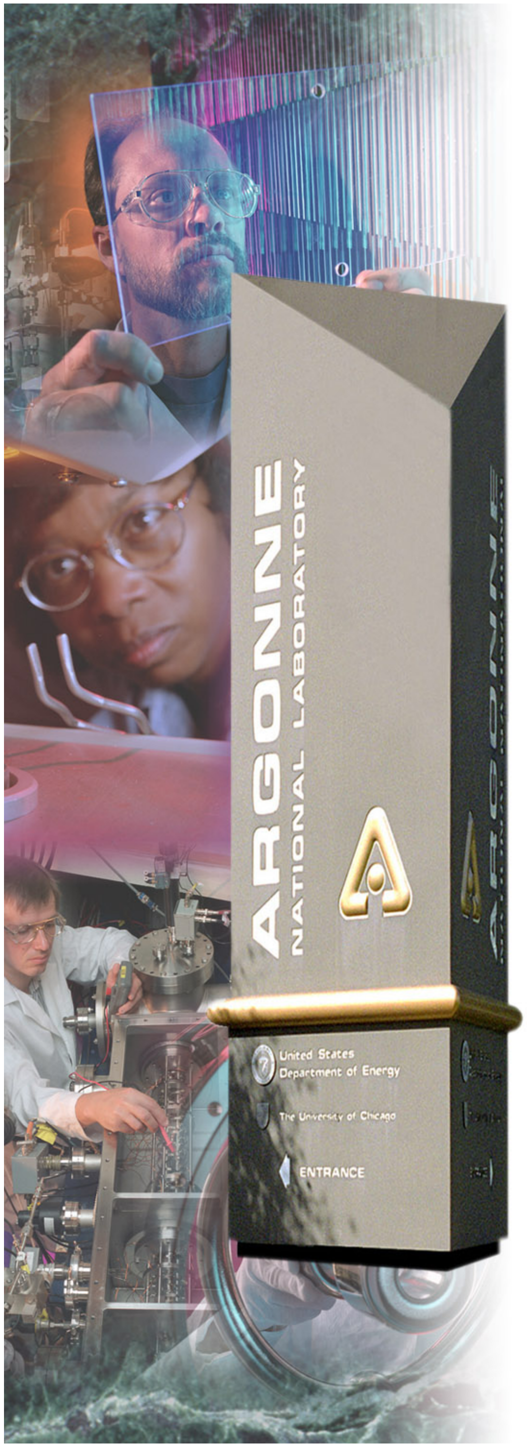

Mechanical Properties of Spoke Cavities

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July 12, 2005

Argonne National Laboratory
A U.S. Department of Energy Office of Science Laboratory
Managed by The University of Chicago

Collaborators

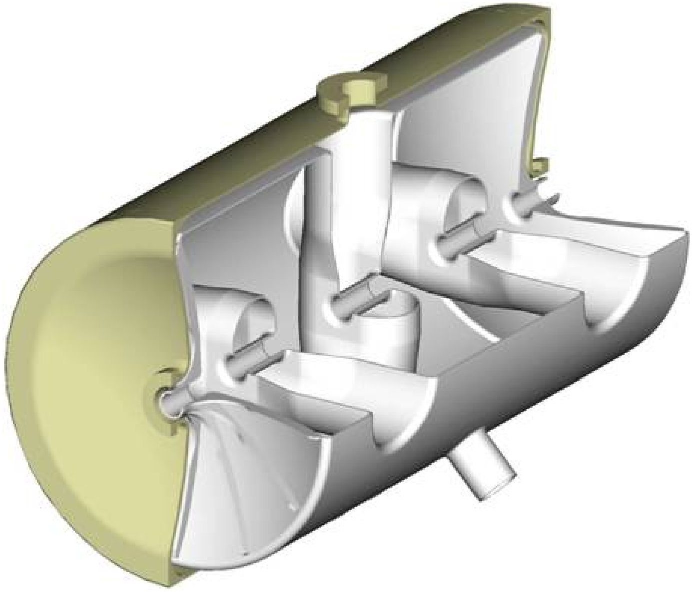
- **ANL**
  - Ken Shepard, Mike Kelly, Joel Fuerst, Mark Kedzie, Gary Zinkann
- **AES**
  - John Rathke, Tom Schultheiss
- **Energen**
  - Chad Joshi, Chiu-Ying Tai

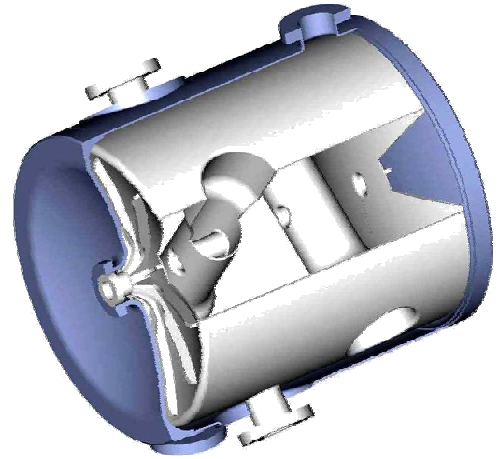
Spoke Cavity Mechanical Properties

- **SC cavities typically have both a small loaded and a small intrinsic bandwidth. This makes them very sensitive to mechanical deformations which result in frequency variations.**

- **Mechanical Properties:**
  - cw operation => microphonic induced noise.
  - pulsed operation => Lorentz Detuning.

