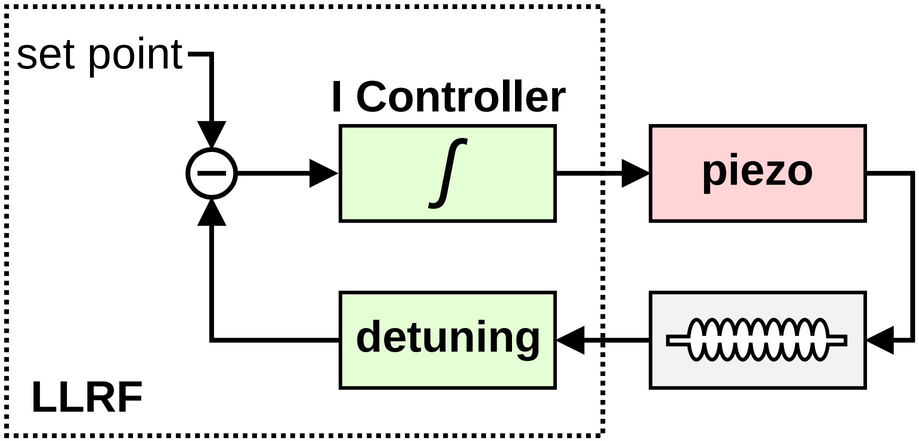
- req. more computing power
- req. coupler calibration

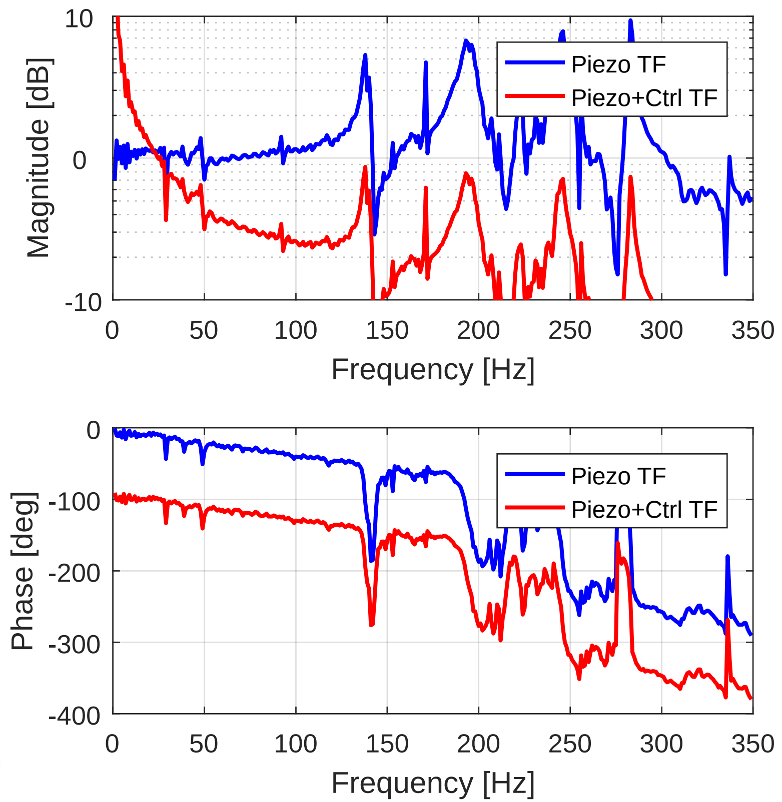
$$\Delta\omega = Im\left(\frac{\frac{d\mathbf{V_C}}{dt} - K_B \cdot \mathbf{I_B} + K_G \cdot \mathbf{V_G}}{\mathbf{V_C}}\right)$$



