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Resonance Control with Pneumatic Frequency Tuners in FRIB Half-Wave Resonators

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Sang-hoon Kim on behalf of

Facility for Rare Isotope Beams/Michigan State University

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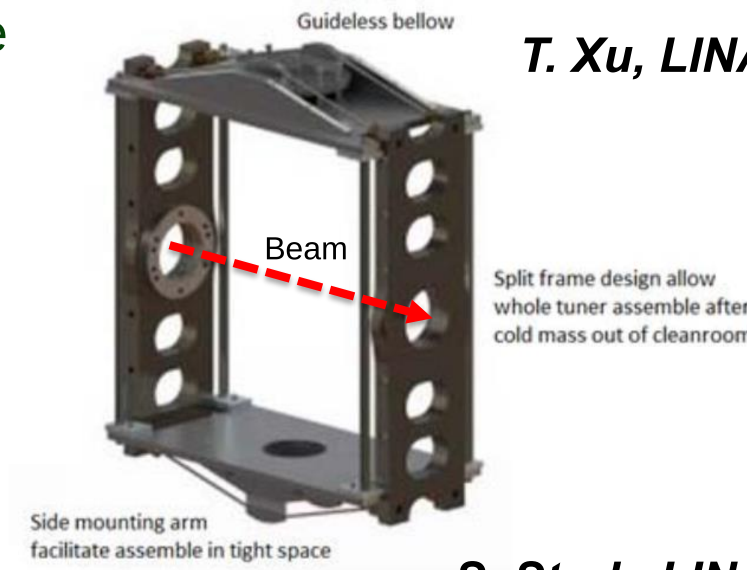
Pneumatic Frequency Tuner for FRIB Half-Wave Resonators

- Both β=0.29, 0.53 322 MHz HWRs use the pneumatic tuners
  - Design and prototyping in collaboration with ANL ***M. Kelly, MRCW'18***
- Easy to build and assemble
- No sliding mechanism
- Control valves are outside of the cryomodule
- Robust and reliable
  - No rework for the cryomodule internal tuner parts so far: 208 cavities in 29 cryomodules have been cold-tested
- All 'non-magnetic' material

