Microphonics Measurement and Compensation

in Superconducting Radio Frequency Cavities

Radosław Rybaniec (DESY)
on behalf of the MSK LLRF Team

TTC Meeting
Milano, 6.02.2018
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 $\rightarrow$ deformation of a cavity $\rightarrow$ change in a resonance frequency $\rightarrow$ 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

\[ f_{1/2} = \frac{f_0}{2Q_L} \]

<table>
<thead>
<tr>
<th></th>
<th>XFEL</th>
<th>CMTB</th>
<th>CMTB</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_L$</td>
<td>4.6e6</td>
<td>2e7</td>
<td>6e7</td>
</tr>
<tr>
<td>Half BW [Hz]</td>
<td>142</td>
<td>32.5</td>
<td>10.8</td>
</tr>
<tr>
<td>Input power [kW] @20MV/m</td>
<td>21.2</td>
<td>4.9</td>
<td>1.6</td>
</tr>
</tbody>
</table>
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

**Microphonics measurement**

![Graph showing microphonics measurement for different cavities.](image_url)
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
> **Phase difference method**

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

\[
\Delta \omega = \tan(\angle V_{\text{for}} - \angle V_C) \frac{\omega_0}{2Q_L}
\]

> **Model based approach**

- req. more computing power
- req. coupler calibration

\[
\Delta \omega = \text{Im} \left( \frac{\frac{dV_C}{dt} - KB \cdot I_B + KG \cdot V_G}{V_C} \right)
\]
PID control

- **P(roportional) I(ntegral) D(ervative)**
- **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

![PID Control Diagram](image-url)
Narrowband ANC

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

\[
w_1 = w_1 + \text{learning rate} \times \text{error} \times x_1 \\
w_2 = w_2 + \text{learning rate} \times \text{error} \times x_2
\]
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

![Diagram of Microphonics Compensation Strategy]
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” detuning information
  - coupling between actuator and sensor
    > blade tuner?

---

L. Lilje et. al.

C. Pagani, et. al.
> Internal Model Control

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

![Block diagram of IMC sensor feedback](image)
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

![Diagram of Cavity, Static Detuning computation, Adaptive filter, and microphonics model](Image)

![Graph showing detuning and cavity gradient](Image)
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!