PID control

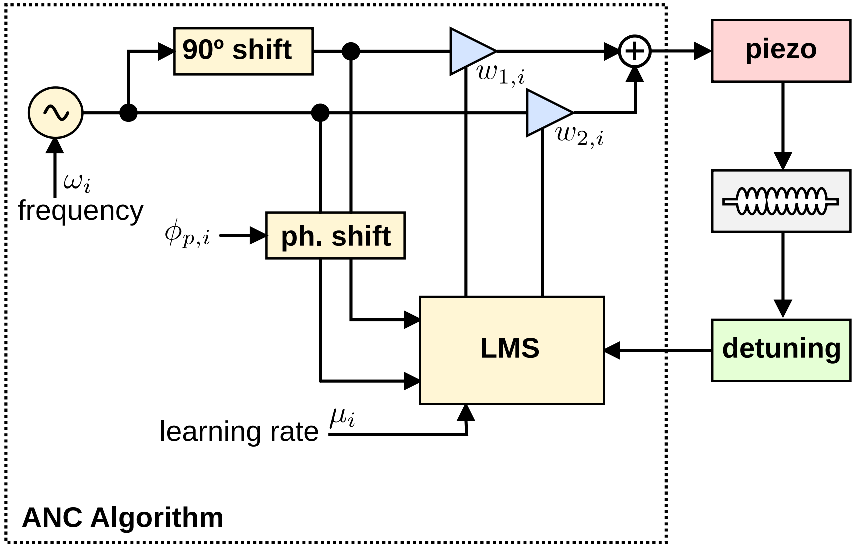
- P(roportional) I(ntegral) D(derivative)
- Algorithm
  - compute error: subtract detuning from a setpoint
  - compute P, I, D of the error
  - apply to the actuator
- System Modeling not required!
  - easy to set-up
- Limited to approx. < 10Hz
  - transfer function resonances



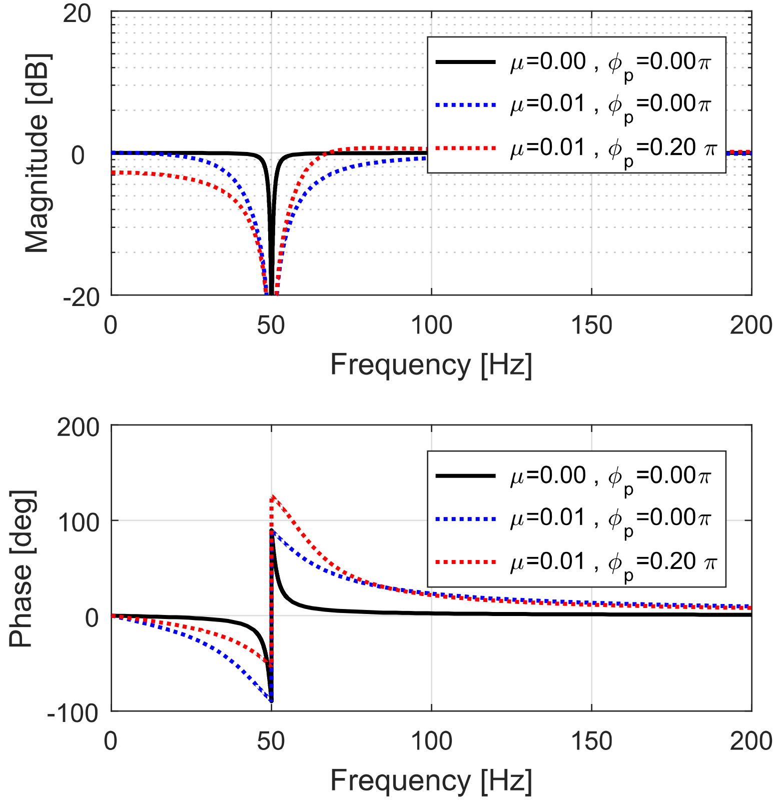


Narrowband ANC

- reference signal (vibrations) is synthesized
- modeling not required
- algorithm adapts to changes in amplitude and phase of disturbances
- notch filter behavior