T. Xu, LINAC'16

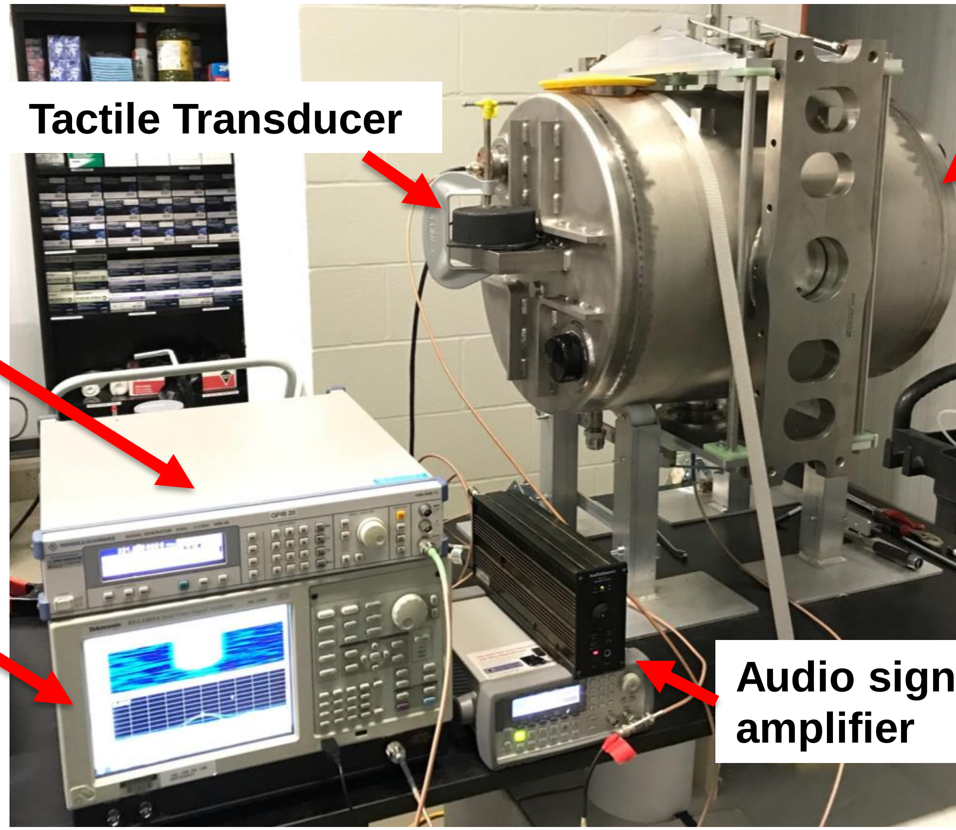


S. Stark, LINAC'16

Outline

- Effects on the cavity mechanical modes
- Proportional solenoid valve control
- Concluding Remarks

