Innovative Tuner Designs for Low-β SRF Cavities

Zachary A. Conway
Argonne National Laboratory
Physics Division-Linac Development Group

Outline

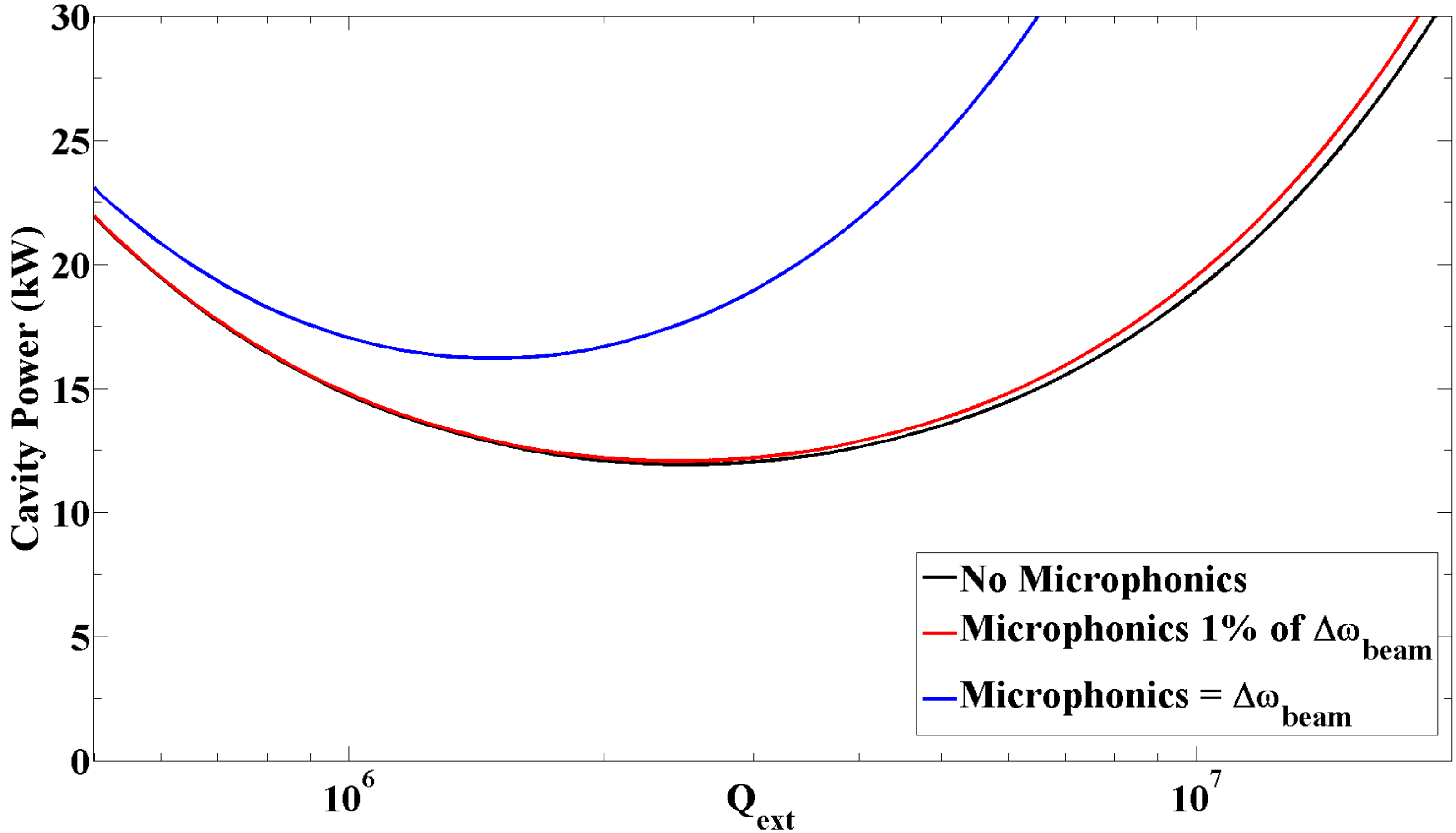
- Why use a tuner?
- Cavity mechanical properties
- Low-β cavity tuner examples

Tuner Requirements

	Operating Mode: CW	Operating Mode: Pulsed
Slow Tuning	▪ Center Cavity Frequency	▪ Center Cavity Frequency

Fast Tuning	▪ Microphonics
	  ▪ He Pressure Fluctuations
	  ▪ Resonant Vibrations
	▪ Over Couple – Additional RF Power $$$
		▪ Lorentz Detuning
		▪ Over Couple – Additional RF Power $$$

Why use a tuner?



