Resonance Control in the SRF Cavities

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In partnership with:
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Italy/INFN
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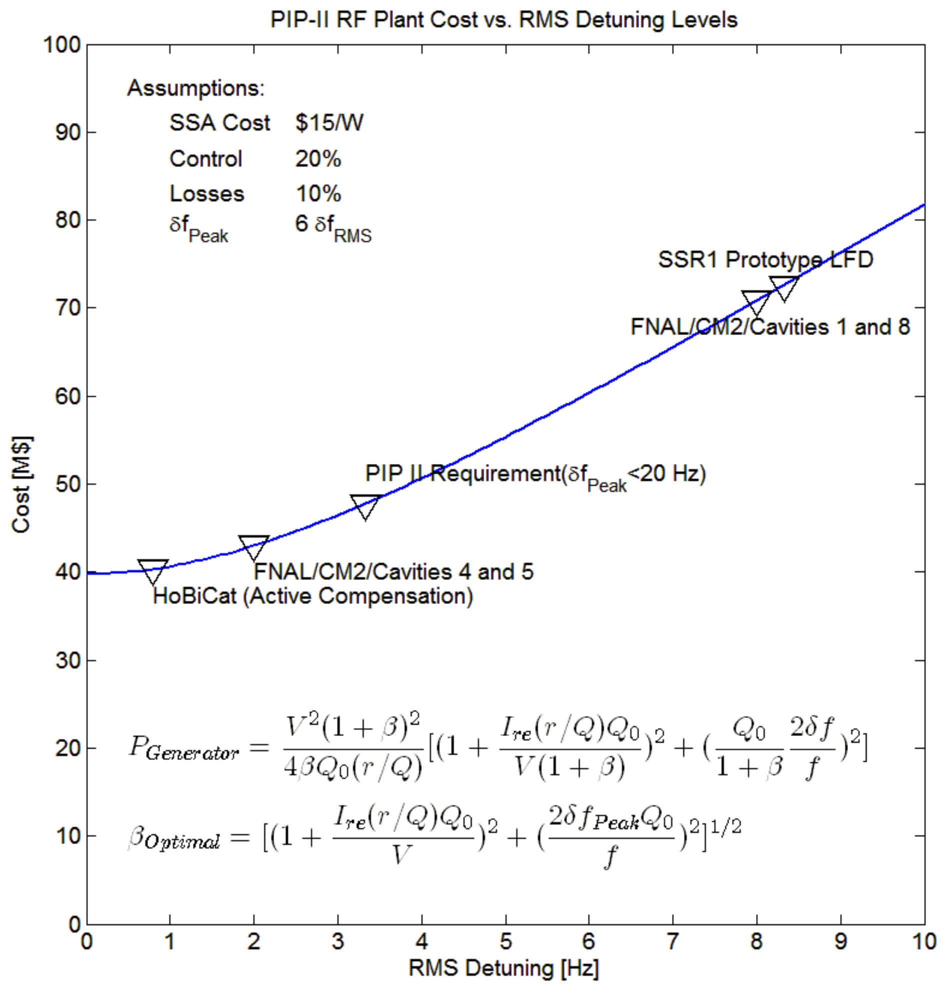
Cavity Microphonics