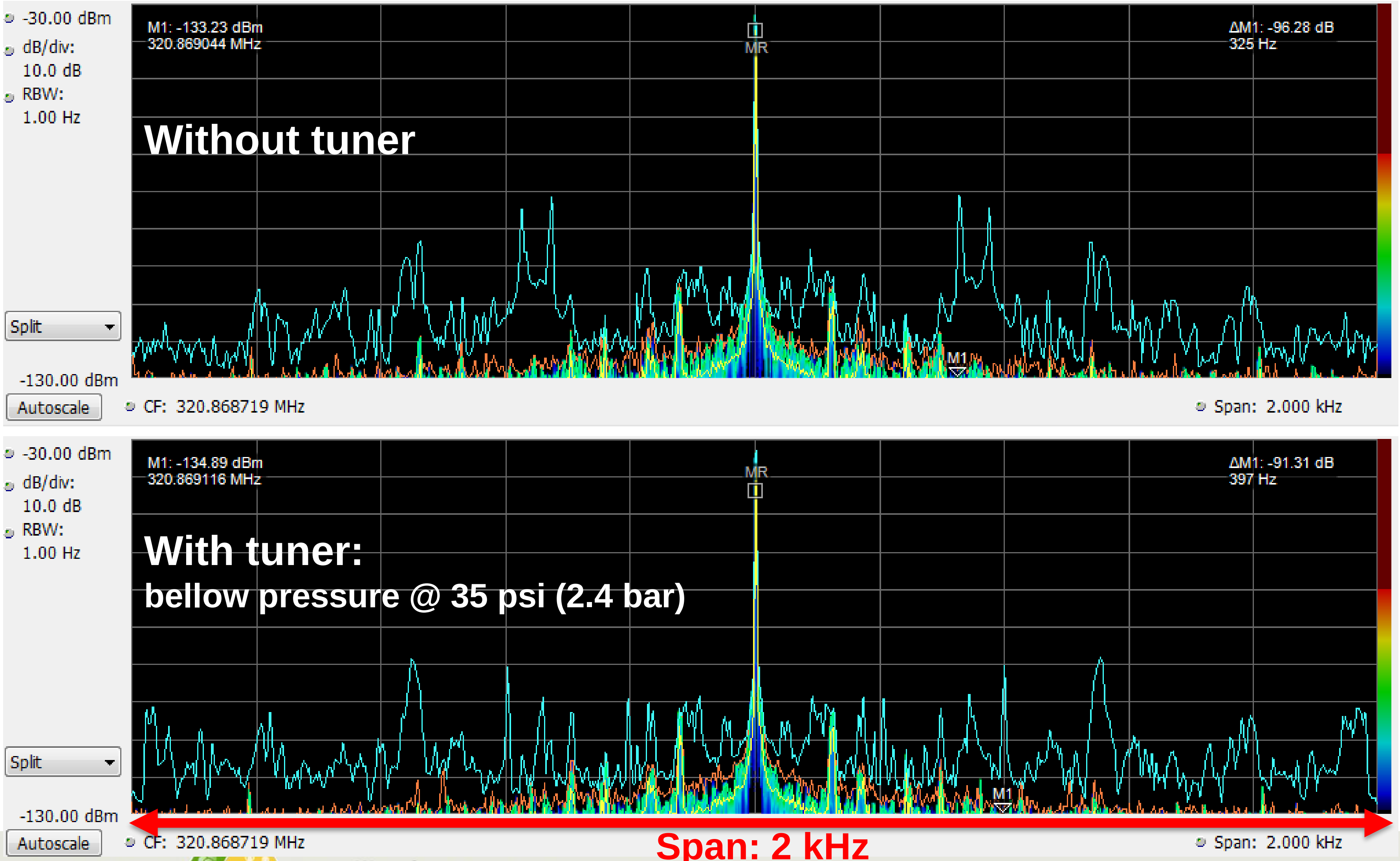
Bench Test to Measure Mechanical Modes



- Measured:
  - Sideband amplitudes sweeping the frequency of the sinusoidal audio signal: mechanical modes sensitive to the cavity RF resonant frequency
  - Decay times of the dominant modes: Q factors

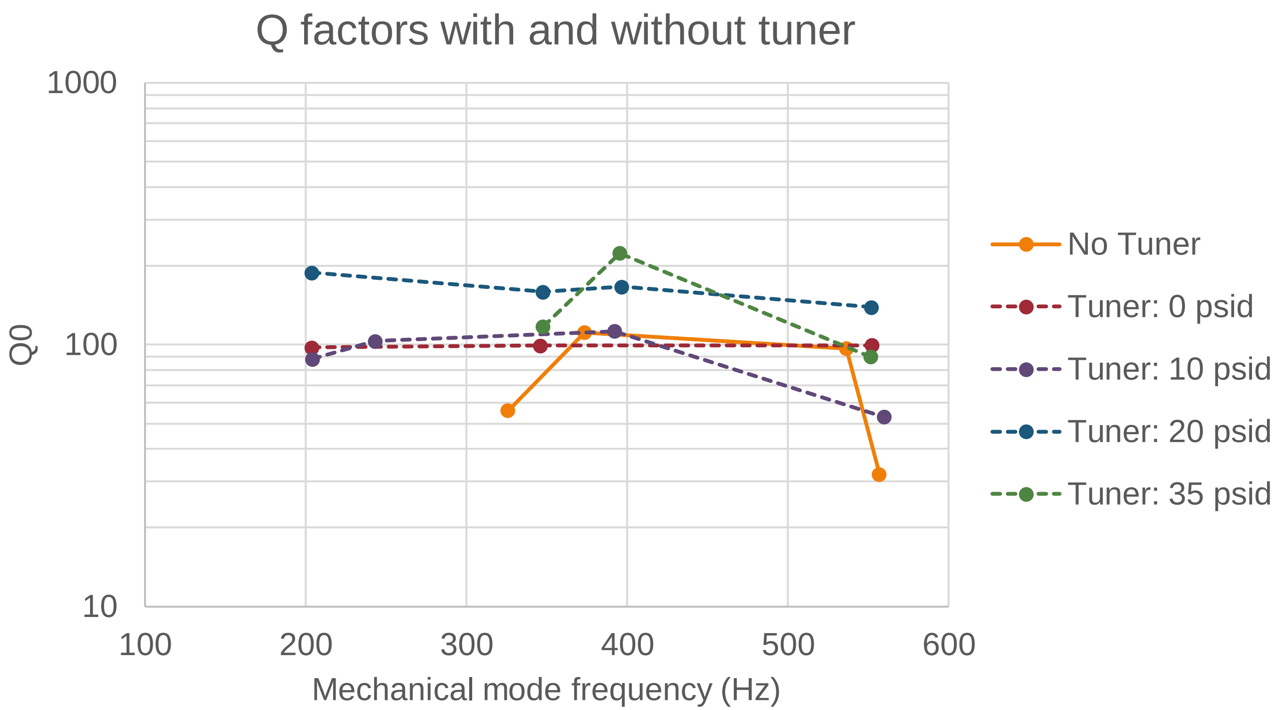
Cavity Mechanical Resonance Changes with the Tuner