- Accelerator cavities must be operated with a stable phase and amplitude
- High beam loading – Reduced dependence on RF frequency errors

Mechanical Considerations

- Design to minimize microphonics (can be extremely effective if considered early)
  - Decoupled the RF accelerating mode from common mechanical vibrations
    - cw operation - helium pressure fluctuations (M. Kelly, THIOB04, QWR)
    - pulsed operation - Lorentz detuning (W. Schappert, FRIOA01)
  - Do as much as you can then use a tuner and overcouple to control RF field

$$\Delta f \propto \int_{\Delta V} \left[\mu_0 \left| \vec{H}_0(\vec{x}) \right|^2 - \varepsilon_0 \left| \vec{E}_0(\vec{x}) \right|^2 \right] d^3x$$

Slater Perturbation Theorem

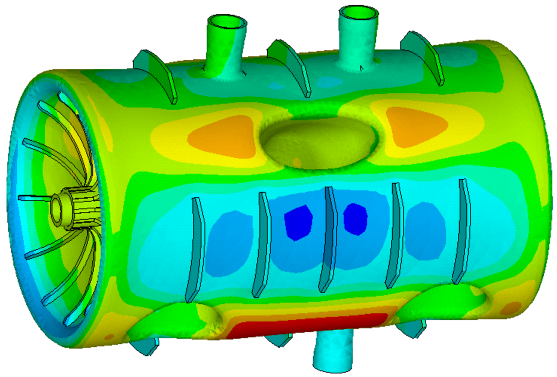
- For example
  - cw operation – balance contributions to Δf
  - pulsed operation - fabricate with a high rigidity

Cavity Mechanical Design

β = 0.5 345 MHz Triple-Spoke Cavity

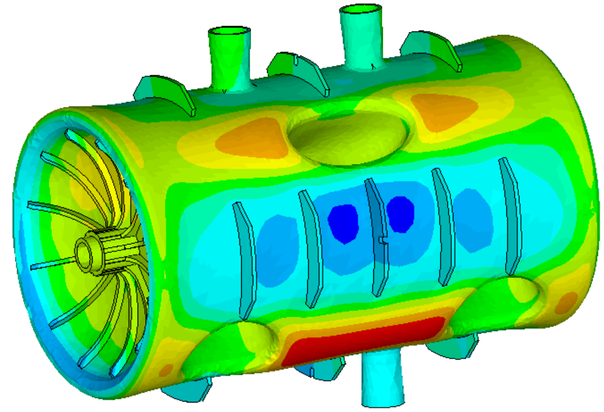
Room temperature test results

1)



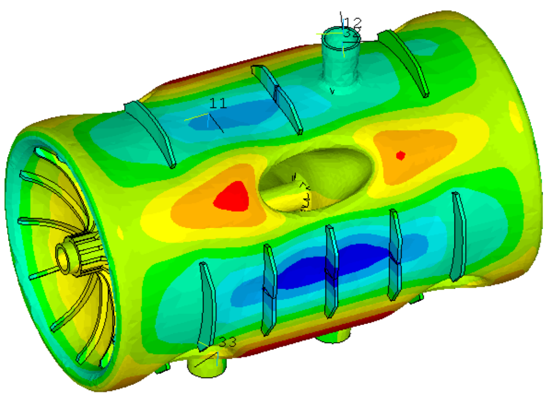
measured Δf/ΔP = -12.4 Hz/torr

2)



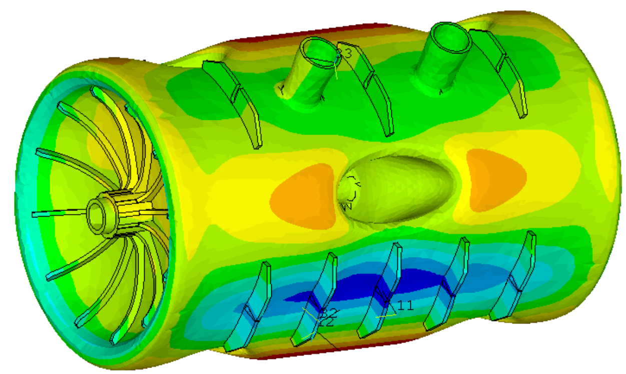
Δf/ΔP = -6.3 Hz/torr

3)



Δf/ΔP = -2.5 Hz/torr

4)