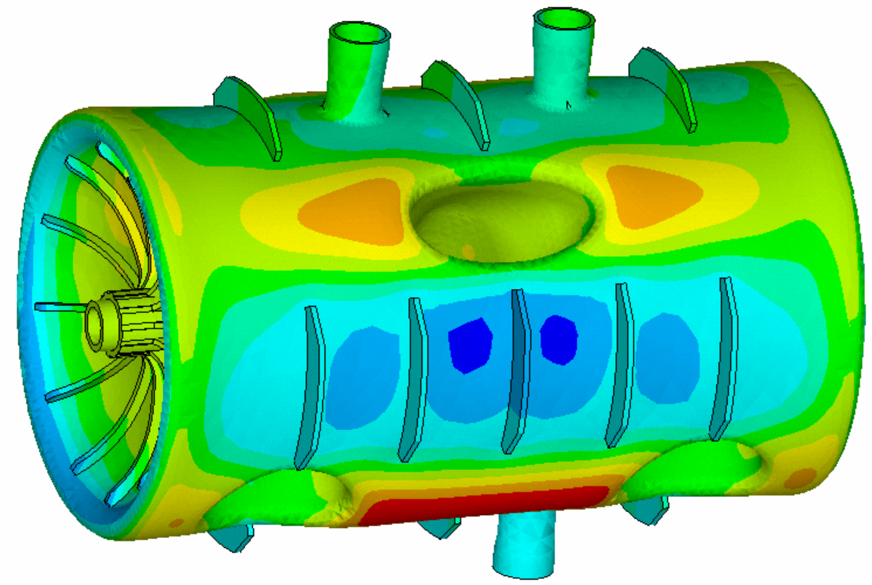
Spoke Cavity Mechanical Properties

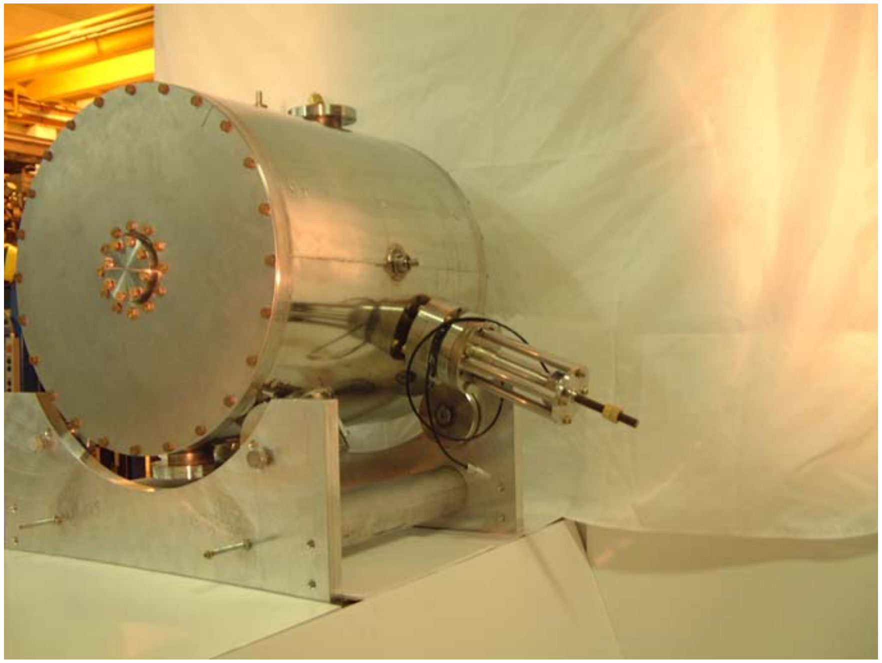




- **Methods of controlling amplitude and phase errors:**
  - Overcoupling
  - Reactive Tuners
  - Fast Mechanical Tuners
    - *Piezoelectric actuated*
    - *Magnetostrictive actuated*