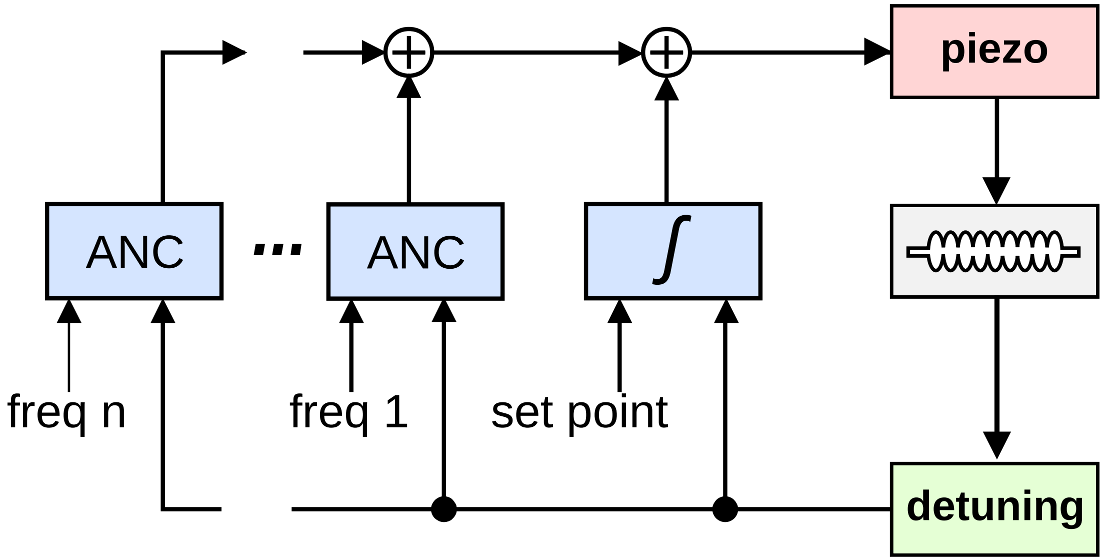


w1=w1+learning_rate*error*x1
w2=w2+learning_rate*error*x2

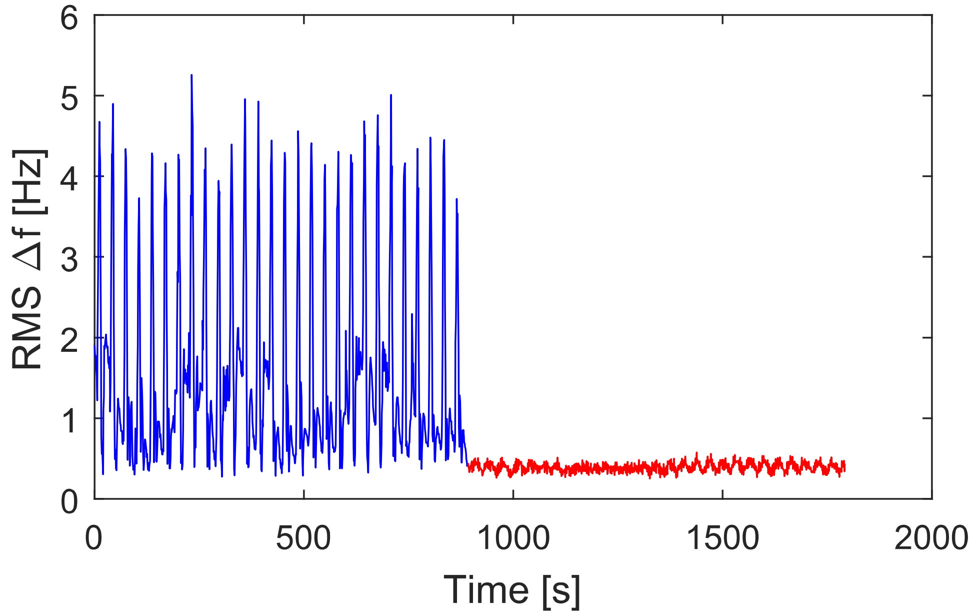


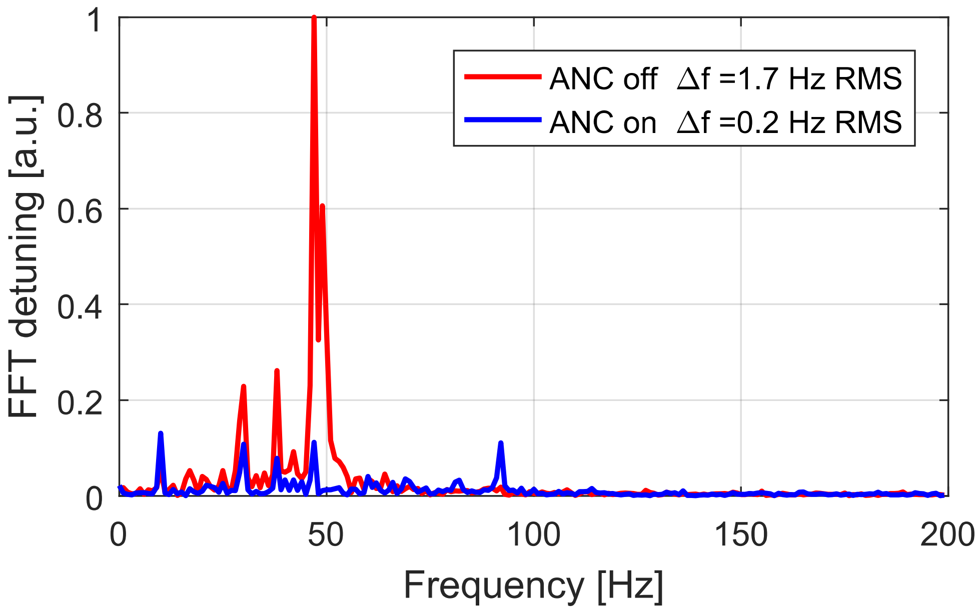
Microphonics compensation strategy at CMTB

- Most dominating disturbances at 30 and 49 Hz
- Integral feedback controller for slow drifts (Helium) compensation
