Resonance Control in the SRF Cavities

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In partnership with:
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Cavity Microphonics

- SRF cavities manufactured from thin sheets of niobium and operate with narrow bandwidths
- Mechanical distortion of the cavities can change the resonant frequency requiring more RF power to maintain the gradient
- Providing sufficient margin increases capital and operating costs
Mitigating Microphonics

- Suppressing cavity detuning requires multi-pronged approach including (but not limited to)
  - Cavity/Cryomodule Design
  - Tuner Performance and Reliability
  - Passive Suppression
  - Active Compensation
- PIP-II has very aggressive resonance control specifications

<table>
<thead>
<tr>
<th>Wideband CW</th>
<th>Mode</th>
<th>Current</th>
<th>Frequency</th>
<th>Half Bandwidth</th>
<th>LFD</th>
<th>Peak Detuning</th>
<th>Peak Detuning/BW</th>
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<tbody>
<tr>
<td>ARIEL</td>
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<tr>
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<td>176</td>
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<tr>
<th>Wideband Pulsed</th>
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<tr>
<td>FRIB</td>
<td>p-CW</td>
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<td>0.7</td>
<td>322</td>
<td>15</td>
<td>0.47</td>
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<tr>
<td>cERL</td>
<td>p-CW</td>
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<td>0.7</td>
<td>322</td>
<td>15</td>
<td>0.47</td>
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Cavity/Cryomodule Design

- **SSR1 Cavity and tuner design** were completed some time ago
  - Considerable effort has gone into minimizing $\frac{df}{dP}$ for the SSR1 cavities
  - Low $\frac{df}{dP}$ may reduce sensitivity to TAOs
- Design of 650 Cavity/Tuner system is currently underway
  - Effort to minimize LFD
- SSR1 cryomodule design is incorporating lessons learned from LCLS-II
  - Thermally strapping instrumentation lines to reduce TAOs
Tuner Performance and Reliability

• LCLS-II tuner developed in close collaboration with experienced vendors with strong emphasis on reliability
  – PI Encapsulated piezo stacks
  – Phytron cryogenic stepper motors
• Tuner component reliability testing program is ongoing
  – Radiation hardness
  – Piezo heating during pulsed operation
• Cold testing of complete cavity/tuner assemblies is critical
Passive Suppression

- LCLS-II production testing provides important lessons for PIP-II
- Initial microphonics levels were much higher than expected
  - Thermo-acoustic oscillations (TAOs) identified as primary source of detuning
- Over the course of a year cross-disciplinary effort was able to bring levels down to specification
- Effort required multiple cryomodule design modifications during “production” testing
PIP-II Cavity Test Stand Environment

- Considerable effort has gone into eliminating TAOs and other noise sources in the LCLS-II cryogenic system
- No comprehensive effort yet to identify and mitigate noise sources in STC
  - Noise background and valve icing in adjacent HTS would indicate that TAOs are likely present
- Improving the cryogenic system will require time and resources but must be undertaken if test stand resonance control tests are to be taken seriously
- Similar efforts will be required for cryomodule and string test
**STC Testing**

- Demonstration in the previous year using showed that it was possible to stabilize the SSR1 resonance in pulsed mode to within a factor of 2 (or better) of the specification.
  - Specification may well have been met but it is unclear because of uncertainties in cavity gradient (possible coupler damage)
- Problems with SSR1 production prevented repeating the demonstration this year
  - SSR1 production problems apparently now resolved
- Hope to repeat demonstration during next upcoming SSR1 test
LCLS-II Active Compensation Tests

• TD/Resonance Control group working in collaboration with LCLS-II/LLRF group to implement FNAL developed algorithms on LCLS-II hardware

• LCLS-II tests have given a much better understanding of what will be required for active compensation
  – Now possible to measure cavity transfer function and noise spectrum, automatically generate a compensation filter, and predict the feedback suppression factor

• LCLS-II active compensation tests are ongoing
Pulsed vs CW Operation

- Good results with active control for both pulsed and CW operation
- Range of possibilities between original PIP-II pulsed mode specifications and pure CW operation
  - Some low power CW drive always envisioned to provide continuous sensitivity to detuning
  - Mechanical excitation depends on RF pulse risetime
Feedforward Compensation

- Current LCLS-II noise spectra show a large (~50%) component just below 30 Hz that slowly oscillates
  - Interference between two large induction motors operating
    - One source had been identified as Kinney pump
    - Other needs to be identified
  - Passive suppression may be limited
- DESY has had success using feedforward to compensate for external vibration sources
  - Need to incorporate this capability into PIP-II resonance control hardware
Conclusion

- Resonance stabilization is recognized as a critical consideration in the design of PIP-II
  - Resonance control needs to be part of specifications and review for each component of the machine
- PIP-II production testing has been delayed but is expected to resume shortly
  - Time for resonance control studies allocated during production tests
- In the meantime LCLS-II testing has provided considerable insight to what will be required for both passive suppression and active control of the PIP-II cavities
  - Template for successful collaboration needed during upcoming PIP-II cryomodule tests
  - Passive suppression is critical
  - Active compensation alone will not be adequate
  - Lessons learned are being incorporated into PIP-II design
- Need to adapt our strategy to take into account what we have learned