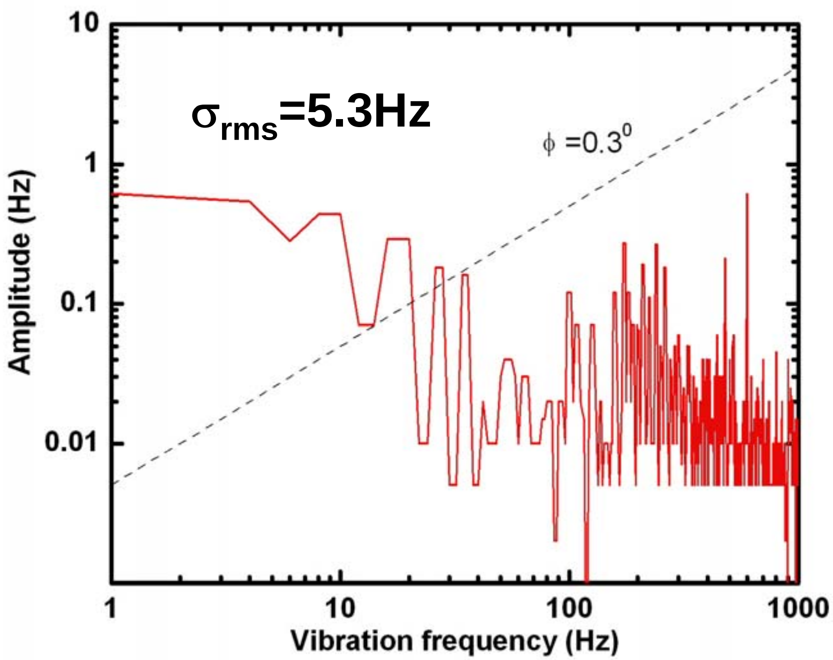
Outline

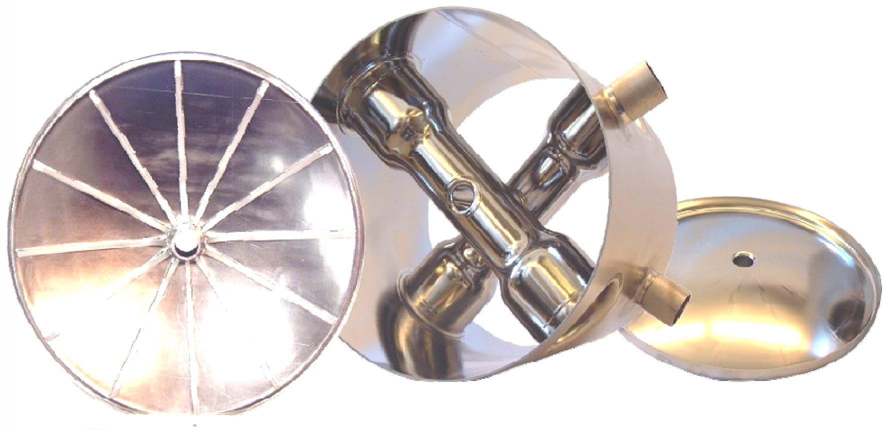




- **Cavity mechanical properties.**
- **Fast mechanical tuners.**

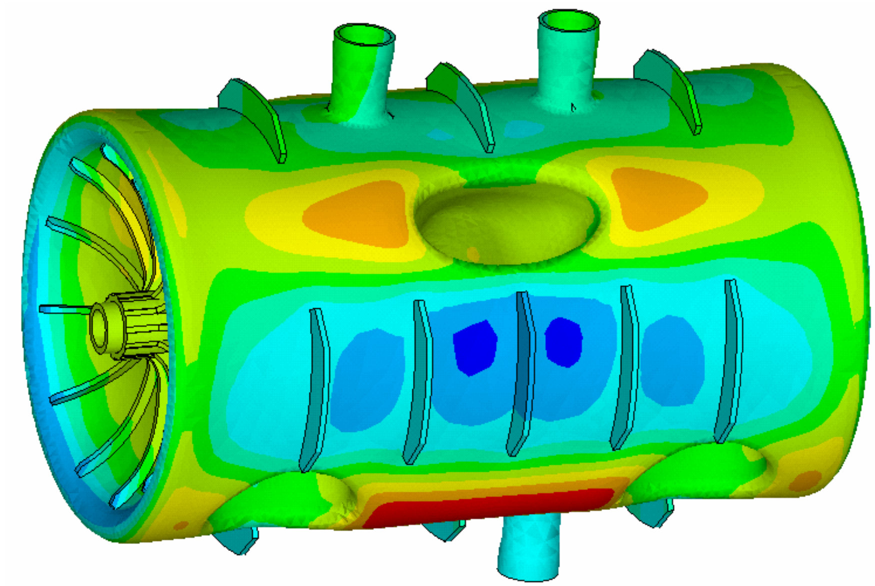
β = 0.4 Double Spoke Microphonics





- **Results of first cold test of a production model double spoke cavity with an integral stainless steel housing holding the liquid helium bath.**
- **$\Delta f/\Delta P$ = -76 Hz/torr**

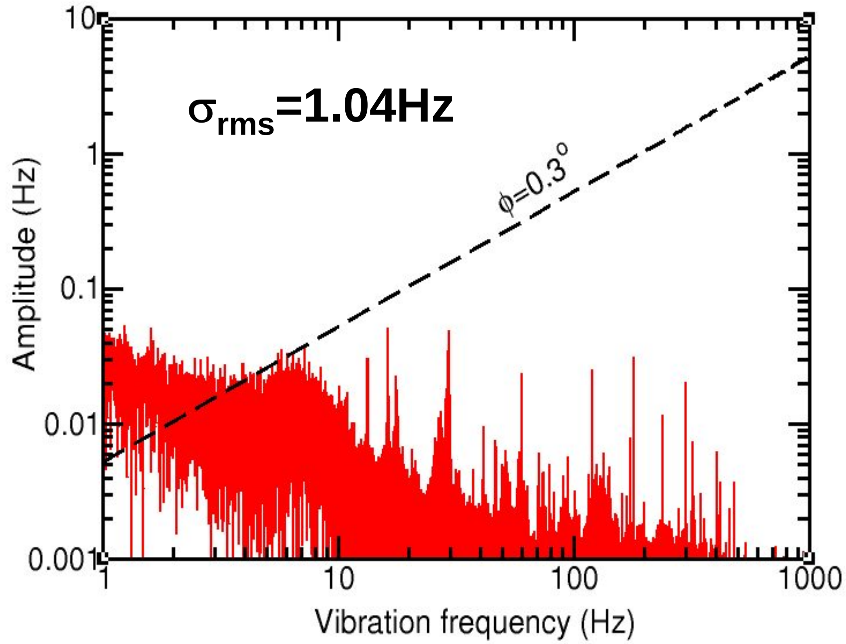
β = 0.5 Triple Spoke Cavity

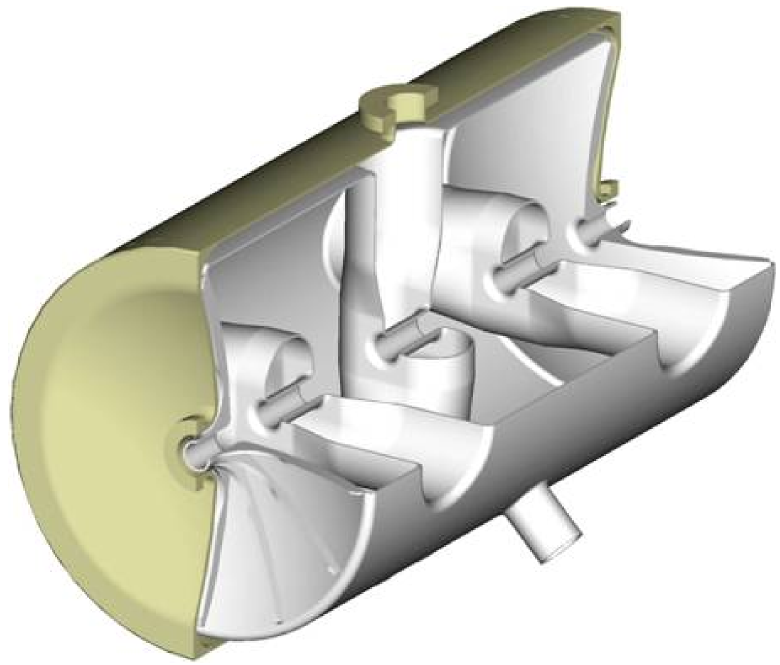


- **β=0.5 triple spoke cavity designed* to minimize Δf/ΔP.**
- **Designed to balance the electric and magnetic field contributions to frequency shifts due to uniform external pressure.**