Measured sweeping the audio frequency from 20 Hz to 1 kHz with 1.25 Hz/sec speed, Resolution BW: 1 Hz



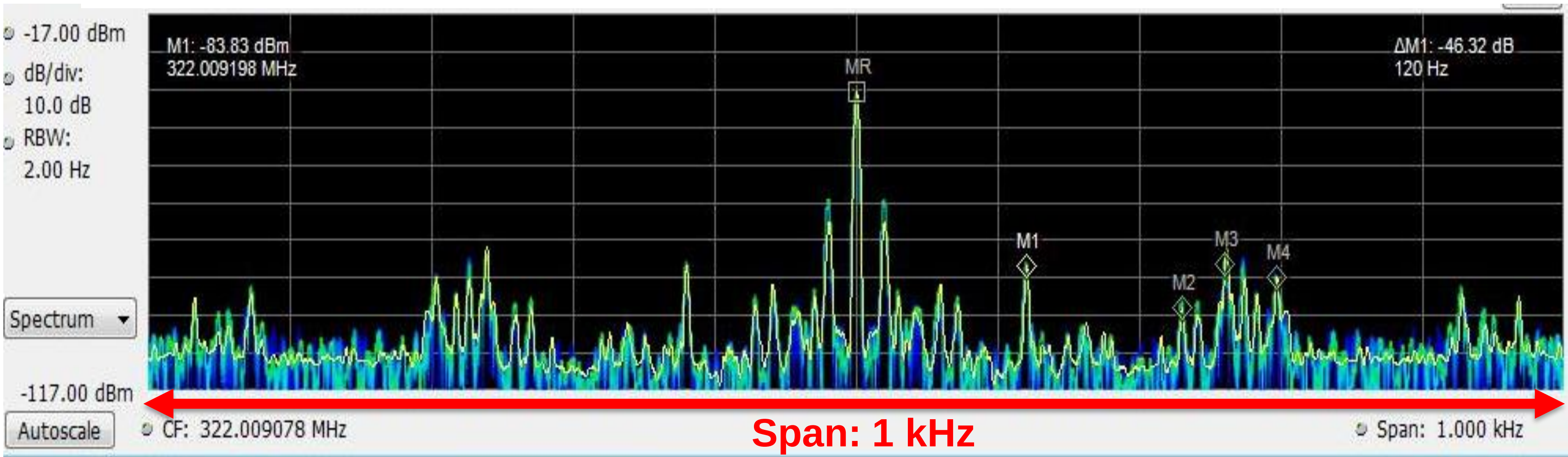
Mechanical Mode Q Factor

- No improvements in damping with the tuner, however, 'impedances' of the dominant modes are improved, as shown in the previous slide:
  - Likely due to addition of the heavy bars on the beam ports
- The highest Q factor is comparable to that in a TESLA cavity equipped with the tuner (Lilje et al., EPAC'02)



Resonance Control Stability in Cryomodules

Typical forward RF regulated for phase lock: β=0.53 HWR (Q_L=1e7) at 2 K, E_{acc} = 8.6 MV/m (16% higher than the design), on resonance