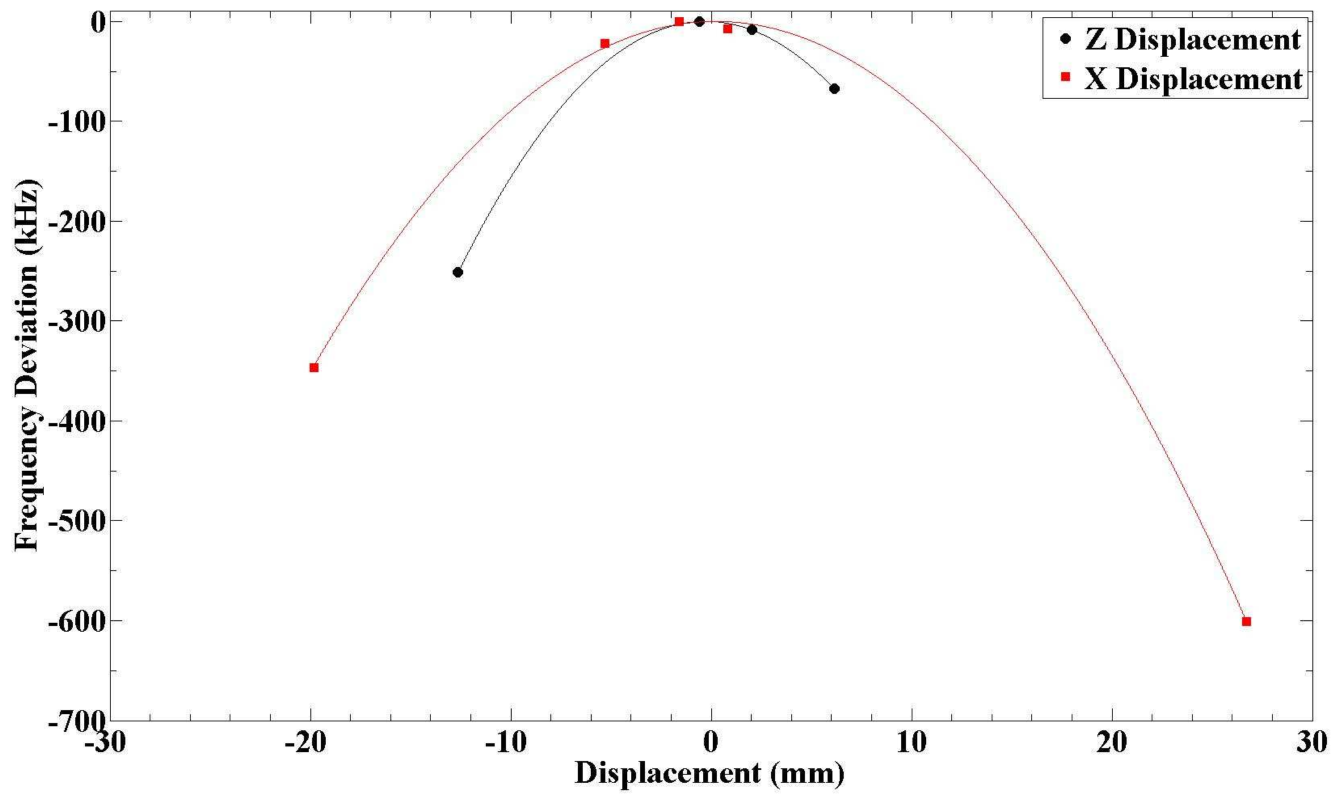
Δf/ΔP = -0.5 Hz/torr

Z.A. Conway, SRF2005, TUA06

T. Schultheiss & J. Rathke, AES, Modeling

β = 0.077 72MHz Quarter-Wave Cavity

Frequency Shift Due To Pendulum-Like Oscillations of Center Conductor



Peak-to-Peak Frequency Deviation For A Center Conductor Offset From Electrical Center Along Z.

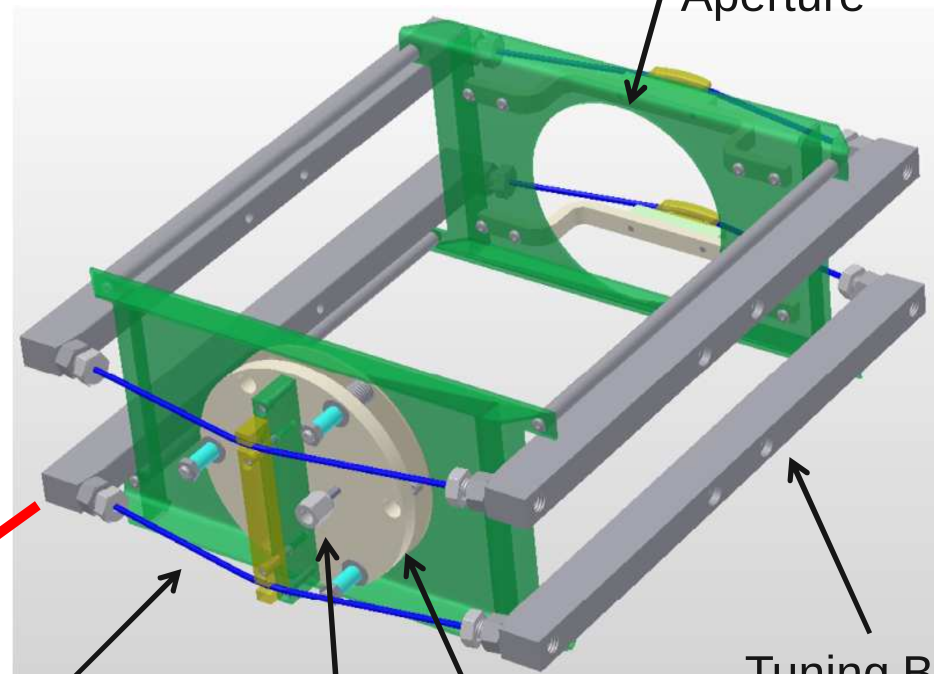
Displacement (mm)	0	0.25	0.5	1
$\Delta f_{p\text{-}p}$ (Hz)	0.2	15	33	66