*** Modeling performed by AES.**

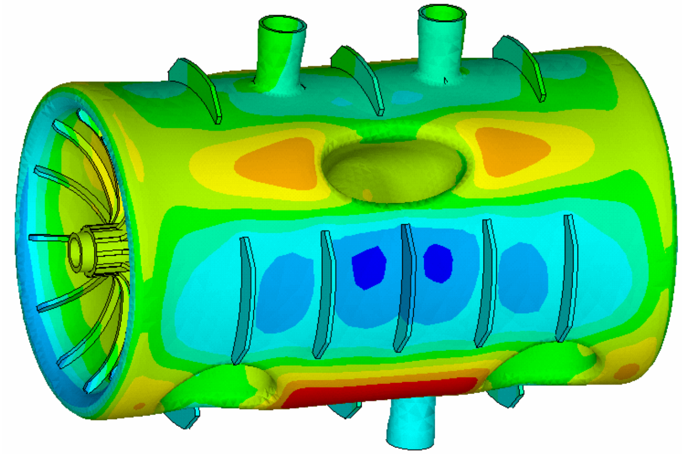
β = 0.5 Triple Spoke Microphonics



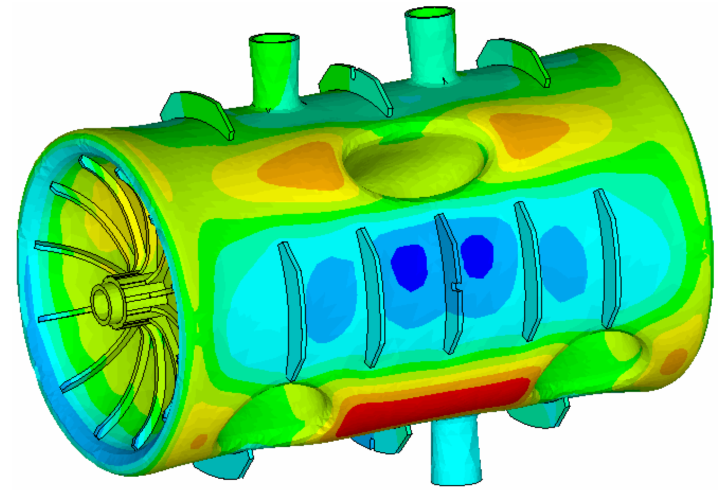


- **Cavity tested in a realistic accelerator environment.**
  $\Delta f/\Delta P$ = -12.4 Hz/torr

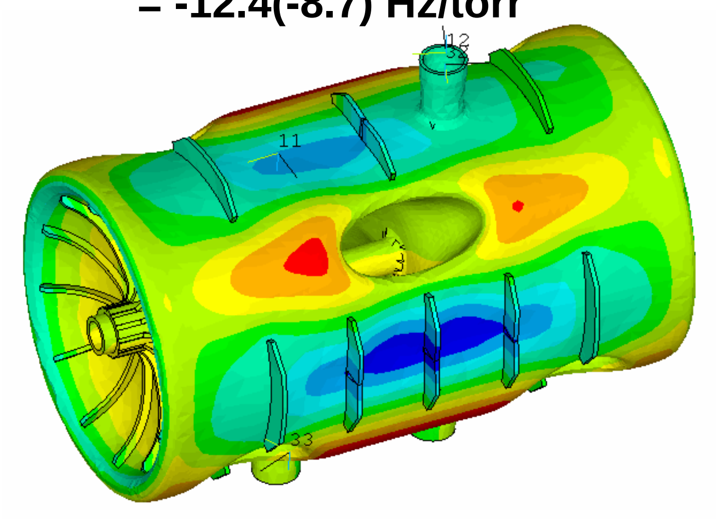
β = 0.5 Triple Spoke Cavity



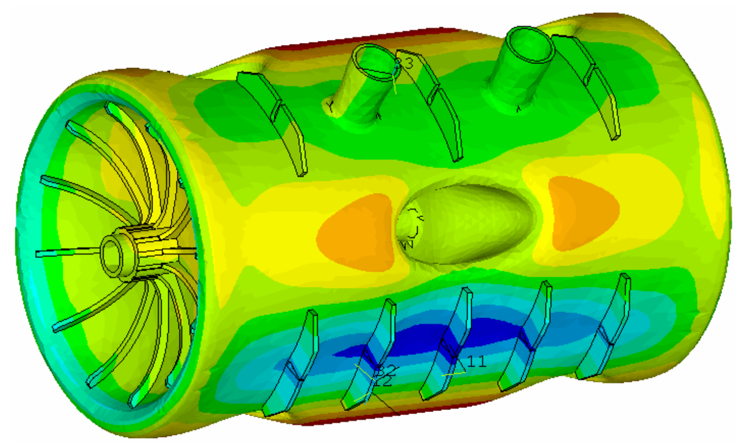
measured Δf/ΔP(predicted) = -12.4(-8.7) Hz/torr