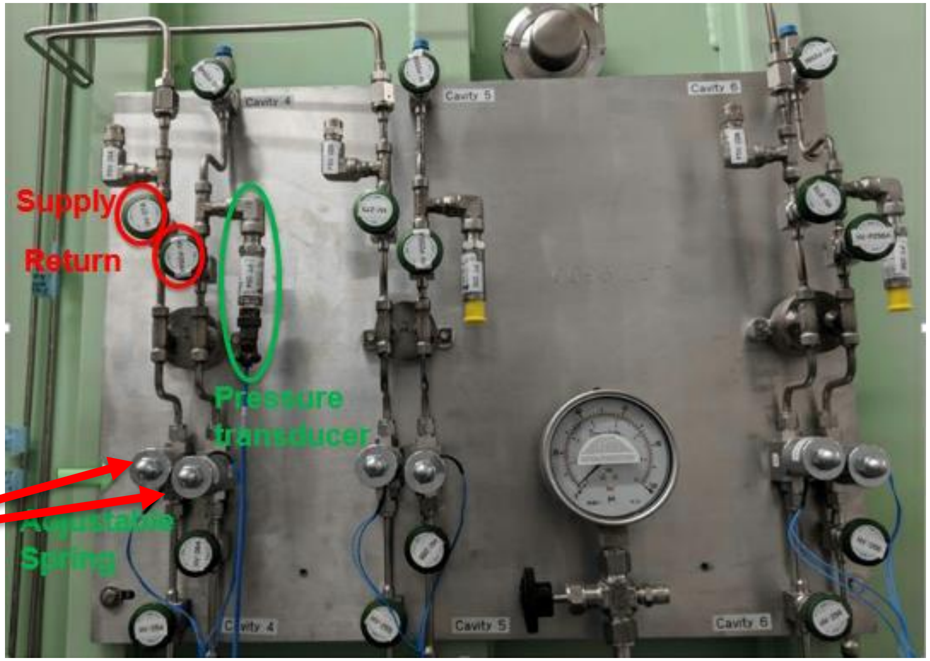
- No problematic microphonics were observed in the offline cryomodule tests, when operated at the design gradient, temperature, and on resonance
  - β=0.53 HWR operation at 4.3 K caused broadband microphonics: P_{diss} ~100 W
  - A higher gradient together with phase-lock at detuned sometimes caused the ponderomotive effect

Frequency Control with the Proportional Solenoid Valves

H. Maniar, MRCW'18

- Proportional solenoid valve
  - Integrated with the designated conductance-limit line
- Driver module: supplied by the valve vendor
  - Input from the LLRF controller: control voltage, 0 to 5 Vdc
  - Output to the valve: pulse-width-modulated current for a fast rising time and to minimize the magnetic hysteresis
- Control voltage
  - PI control to minimize the hysteresis
  - Error signal: detuning filtered by 1 Hz