- 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

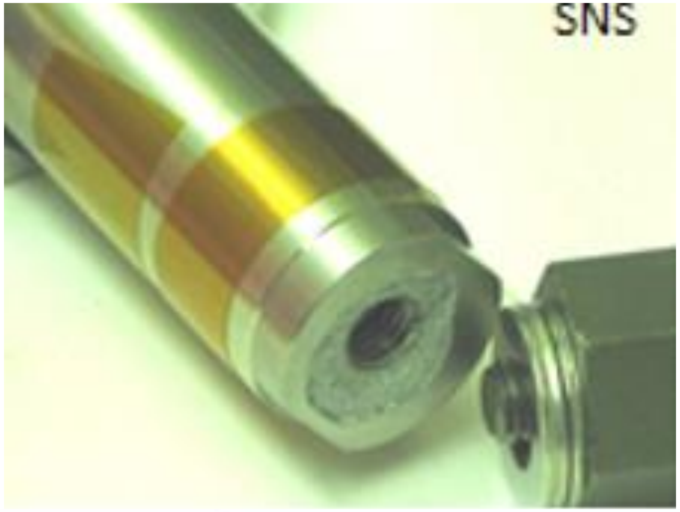
				Mode	Gradient	Current	Frequency	Half Bandwidth	LFD	Peak Detuning	Peak Detuning/BW	LFD/BW
					MV/m	mA	MHz	Hz	Hz	Hz		
Wideband CW												
ARIEL	TRIUMF		e-	CW	10	10	1300	220				
SPIRAL-II		30 MeV, 5 mA protons -> Heavy Ions	Ion	CW	11	0.15-5	88	176				
Wideband Pulsed												
XFEL	DESY	18 GeV electrons – for Xray Free Electron Laser – Pulsed)	e-	Pulsed	23.6	5	1300	185	550			**3**
ESS	Sweden	1 – 2 GeV, 5 MW Neutron Source ESS - pulsed	p	Pulsed	21	62.5	704	500	400			**1**
Narrowband CW												
CEBAF Upgrade	JLAB	Upgrade 6.5 GeV => 12 GeV electrons	e-	CW	20	0.47	1497	25		10	**0.40**	
LCLS-II	SLAC	4 GeV electrons –CW XFEL (Xray Free Electron Laser)	e-	CW	16	0.06	1300	16		10	**0.63**	
FRIB	MSU	500 kW, heavy ion beams for nuclear astrophysics	Ion	CW	7.9	0.7	322	15		20	**1.33**	
cERL	KEK											
Narrowband Pulsed												
PIP-II	Fermilab	High Intensity Proton Linac for Neutrino Beams	p	Pulsed	17.8	2	650	30	300	20	**0.67**	**10**

Cavity/Cryomodule Design

- SSR1 Cavity and tuner design were completed some time ago
  - Considerable effort has gone into minimizing df/dP for the SSR1 cavities
  - Low 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

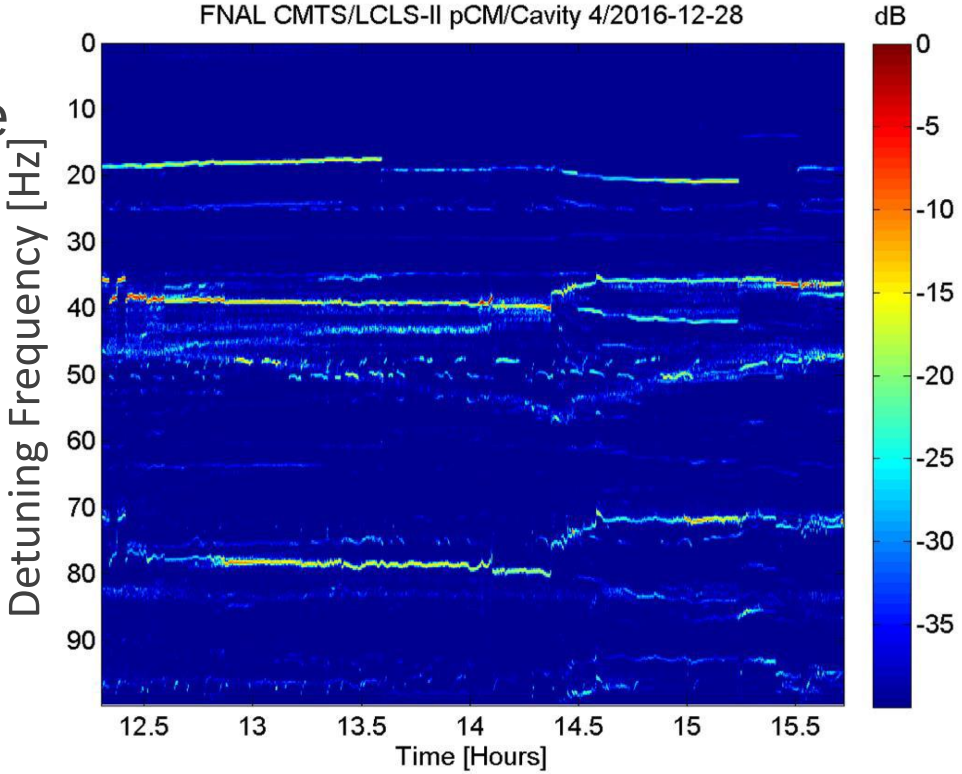
Tuner Performance and Reliability

- 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 to during “production” testing