Δf/ΔP = -6.3(-4.7) Hz/torr



Δf/ΔP = -2.5(-0.3) Hz/torr

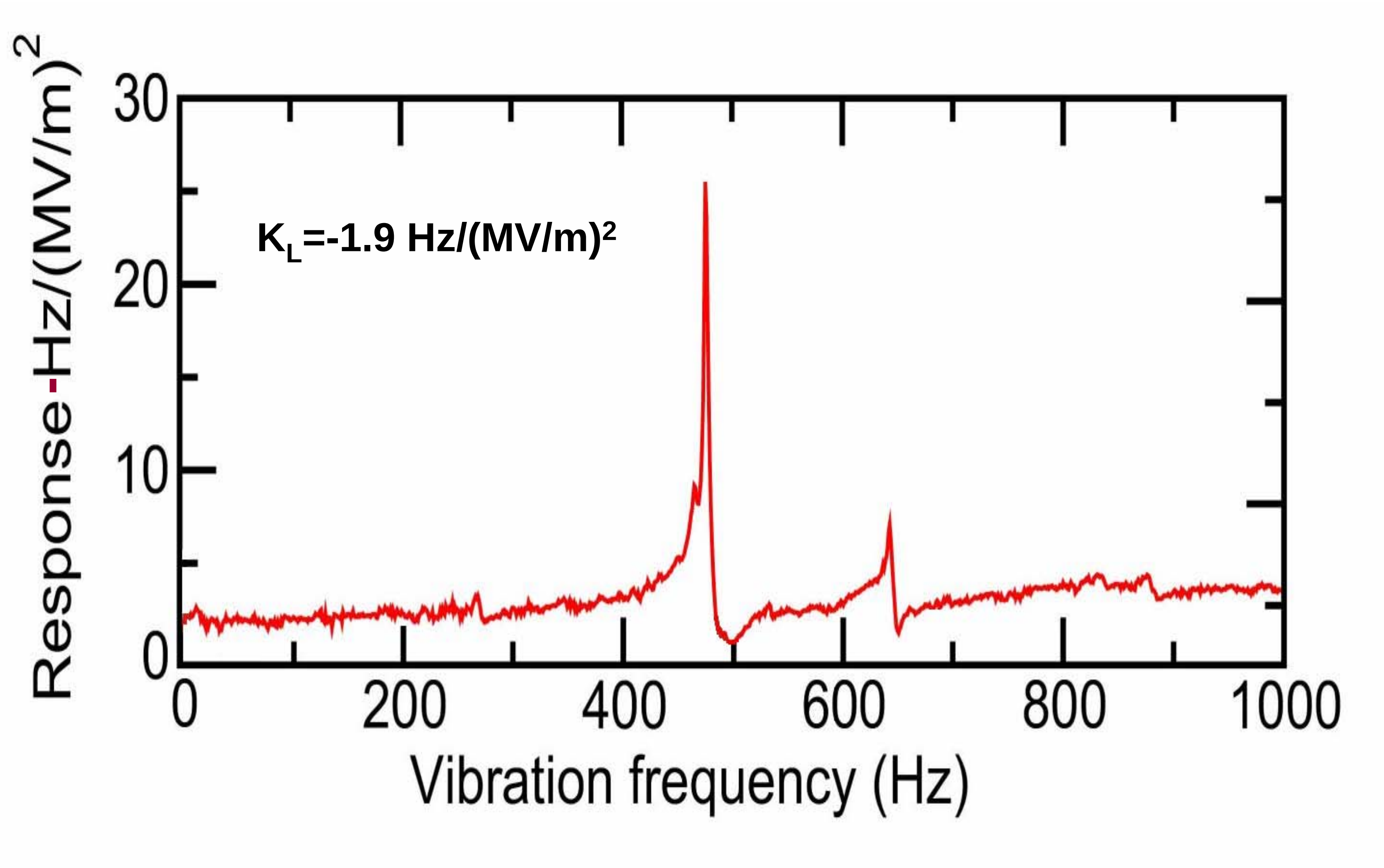


Δf/ΔP = -0.5(+5.4) Hz/torr

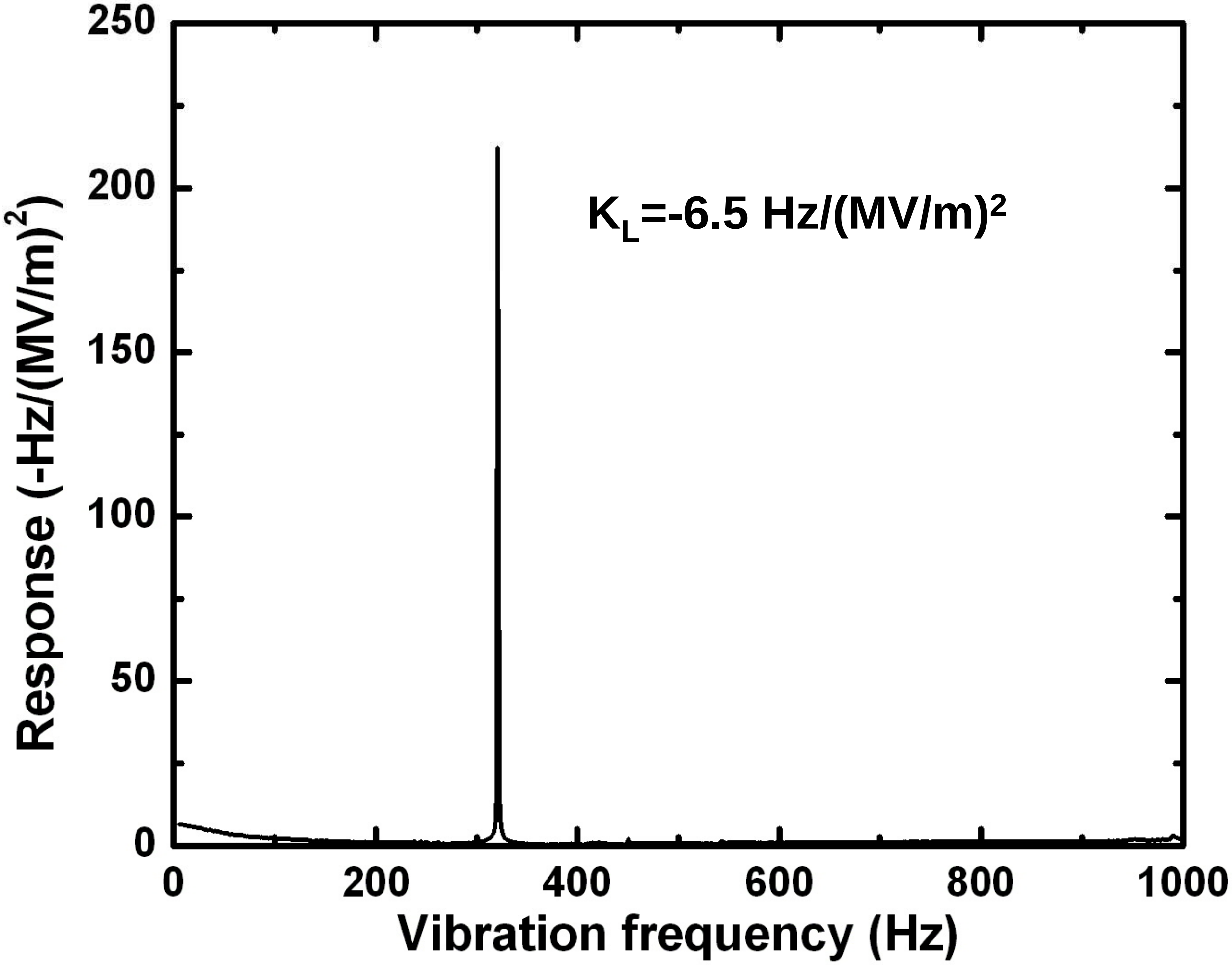
Changing Gears

- **Finished talking about microphonics.**
- **I am now going to talk about Lorentz detuning.**

