Measurement and Control of Microphonics for RIA

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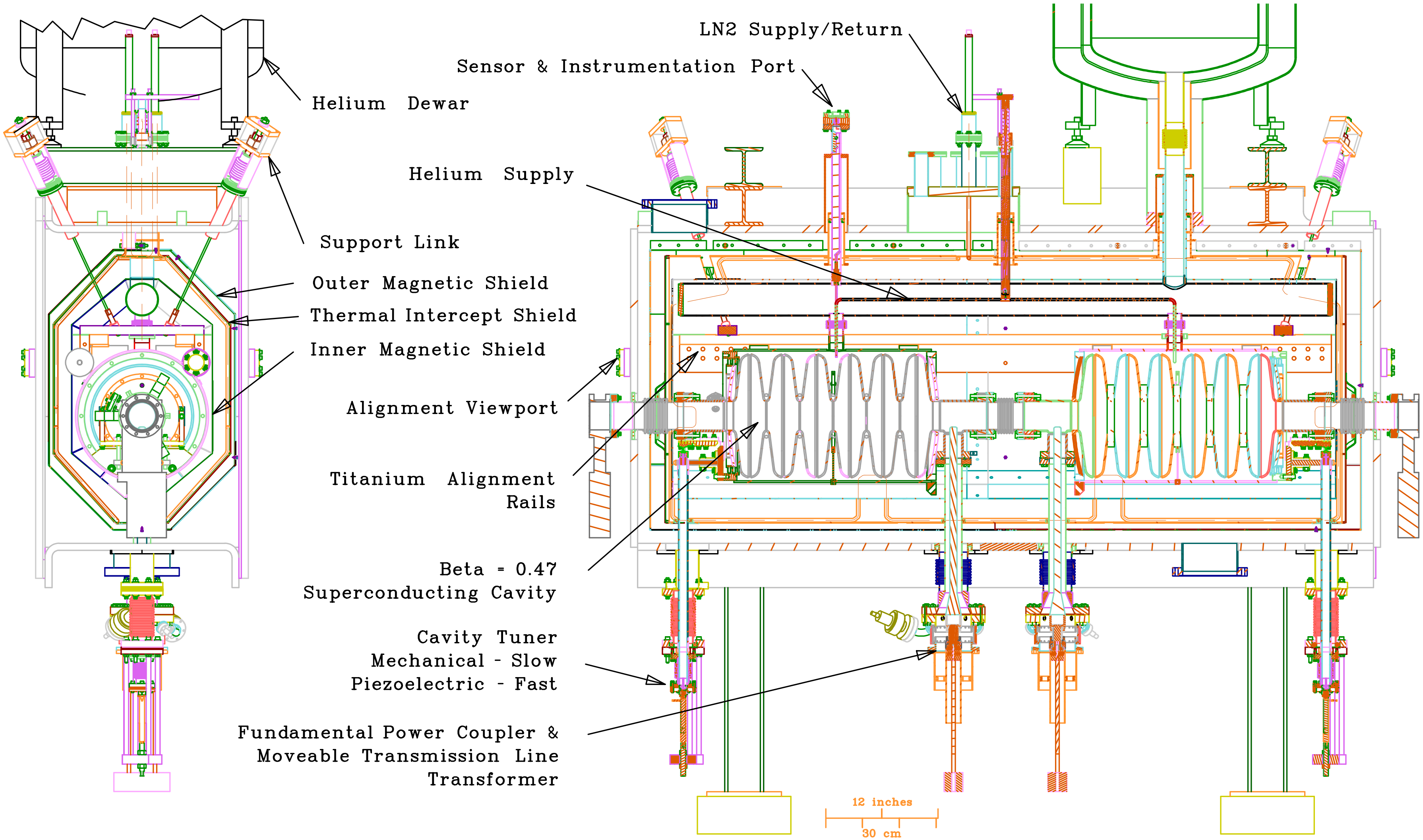
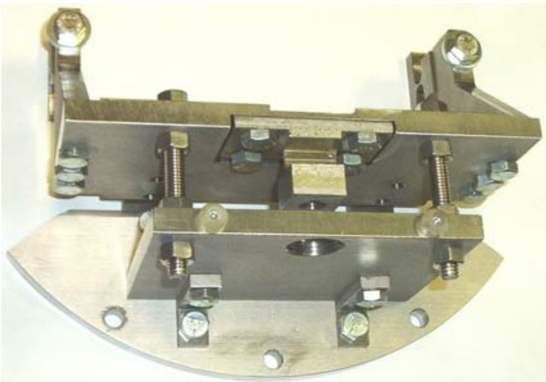
Outline