- Active Noise Control for the 30 and 49 Hz disturbances
  - up to 4 frequencies per cavity
- Both phase difference and model based estimation implemented



Microphonics compensation at CMTB - results





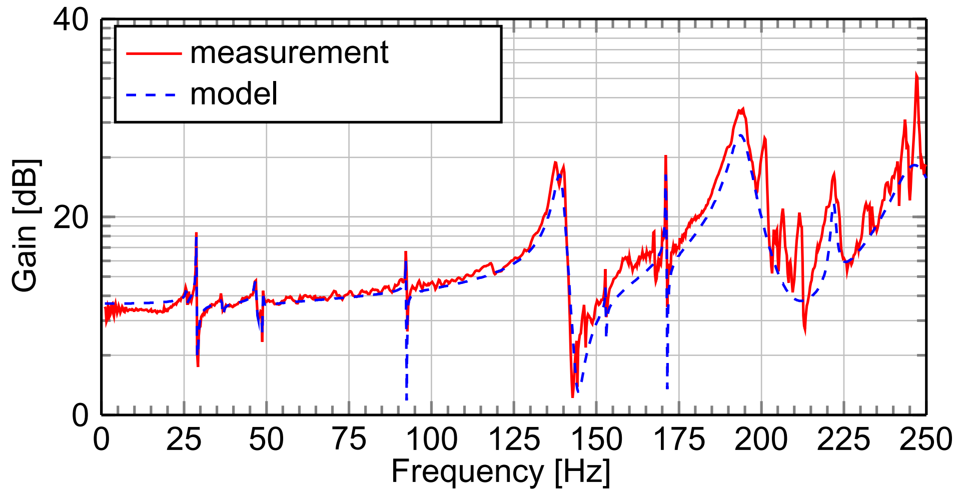
- By employing this methods it was possible to meet the XFEL specification
  - 0.01% dA/A RMS
  - 0.01° dP RMS