Pressure manifold for pneumatic tuner for β=0.29 Cryomodule

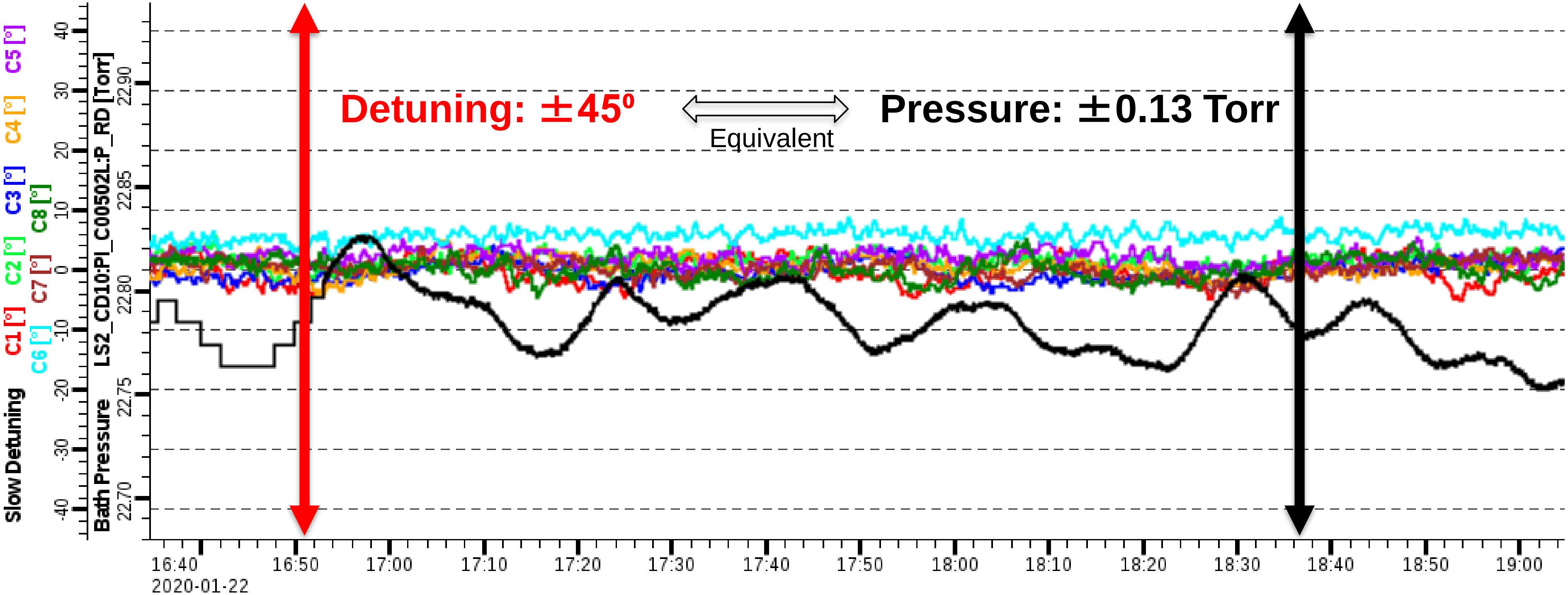


Proportional solenoid valves for supply and return

Operating tuner pressure: 20 – 60 psia (1.4 – 4.1 bara)

Slow Frequency Control: Example

Typical Tuner Control of β=0.53 HWR Cryomodule in Linac (Average Q_L=1e7)