- SRF for the Rare Isotope Accelerator (RIA)
  - Cryomodule and cavity design
  - Frequency tuner
- Beam loading & rf requirements
- Microphonics
  - Vibration Sources
  - Cryomodule and cavity design issues
  - Methods of control
  - Measurement
  - Adaptive feedforward cancellation
- Summary

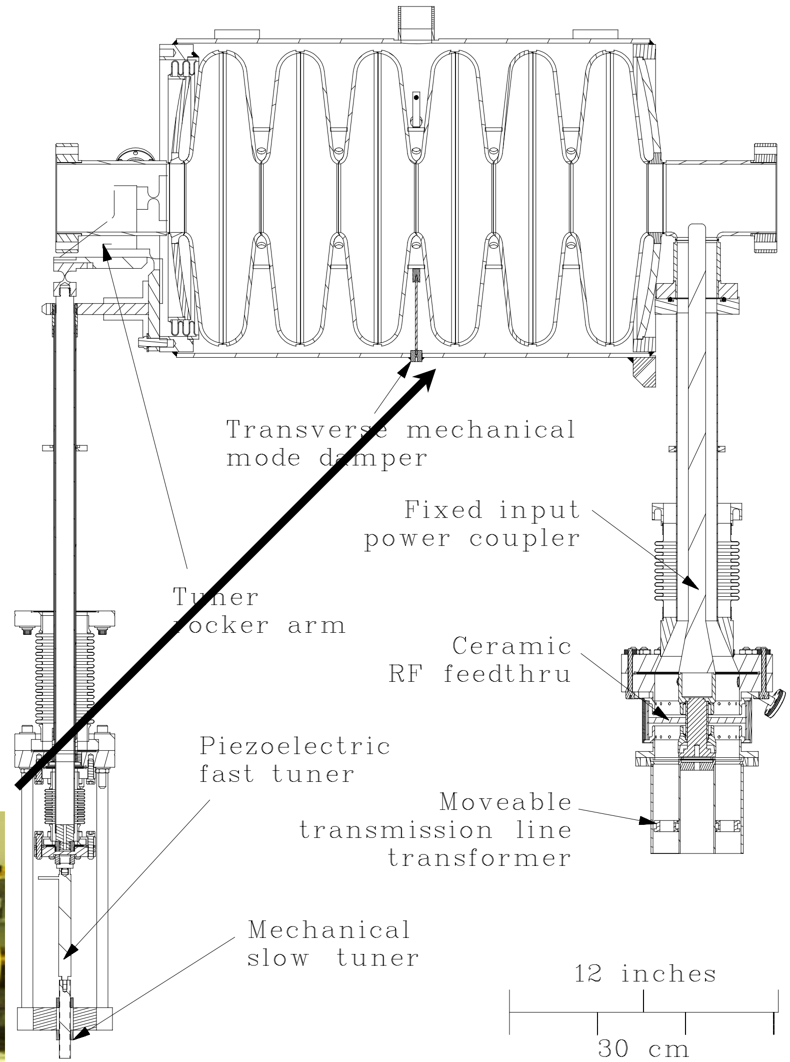
Prototype 805 MHz β=0.47 Cryomodule



β=0.47 Tuner-Cavity-Power Coupler



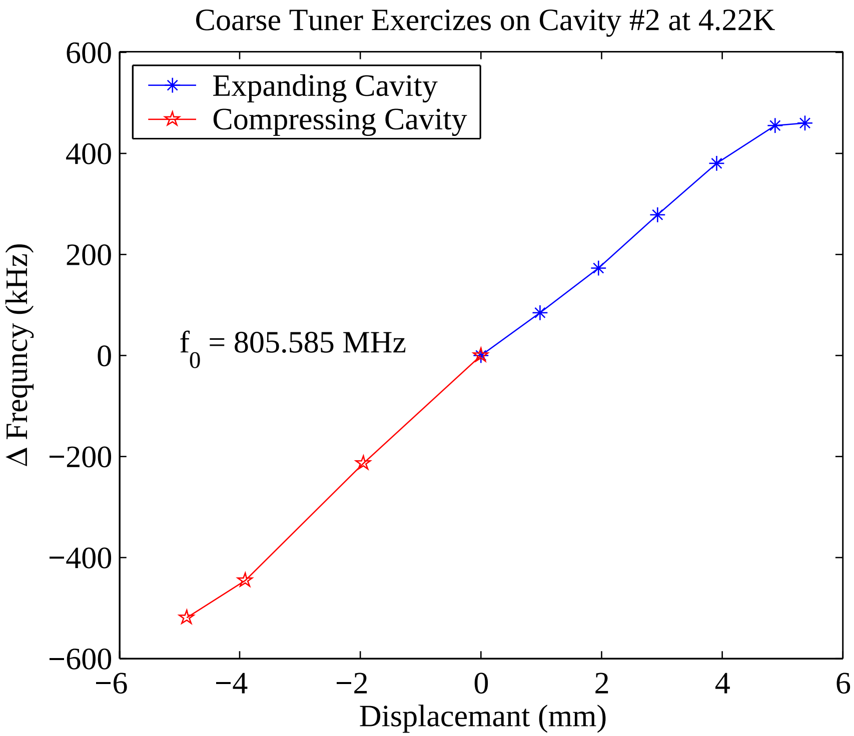
Tuner



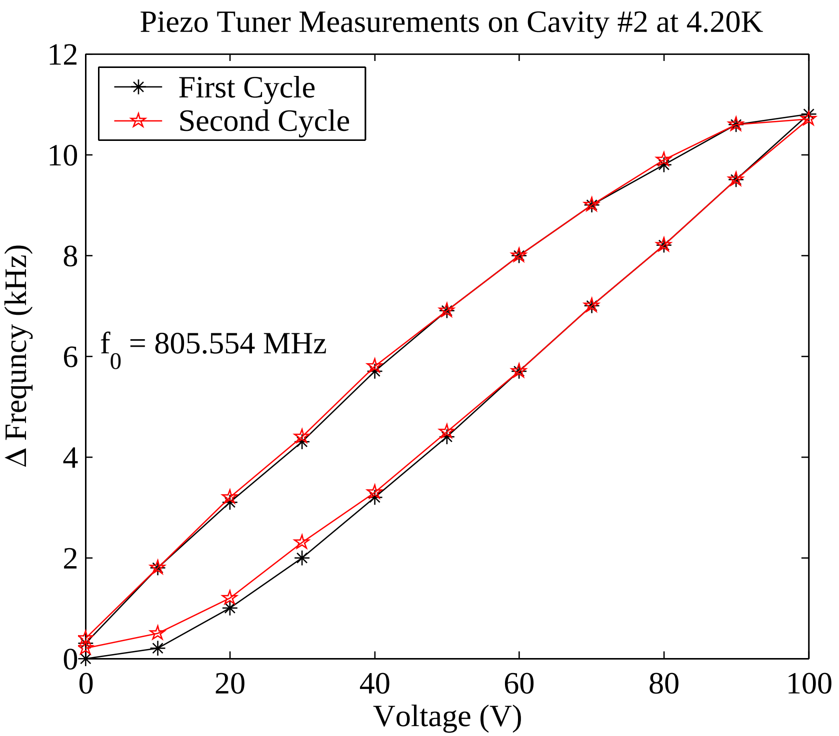
Power Coupler

He Vessel

External/room temperature tuner



Coarse tuner ~ 1 MHz



Fine tuner ~ 10 kHz

90 µm piezoelectric (PI)

Beam loading & rf requirements

- Design beam for RIA driver linac
  - cw (no dynamic Lorentz detuning)
  - 400 kW, 400 MeV/u $^{238}U^{88,89,90+}$
  - 0.37 mA

Type	6-cell	6-cell	6-cell
β_g	0.47	0.61	0.81
V_a(MV)	5.12	8.17	13.46
P_{beam}(W)	1660	2640	2600*
Q_{beam}	$9.1x10^7$	$9.1x10^7$	$1.4x10^8$
P_g(W)	3320	5280	5200
Q_L	$3.0x10^7$	$3.0x10^7$	$4.7x10^7$
Control bandwidth $\Delta_{allowed}$(Hz)	25	25	16

*Decreased from Maximum value due to transit time factor

- Experience
  - S-DALINAC, $Q_L \sim 3x10^7$
  - CEBAF Upgrade, $Q_L \sim$ low 10^7