β = 0.4 Double Spoke Lorentz Transfer Function

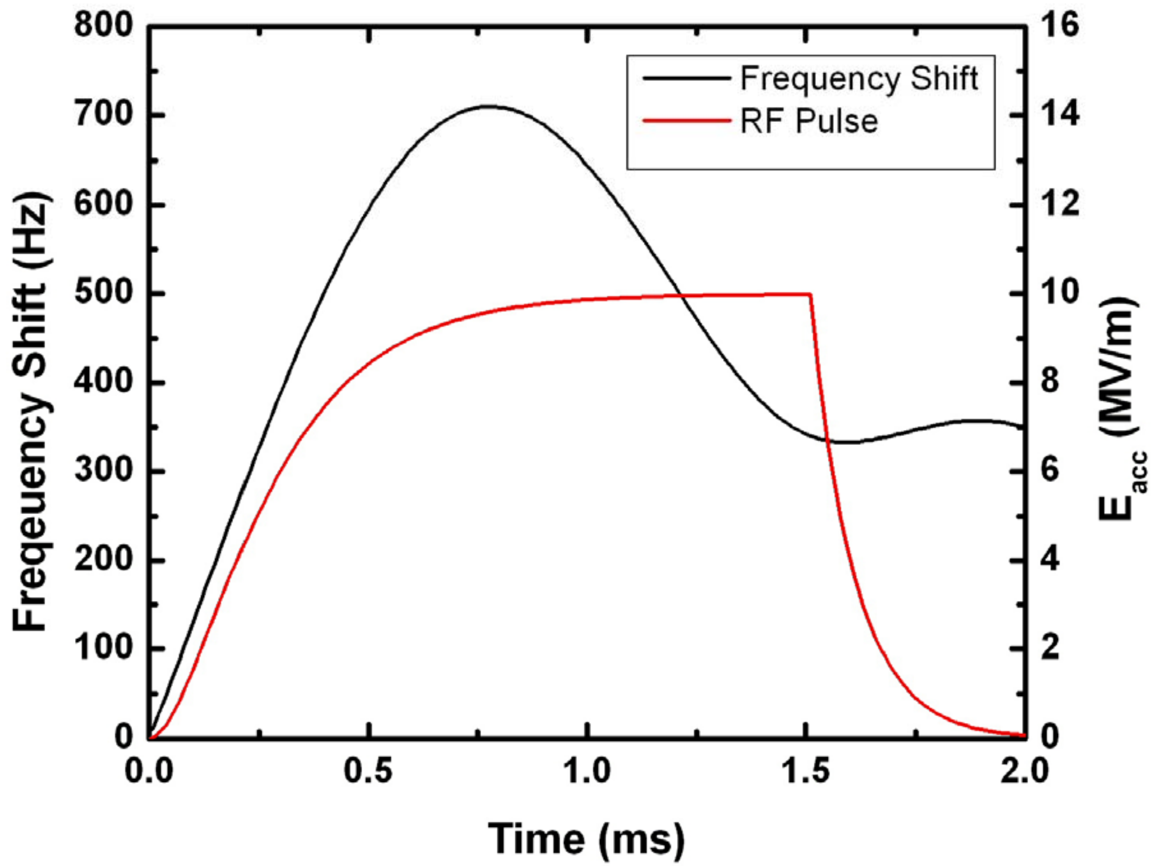


β = 0.5 Triple Spoke Lorentz Transfer Function

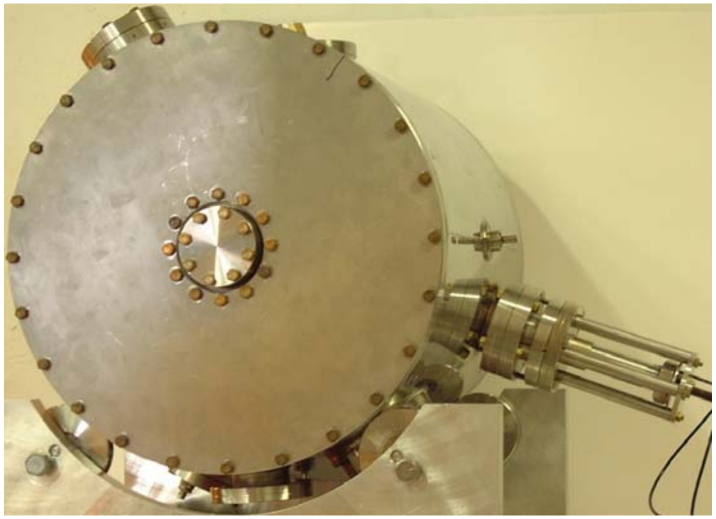


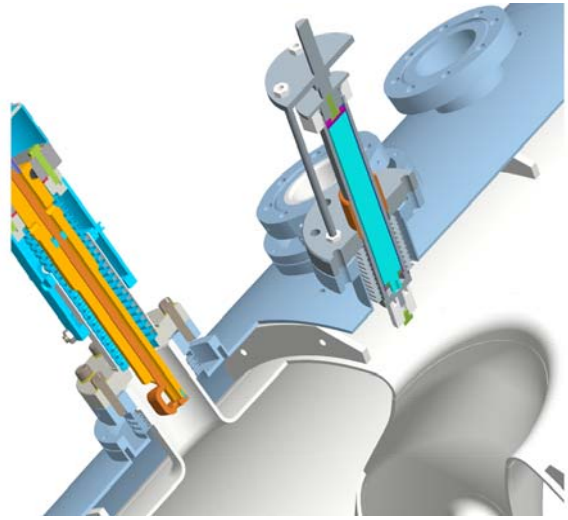
Frequency Variation Due to Pulsed Fields Prediction

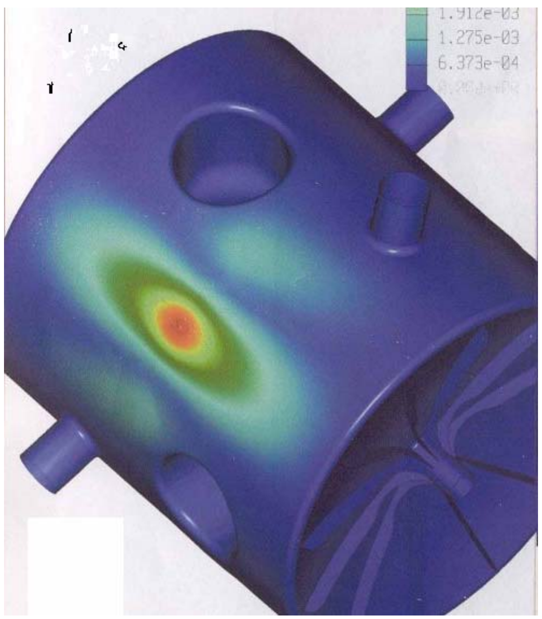
$$\text{Response(t)} = \int_{-\infty}^{\infty} \left(\text{Transfer Function}(\omega) * \text{Input}(\omega) \right) e^{-i\omega t} d\omega$$