Possible to eliminate microphonics due to pendulum mode if done correctly. (J.R. Delayen 1987)

Types of Tuners In Use/Development Today

- Mechanical
  - Course slow tuners
    - Control The Applied Force
    - Control The Applied Displacement
  - Fine fast tuners
    - Piezo electric
    - Magnetostrictive
- Electromagnetic: Voltage Controlled Reactance (VCX)
  - Limited application range without further R&D
    - Stored Energy < 25 J
    - Frequency < ~100 MHz
  - No plans to use in future accelerators

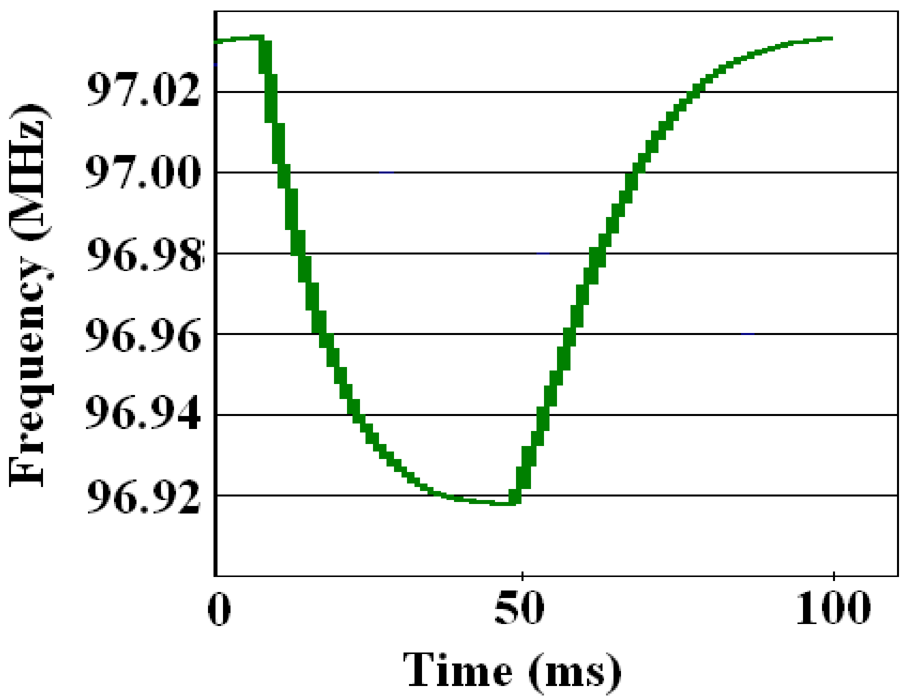
Tuners Which Control The Applied Force



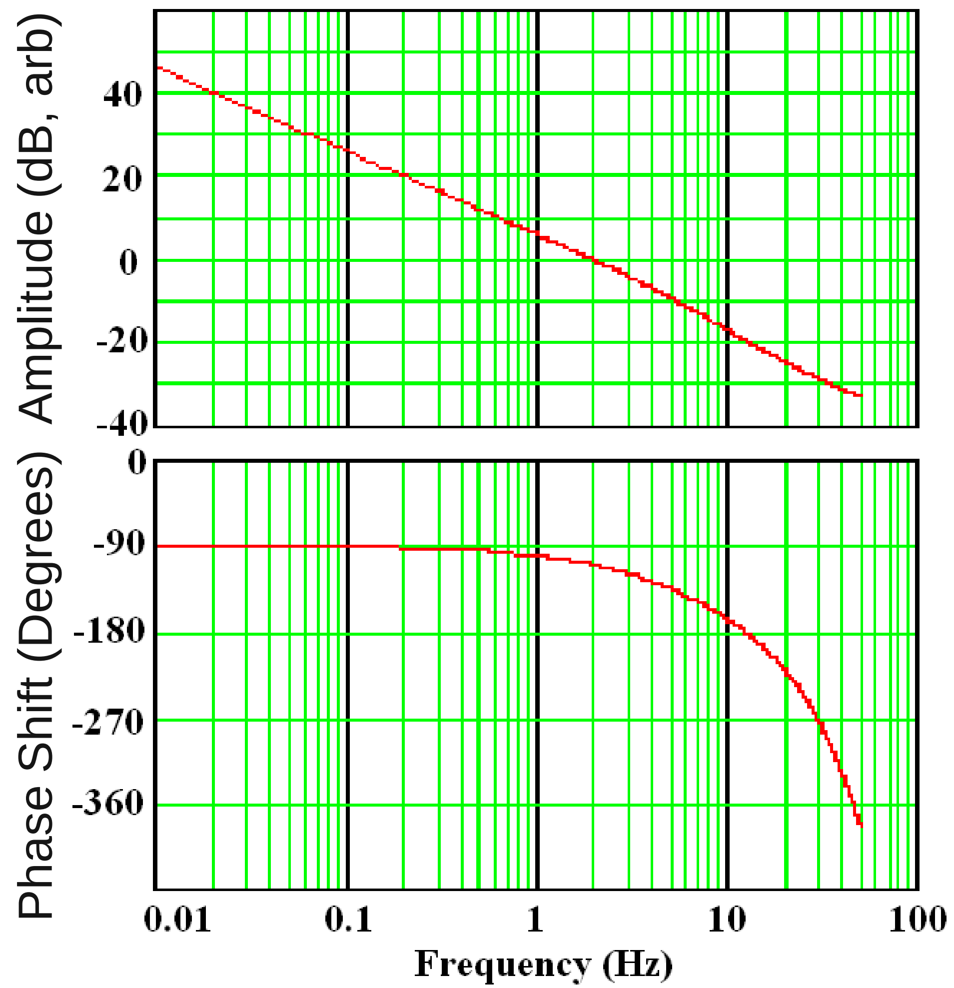
- Tuner compresses cavity by squeezing at the beam ports
- This design separates the mechanically compliant course tuner from the rigid fast tuner
- ANL approach has essentially no direct interaction with the clean assembly