Microphonics – Vibration Sources

- Pumps/rotating machinery
  - Sinusoidal disturbances at harmonics of revolution frequency
- cw/pulsed operation
  - For pulsed operation dynamic Lorentz detuning will dominate
- Helium oscillations
  - 2 K superfluid (no boiling and less pressure fluctuations compared to 4 K)
  - Cryoplant
  - Thermo-acoustic oscillations
- White/broadband noise

Microphonics – Cryomodule Design

- Cavity design
  - Stiffen
  - Compensation (cancel E & B-field detuning)
- Mechanical resonances
  - Eliminate and shift to high frequency (>200 Hz)
- Isolation
  - Ground, piping, waveguides, pumps
  - Inertia

Microphonics – Methods of Control [1]

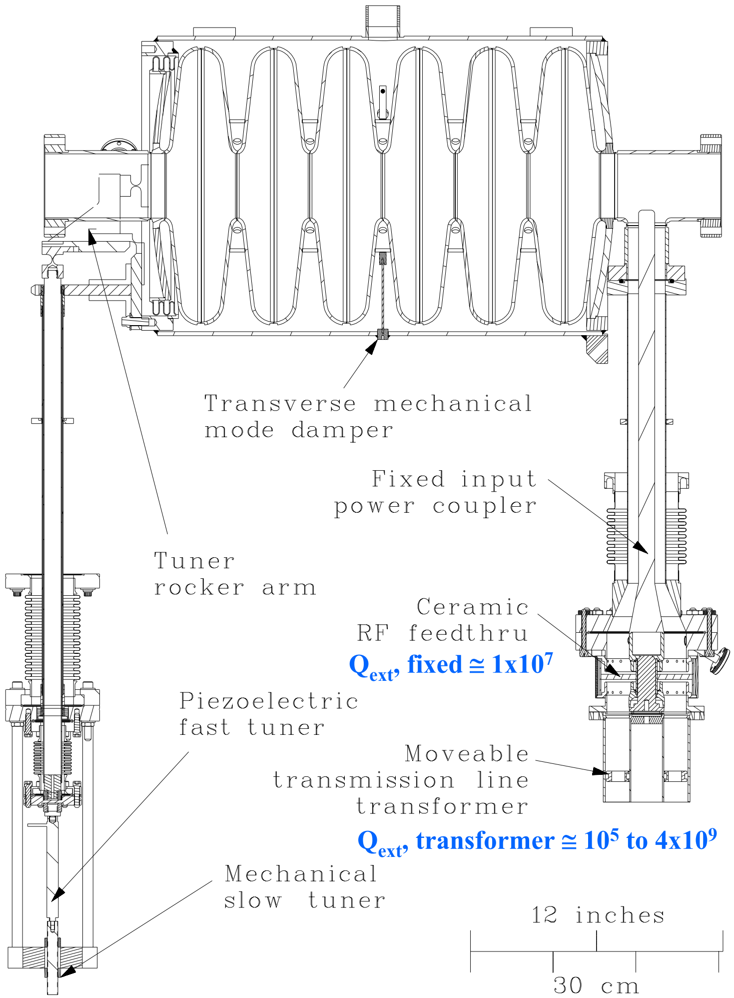
- Passive and active damping
  - Sources
  - Transmission (pipes, ground, waveguide)
- Passive damping of the cavity
  - Friction (QWR, Facco)
- Lorentz force
  - Small change in cavity amplitude (Delayen)
- Reactive element
  - Use input or dedicated coupler
  - VCX (Shepard), Copper cavities (CERN PS)
- RF phase drift
  - $f_{vib} >> \Delta f_{RF}$, use vector-sum control