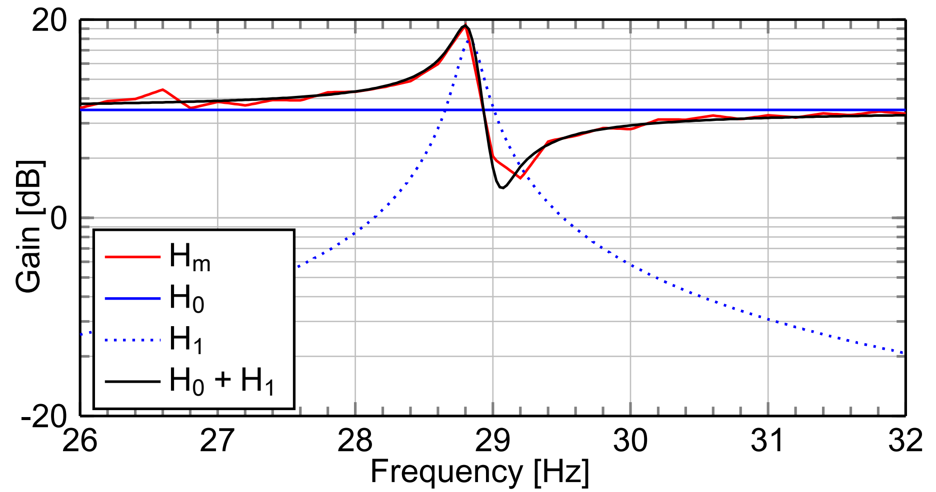
Piezo transfer function modeling

- Required for more advanced controllers
- Automatic identification is difficult
- Resulting model is very complex
  - 27th order

$$H(s) = \left(H_0(s) + \sum_{k=1}^{N} H_k(s) \right) \cdot H_d(s)$$

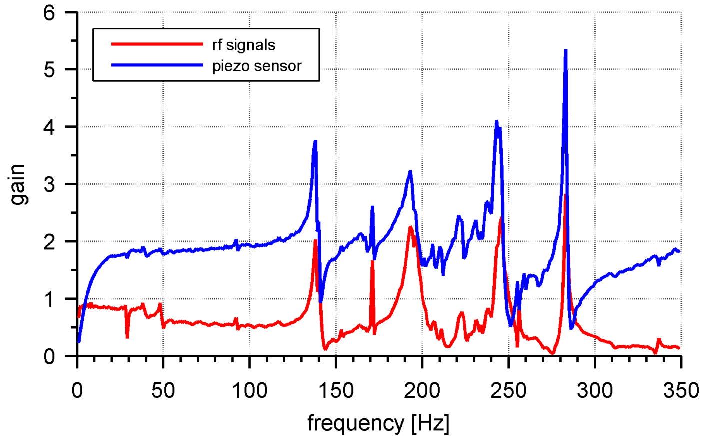
$$H_k(s) = \frac{\omega_{m,k}^2 M_k}{s^2 + 2\xi_k \omega_{m,k} s + \omega_{m,k}^2}$$

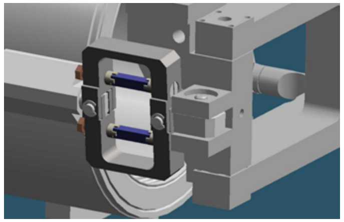




Ideas - piezo sensor feedback

- Cavities are equipped with a pair of piezo elements
  - one acts as an actuator, second can be used as sensor
- Advantages
  - RF not required
    - signal available between RF pulses
- Disadvantages
  - no “DC” detunng information
  - coupling between actuator and sensor
    - blade tuner?





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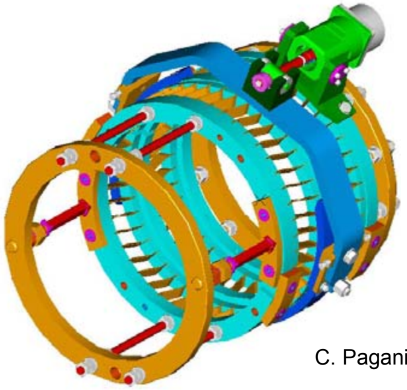