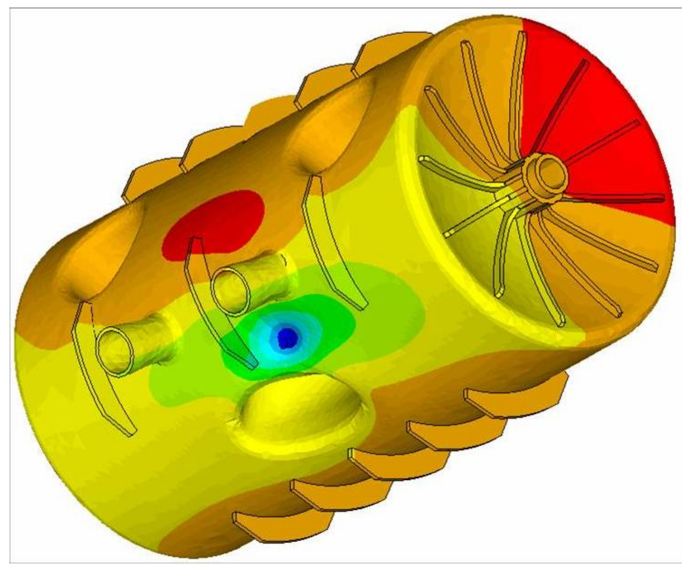


Spoke Cavity Fast Mechanical Tuning





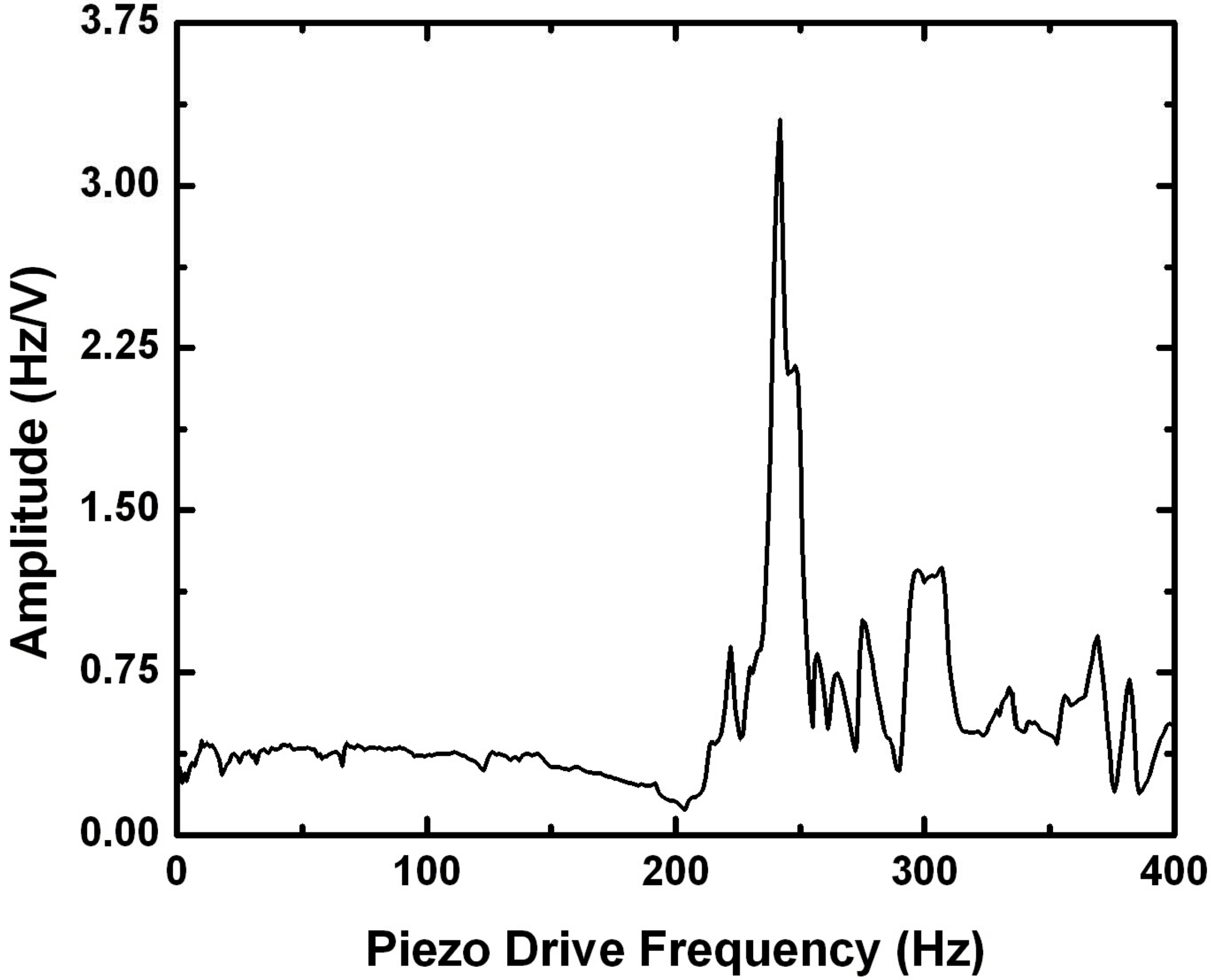




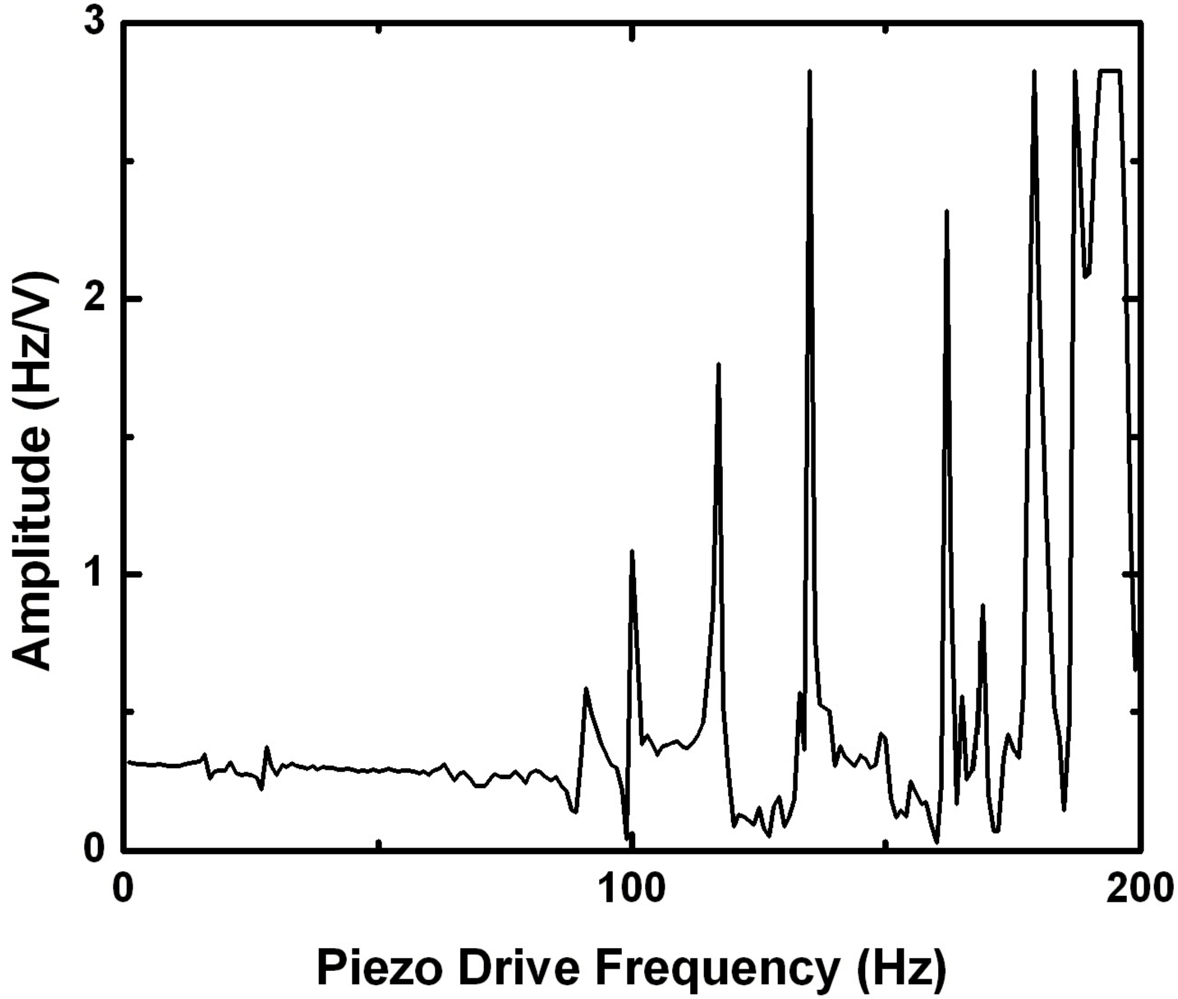
Piezoelectric Actuated Fast Tuner

- **Response time <1ms.**
- **Layered piezo-ceramic material electrically connected in parallel operating at ~20K with a resolution of 2nm purchased from Physik Instrumente.**
- **Not designed for high frequency operation.**

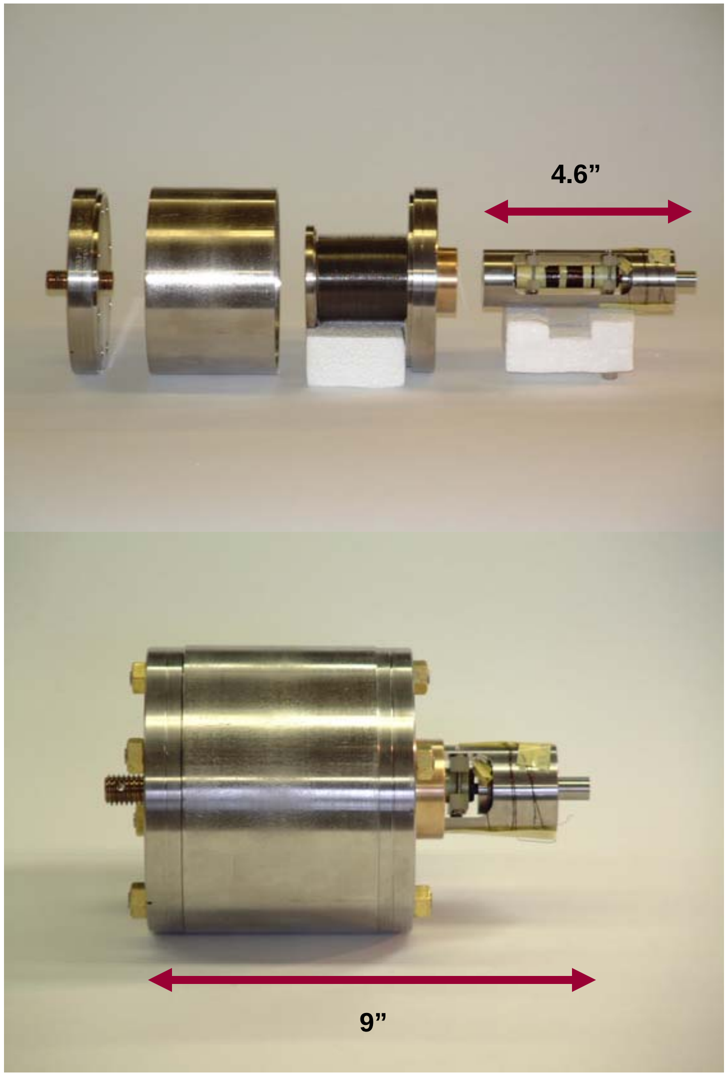
β = 0.4 Double Spoke Piezo Transfer Function



β = 0.5 Triple Spoke Piezo Transfer Function



Magnetostrictive Actuated Fast Tuner



- **Magnetostrictive actuator designed and built by Energen, Inc and slated to be tested at ANL.**
- **Response time <6ms.**
- **Magnetostrictive rod coaxial with an external solenoid operating at 4K.**

Future Work

- Measure microphonic induced noise spectrum of $\beta = 0.5$ triple spoke cavity to measure the effect of modifying the support ribs.
- Pulse a spoke cavity and measure the frequency variation.