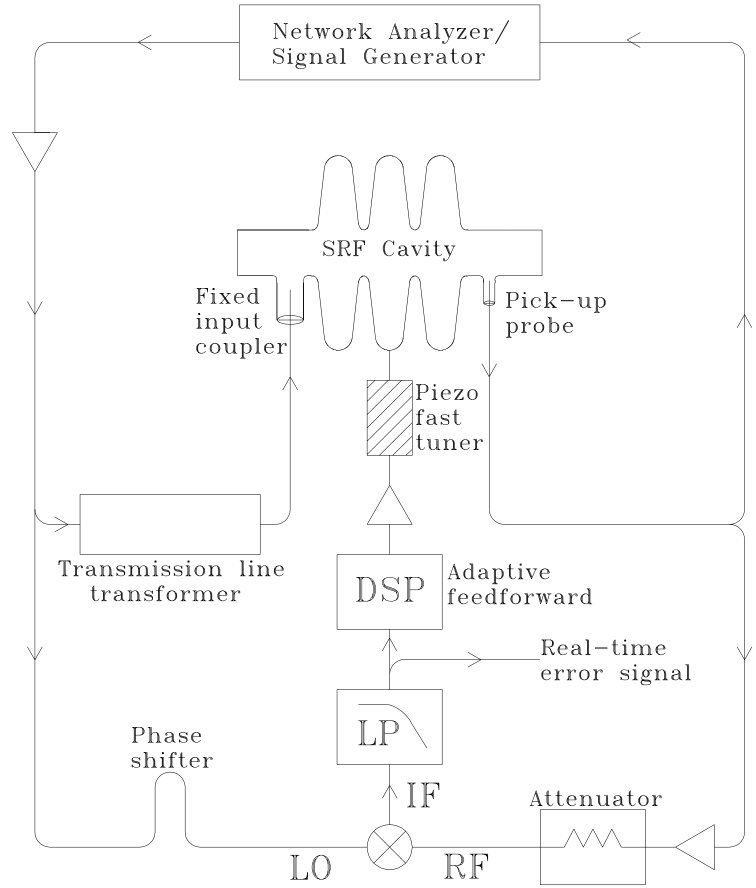
Microphonics – Methods of Control [2]

- Fast mechanical tuner
  - Piezoelectric, magnetostrictive, electromagnet, etc.
    - Cryomodule & cavity
  - Feedforward/feedback
    - Many algorithms and techniques

- Anticipated vibration spectrum
  - Dominated by sinusoidal disturbances
    - 60 Hz asynchronous motors, etc.
  - Vibration frequencies less than 200 Hz
    - Higher depending on cavity isolation and resonances

