Compensation of microphonics in CW operation at CMTB

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LLRF CMTB overview

- Cryo Module Test Bench
  - one superconducting module
  - 8 TESLA cavities 1.3 GHz
  - currently QL=1.5e7 → BW=86 Hz

- MTCA.4 LLRF

- IOT RF power amplifier
  - Vector Sum stabilization
  - CW
  - LP mode
    - max. 2kW per coupler
    - 20W/module

- Detuning controller
  - Pickup, forward phase difference
Microphonics

- Cavitites detuning caused by mechanical interferences
  - helium pressure change
  - vacuum pumps
  - other sources
- More RF power needed to stabilize accelerating gradient
- Piezo tuners can be used to compensate for it
- RF signals can be used as a source of information
  - probe forward phase difference
  - model based cavity detuning
  - alternatively piezo sensor readout
- Vibration control methods can be used for controlling the microphonics
  - Vibration isolation
  - Active tuning with piezo
Microphonics noise measurement – Vac. Pumps turned on
Vacuum pumps vibration isolation

Courtesy of: Jurgen Eschke
Microphonics noise measurement – Vac. Pumps turned on

Cavity 1 7MV/m

-10 -8 -6 -4 -2 0 2 4 6 8

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

time [s]

detuning [Hz]

Pump on
std=4.156359

Pump off
std=0.436321

Pump isolated
std=1.549270
Microphonic noise statistics

Microphonics measurement

- **Cavity**: 1, 2, 3, 4, 5, 6, 7, 8
- **STD Detuning [Hz]**: 0, 1, 2, 3, 4, 5, 6, 7
- **Pumps off**
- **Pumps on**
- **Pumps isolated**

Legend:
- **Pumps off**
- **Pumps on**
- **Pumps isolated**
Microphonics frequency distribution

4.3MV/m Cavity 1
Piezo actuator → Pickup - Forward phase transfer function

0-400Hz sin wave chirp
Narrowband Active Noise Canceler

- Adaptive feed forward algorithm
- Band-pass filter

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

- PI controller available only for frequencies < 10 Hz
- 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
  - multiple frequencies per cavity

![Diagram]

- ANC
- …
- ANC
- ∫
- cavity
- probe
- error
- IOT
- forward

freq n
freq 1
set point
ANC (30&49Hz) + I controller results

4.3MV/m ANC Cavity 1

- Blue line: ANC off
- Red line: ANC on
ANC (30&49Hz) + I controller results

ANC (30&49Hz) + I controller results

4.3MV/m ANC Cavity 1

anc off
rms = 1.17 Hz
max= 4.34 Hz
anc on
rms = 0.19 Hz
max= 0.77 Hz
ANC (30&49Hz) + I controller results

![Graph showing ANC (30&49Hz) + I controller results for 4.3MV/m ANC Cavity 1. The graph compares ANC off and ANC on, with frequency on the x-axis and FFT detuning on the y-axis.]
ANC resource utilization

> 8 cavities 4 frequencies per cavity

<table>
<thead>
<tr>
<th>Logic Utilization</th>
<th>Used</th>
<th>Available</th>
<th>Utilization</th>
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<tbody>
<tr>
<td>Number of Slice Registers</td>
<td>2662</td>
<td>521200</td>
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<tr>
<td>Number of Slice LUTs</td>
<td>2673</td>
<td>260600</td>
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<td>Number of fully used LUT-FF pairs</td>
<td>2259</td>
<td>3076</td>
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<td>Number of Block RAM/FIFO</td>
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<td>Number of BUFG/BUFGCTRLs</td>
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<td>Number of DSP48E1s</td>
<td>11</td>
<td>1680</td>
<td>0%</td>
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</table>
Vector sum stabilization

10 MV/m, 10 minutes measurement

- RF FB on, PIEZO FB on
  - rms = 0.084 deg
  - max = 0.36 deg

- RF FB off, PIEZO FB off
  - rms = 2.631 deg
  - max = 9.16 deg

- RF FB off, PIEZO FB on
  - rms = 0.527 deg
  - max = 2.69 deg
Future plans

➤ Validate the model based detuning computation

➤ Apply presented methods for Long Pulse operation

➤ High Level Software update
  ▪ automation

➤ Further ANC tests

➤ Thank you for attention!
Microphonics noise measurement – Vac. Pumps Isolated
Microphonics noise measurement – Vac. Pumps turned off