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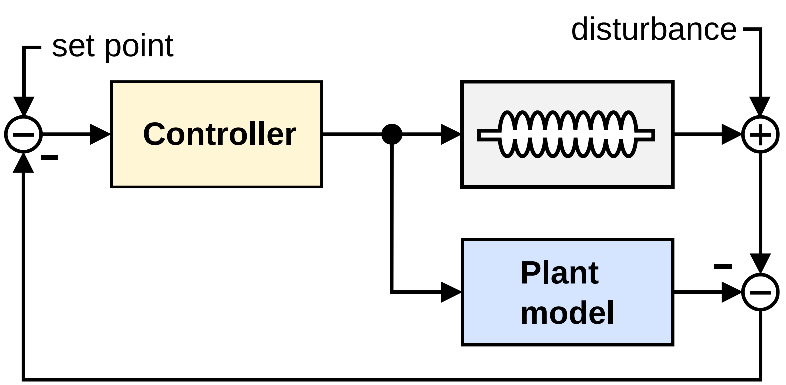
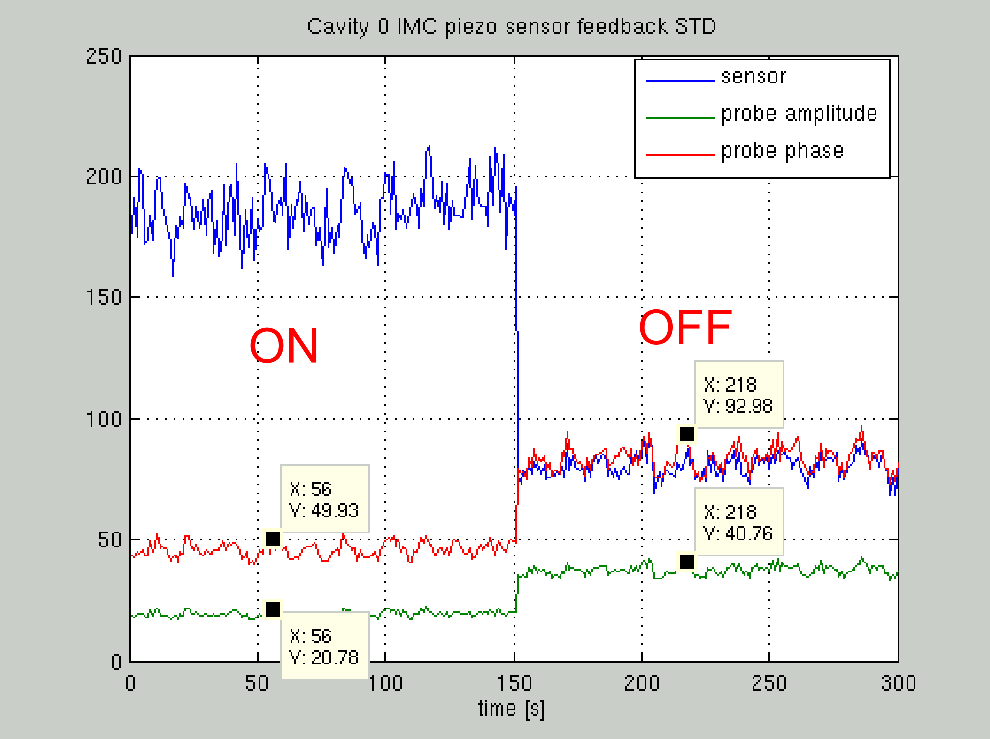
IMC sensor feedback

> Internal Model Control

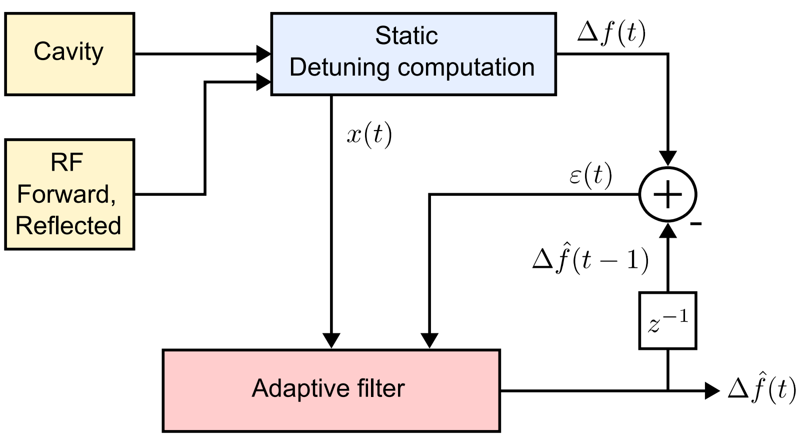
- internal plant model is used to compute the disturbance acting
- decoupling of a piezo sensor from the actuator
- 2x1024 FIR filters