Cavity and microphonics circuit



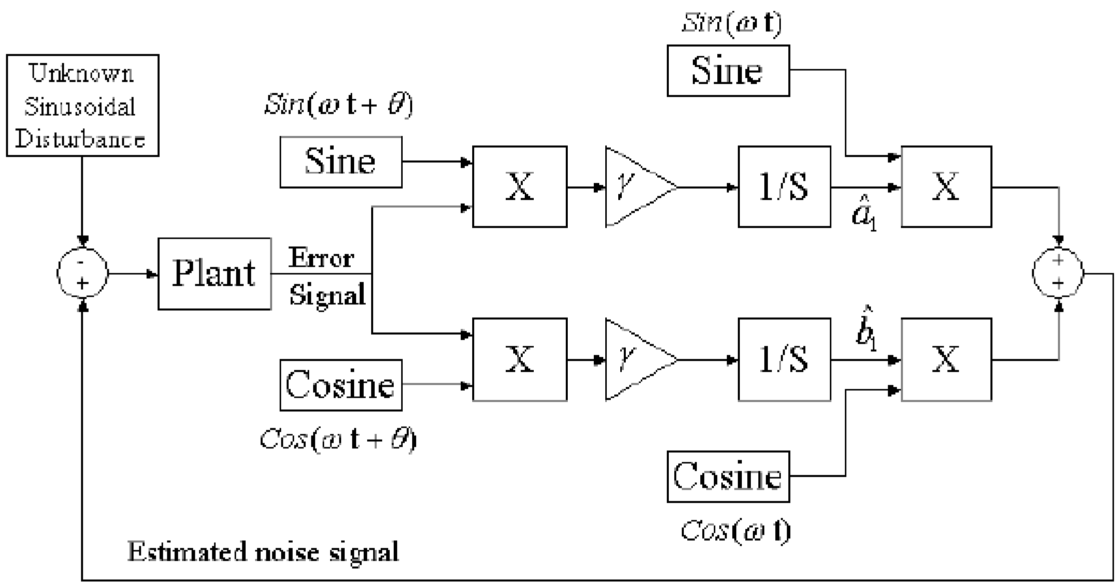


Measured microphonics

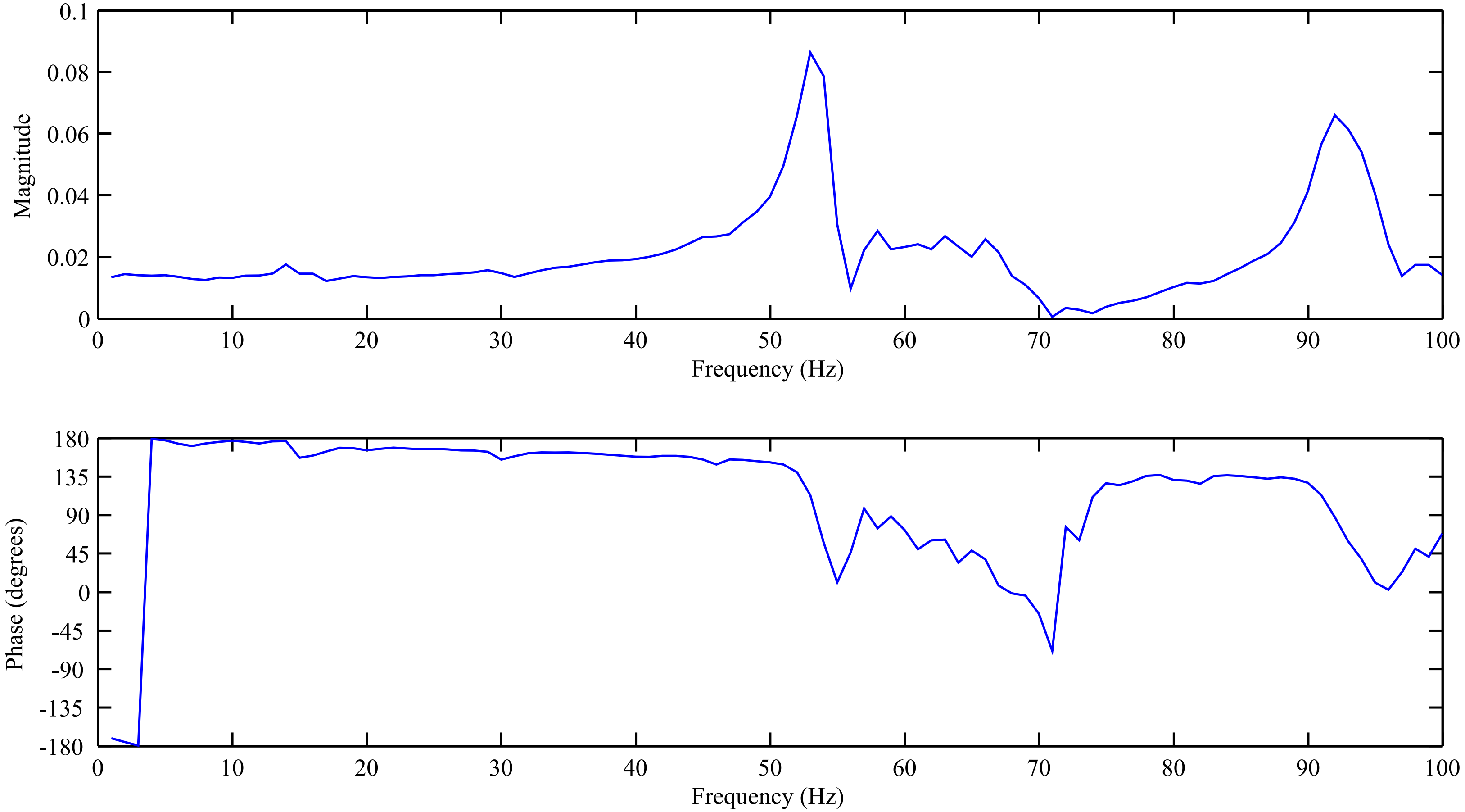
- Measured vibration spectrum
  - Primarily discrete Fourier components
    - Less than 40 Hz pk-pk RF frequency shift
    - Modulation frequencies less than 80 Hz
    - Main components 59.5 & 59.7 Hz
      - Identified using accelerometer as cryoplant screw compressors
    - Additional components near 54 Hz
      - Likely a motor and mechanical resonance

Adaptive Feedforward Cancelation

- Individual sinusoidal disturbances are damped
  - Unlimited number of Fourier components
- Generates a control signal
  - Needs disturbance frequency and rudimentary cavity response (no analytic transfer function)