Helium Gas Actuated Slow Tuner Performance

Slow Tuner Response



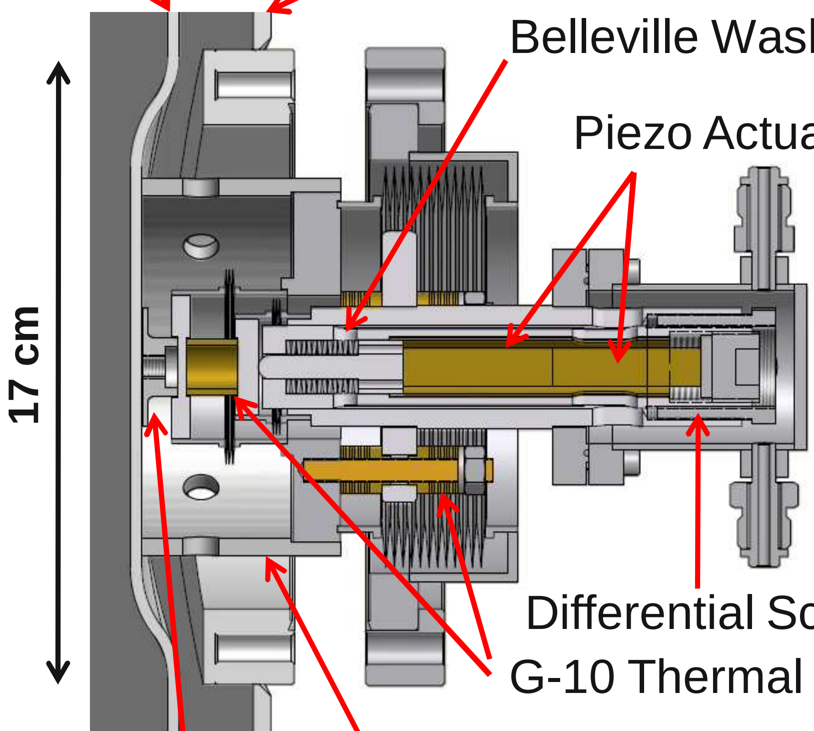
Slow Tuner Transfer Function



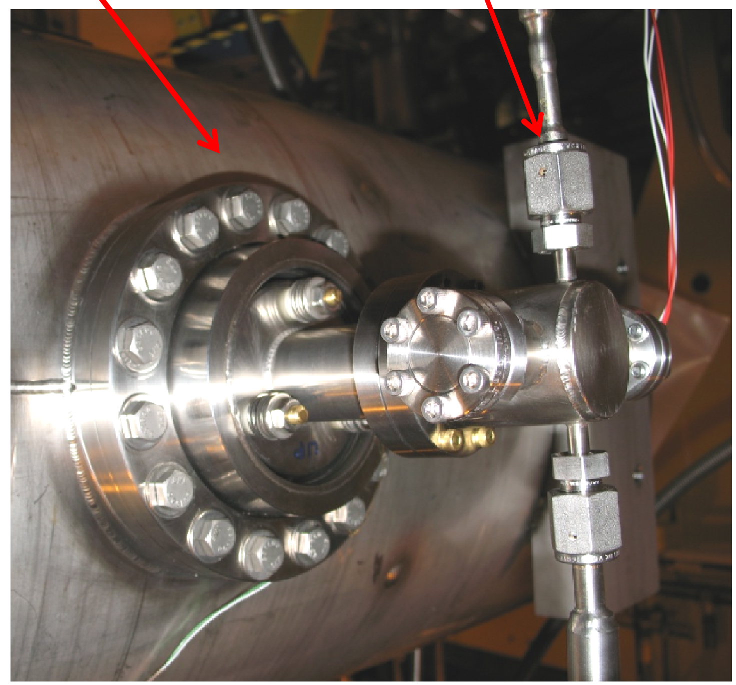
The pneumatic tuner is quite fast
>2500 Hz/sec