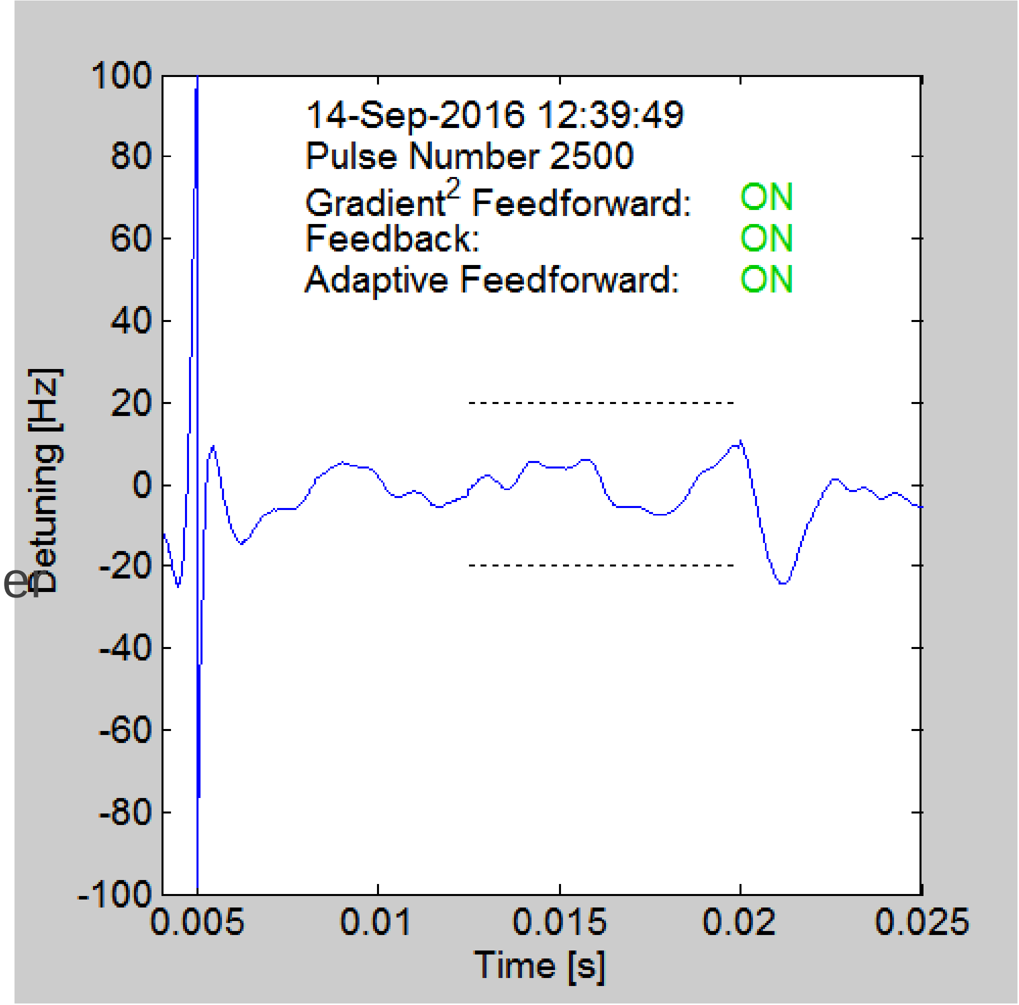


PIP-II Cavity Test Stand Environment

- 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

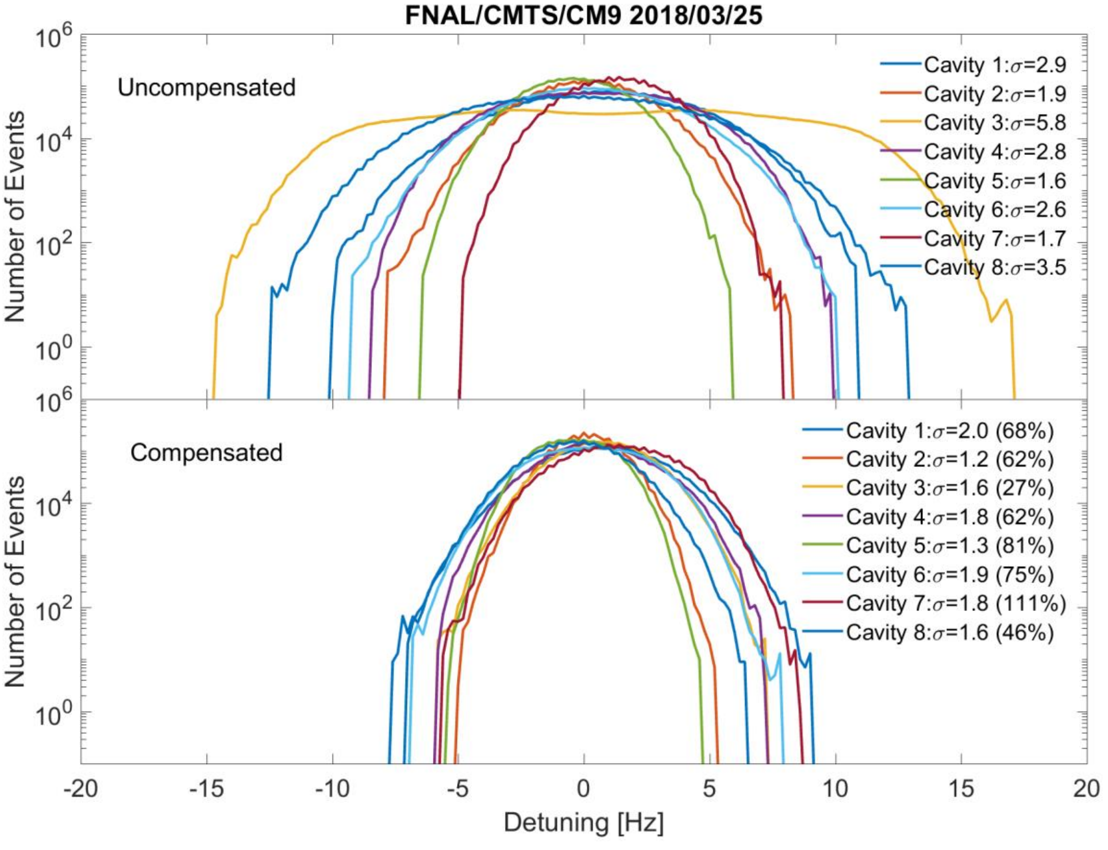
STC Testing

- 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

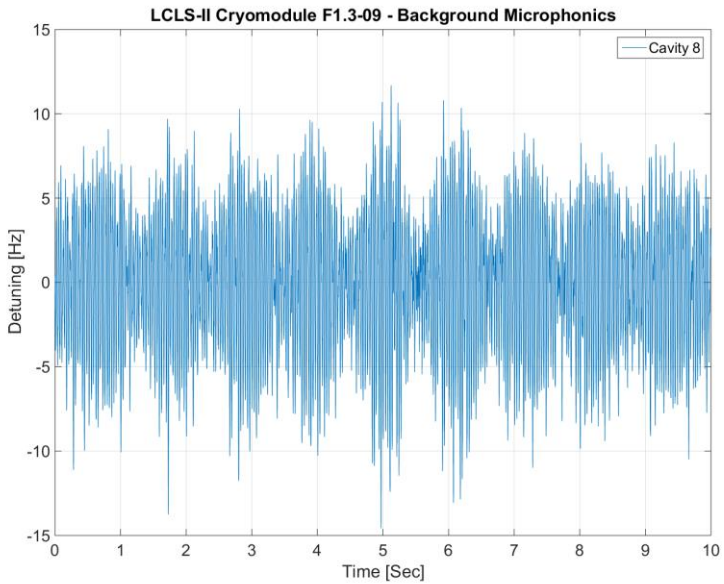


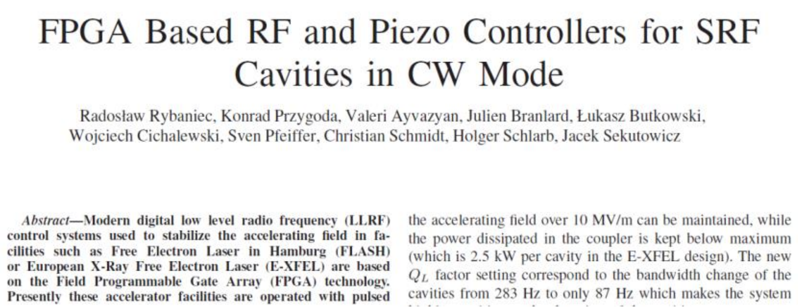
Pulsed vs CW Operation

- 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





FPGA Based RF and Piezo Controllers for SRF Cavities in CW Mode

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Abstract—Modern digital low level radio frequency (LLRF) control systems used to stabilize the accelerating field in facilities such as Free Electron Laser in Hamburg (FLASH) or European X-Ray Free Electron Laser (E-XFEL) are based on the Field Programmable Gate Array (FPGA) technology. Presently these accelerator facilities are operated with pulsed

the accelerating field over 10 MV/m can be maintained, while the power dissipated in the coupler is kept below maximum (which is 2.5 kW per cavity in the E-XFEL design). The new Q_L factor setting correspond to the bandwidth change of the cavities from 283 Hz to only 87 Hz which makes the system

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