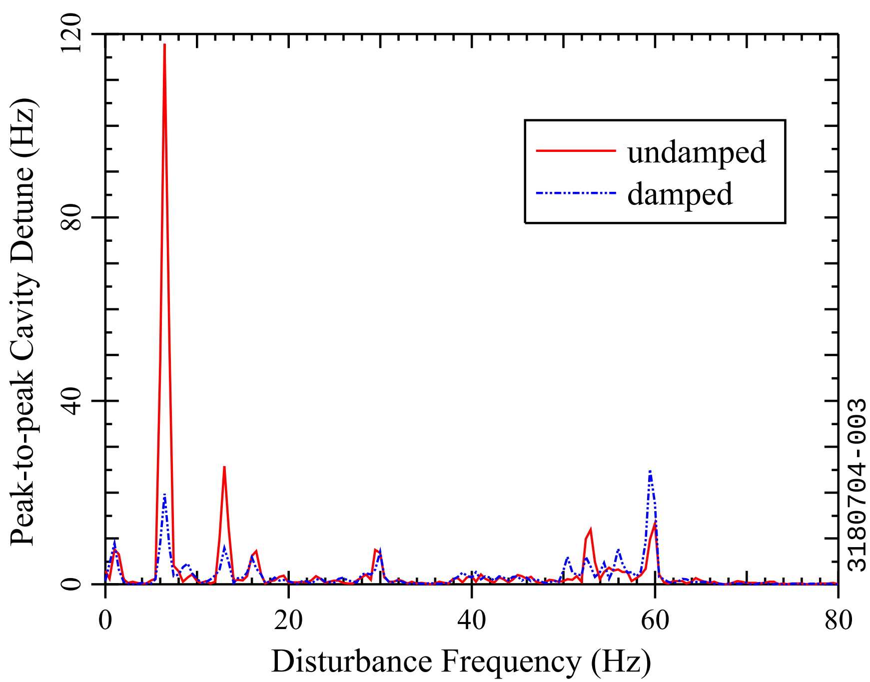


Tuner Bode diagram

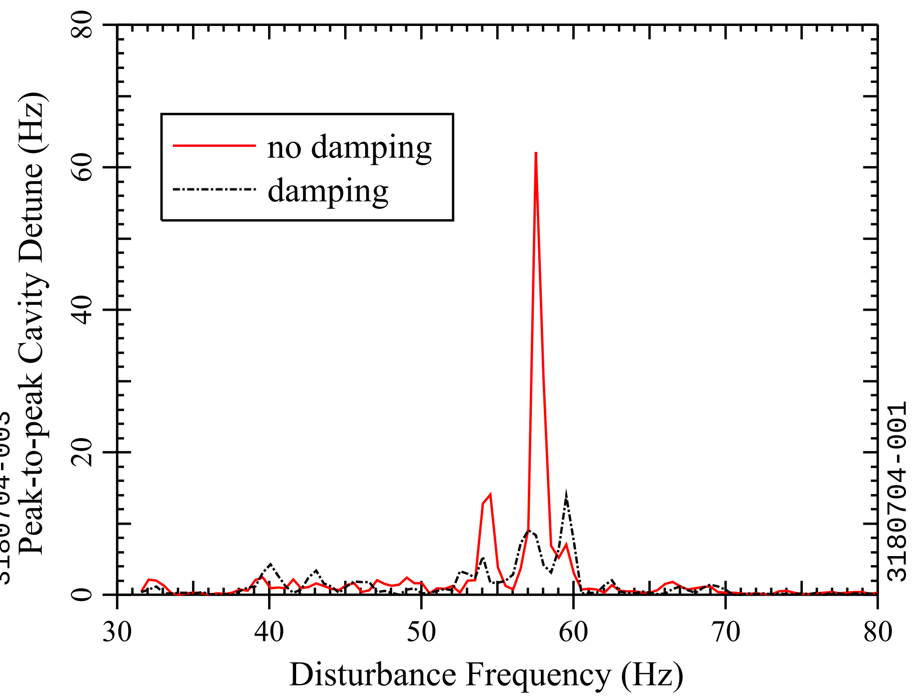


Active damping

- Adaptive feedforward cancellation of sinusoidal disturbances



6.5 Hz helium oscillation



57 Hz electric motor

Summary

- Microphonics dominated by low frequency sinusoidal disturbances from rotating machinery (cw operation)
- Many techniques to damp or alleviate microphonics
  - Source
  - Transmission
  - Design of cryomodule and cavity
  - Passive and active damping
    - Demonstrated Adaptive Feedforward Cancellation for RIA
- CW operation with loaded-Q in the mid-10^7 range (and likely higher) appears feasible