Zinkann et al, PAC'05, WPAT082

Piezoelectric Fast Tuner



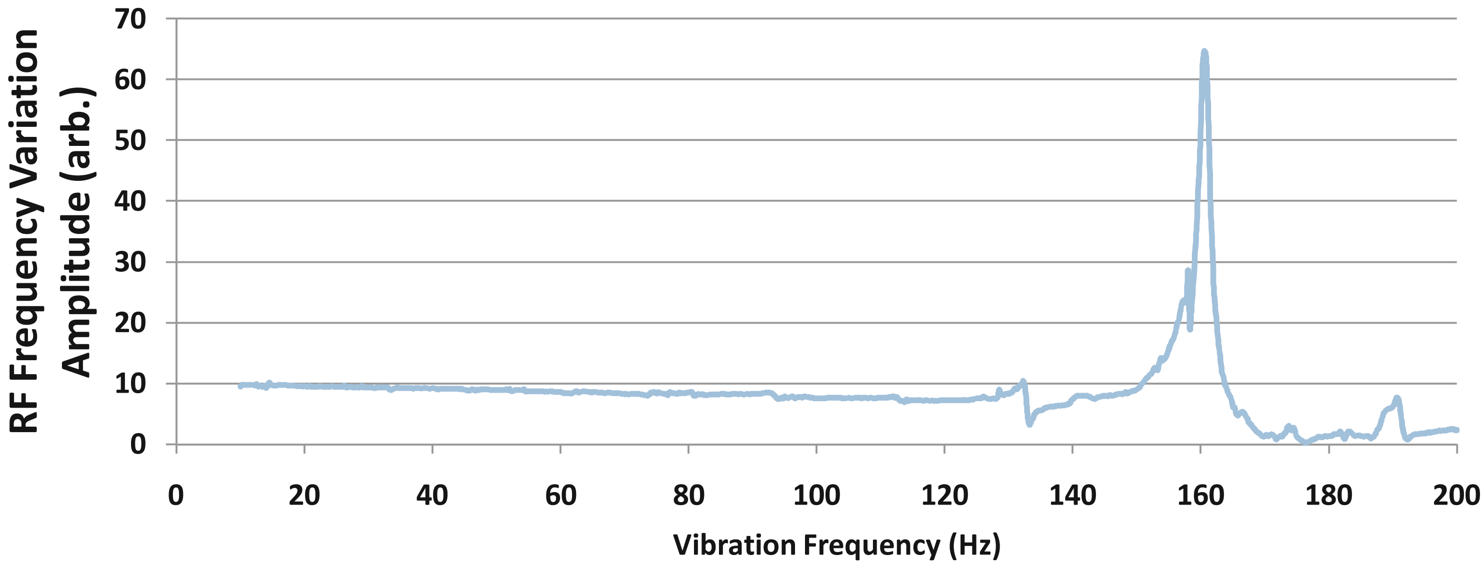
Fast Tuner Cross Section
Nb Ring and Button Welded To Cavity