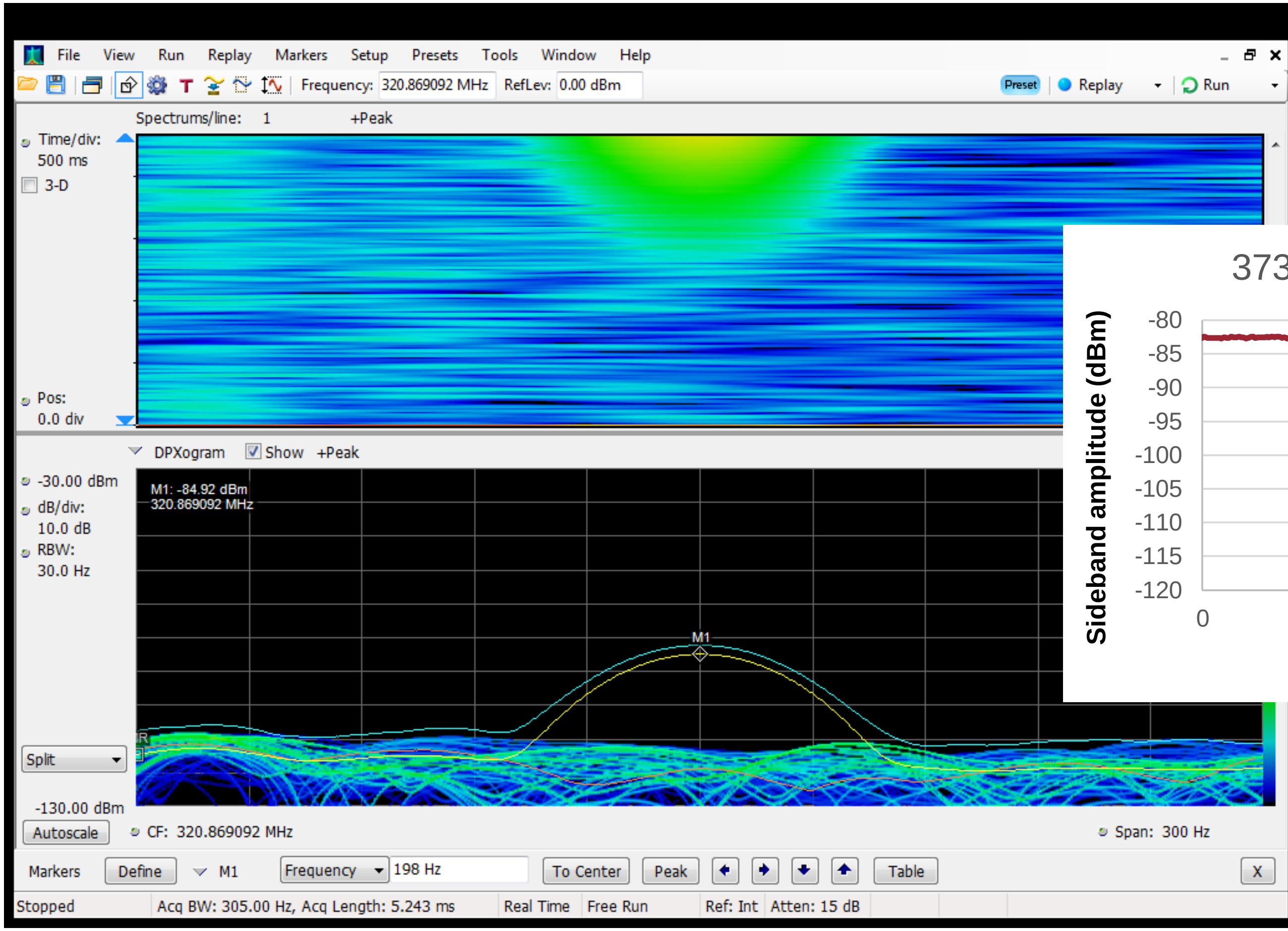


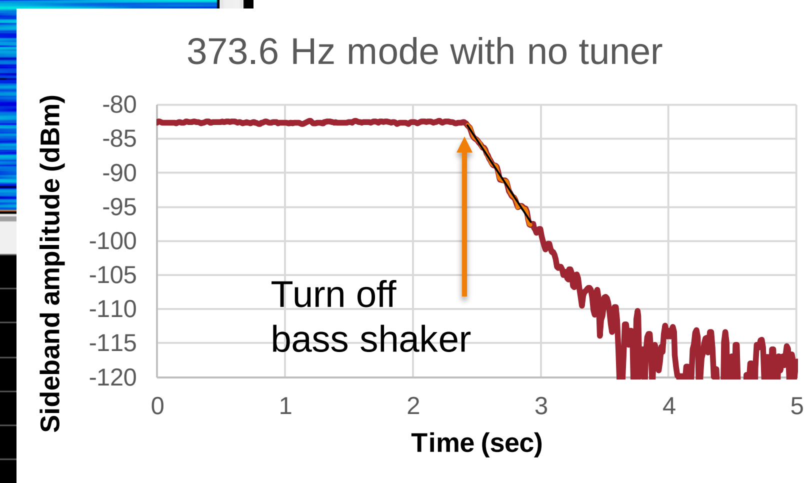
- This can be achieved with a simple optimization of the PI control parameters such as the lower and upper limits of the control voltage, Kp, Ki
  - Practically done within ~1 hour for 8 cavities in the linac RF commissioning
  - Can be better optimized, if required for higher Q_L machines

Concluding Remarks

- In β=0.53 HWR, the pneumatic tuner does not introduce 'harmful' mechanical modes. Rather, it helps reduce impedances of the dominant modes
- This is consistent with cryomodule testing experience; no microphonics issues were observed when operated in the design conditions
- The control of the proportional solenoid valves has been straightforward so far (CW at 2 K). More operational experience will be gained in the linac

Backup: Mechanical mode decay time measurement





Resolution bandwidth: 30 Hz