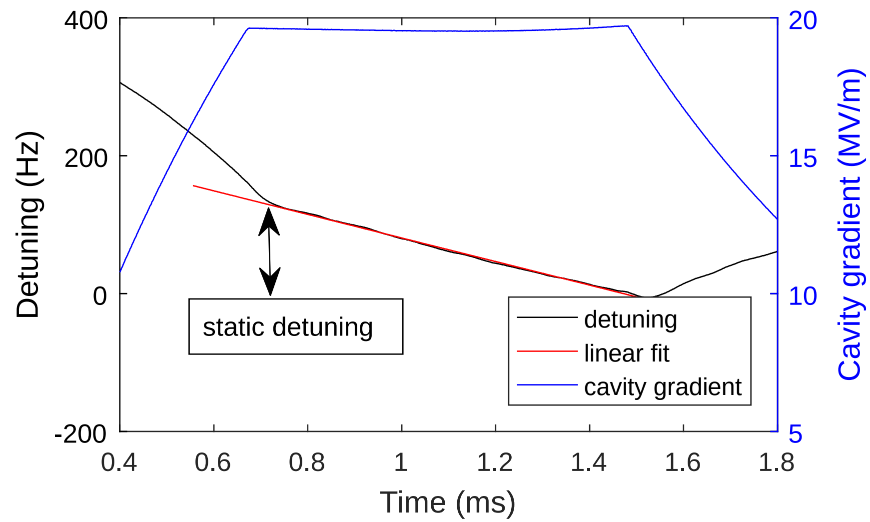


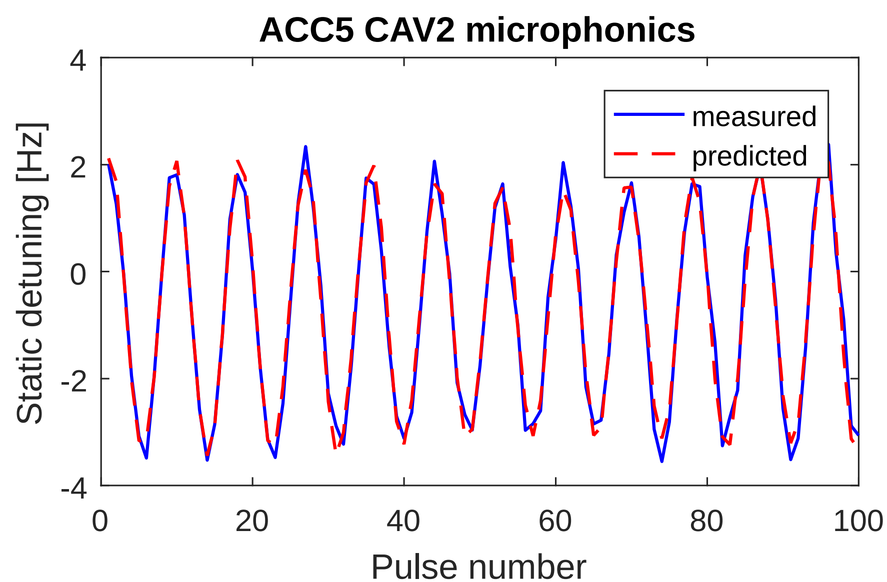


Ideas – microphonics control in short pulsed accelerators

- Apply a compensating signal before a pulse
- Microphonics prediction
  - based on information from previous pulses
- Auto Regressive model (10th order)
  - coefficients identified during operation
  - coefficients recursively changed to minimize one-step prediction error







Summary

- Cavities detuning caused by a mechanical interference
  - helium pressure change <1 Hz
  - vacuum pumps
- Additional RF power needed to stabilize accelerating gradient
- RF signals can be used as a source of information
  - probe forward phase difference
  - model based cavity detuning
  - alternatively piezo sensor information
- General vibration control methods can be applied for a microphonics compensation
  - passive vibration isolation
  - active tuning with piezo
- Thank you for attention!