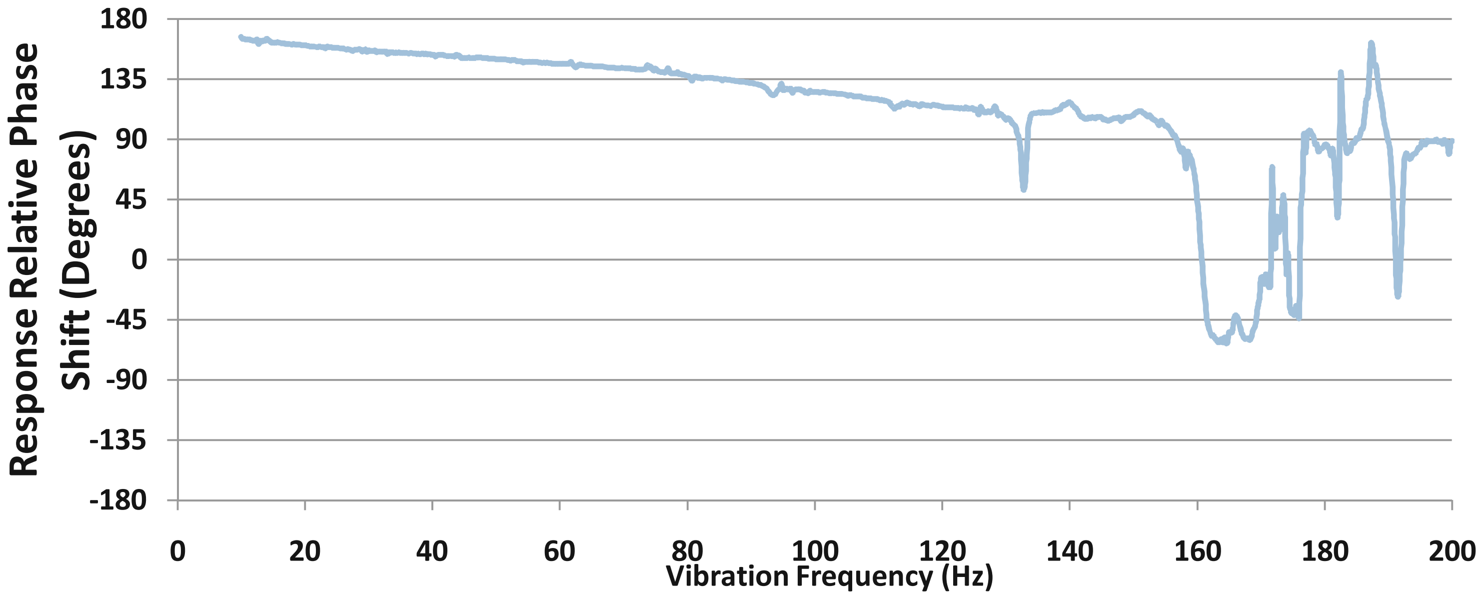


Fast Tuner On HWR Cavity

Kelly et al, LINAC2010, THP057

Fast Tuner Performance on HWR



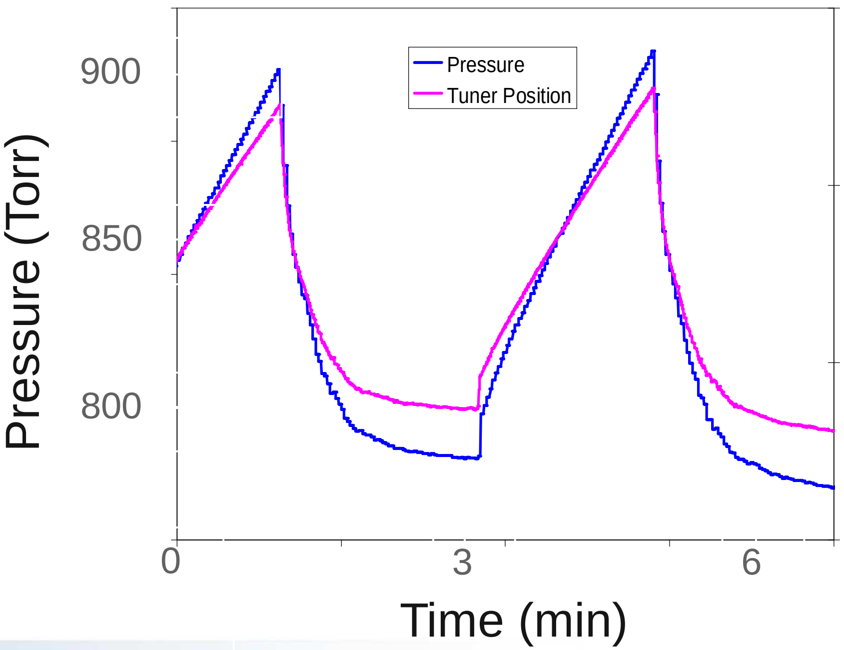


Examples of Low-β Tuners For CW Operation

Tuner Examples

ISAC-II Cryomodule @ TRIUMF

Bottom View Of Cavity

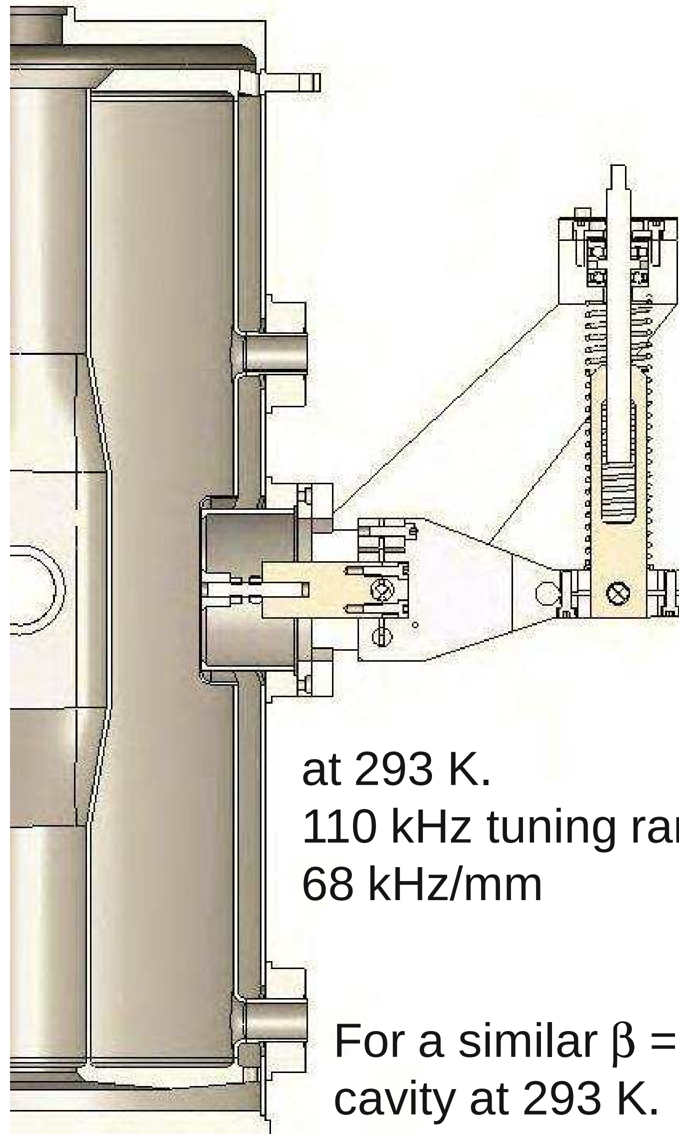