- Use fast mechanical tuners to reduce frequency variations due to microphonics and the Lorentz force.

Lorentz Transfer Function

- **Amplitude modulated RF fields are be expressed as:**

$$\vec{E}_i(\vec{x},t) = A(t)\vec{E}_i(\vec{x})e^{2\pi i f_i t}$$

$$\vec{H}_i(\vec{x},t) = A(t)\vec{H}_i(\vec{x})e^{2\pi i f_i t}$$

• **The local displacement of a cavity surface can be expressed as:**

$$\vec{u}(\vec{x},t) = \sum_i \eta_i(t)\vec{\xi}_i(\vec{x})$$

Frequency Shift

$$\Delta f(t) = f_0 \sum_i \frac{A^2(t)}{\sqrt{2\pi} M_{ii}} \frac{\displaystyle\int_{-\infty}^{\infty} \frac{e^{iwt}}{\left(\Omega_i^2 - w^2 - \frac{i\Omega_i w}{Q_i^{MECH}}\right)} dw}{\displaystyle\int_V \left[\frac{1}{\mu_0 c}\left|\vec{E}_0(\vec{x})\right|^2 + \varepsilon_0 \left|\vec{H}_0(\vec{x})\right|^2\right] d^3x}$$

$$\times \quad \left(\int_{\Delta V} \left[\mu_0 \left|\vec{H}_0(\vec{x})\right|^2 - \varepsilon_0 \left|\vec{E}_0(\vec{x})\right|^2\right] \vec{\xi}_i(\vec{x}) \cdot d\vec{a} \right)^2$$