- Lever connected to tuning plate
- Tuner resolution = 0.04Hz/step (5nm/step)
- Laxdal et al, SRF2011 THIOB06

Tuner Examples

EURISOL R&D

352 MHz β = 0.17 Halfwave



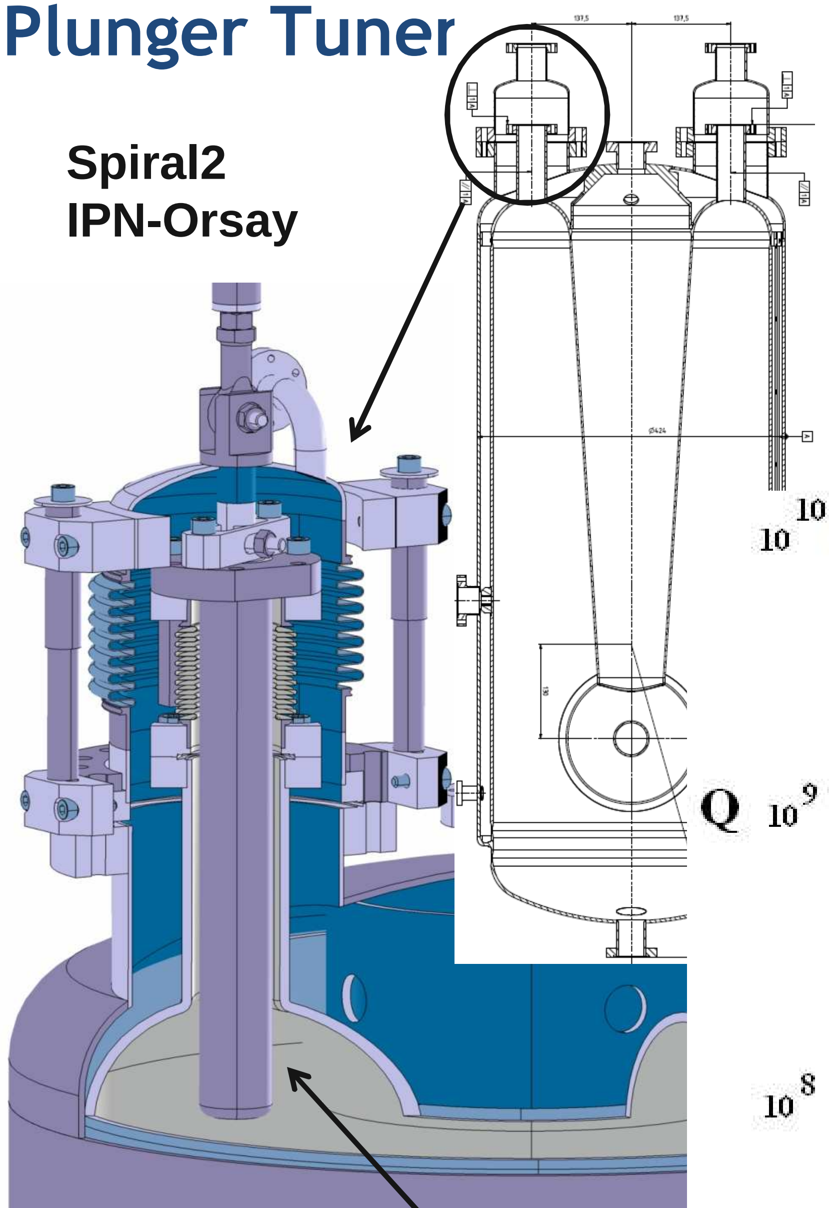
at 293 K.
110 kHz tuning range
68 kHz/mm

For a similar β = 0.31 cavity at 293 K.
150 kHz tuning range
227 kHz/mm

Facco et al, PRST-AB 9, 110101 (2006)

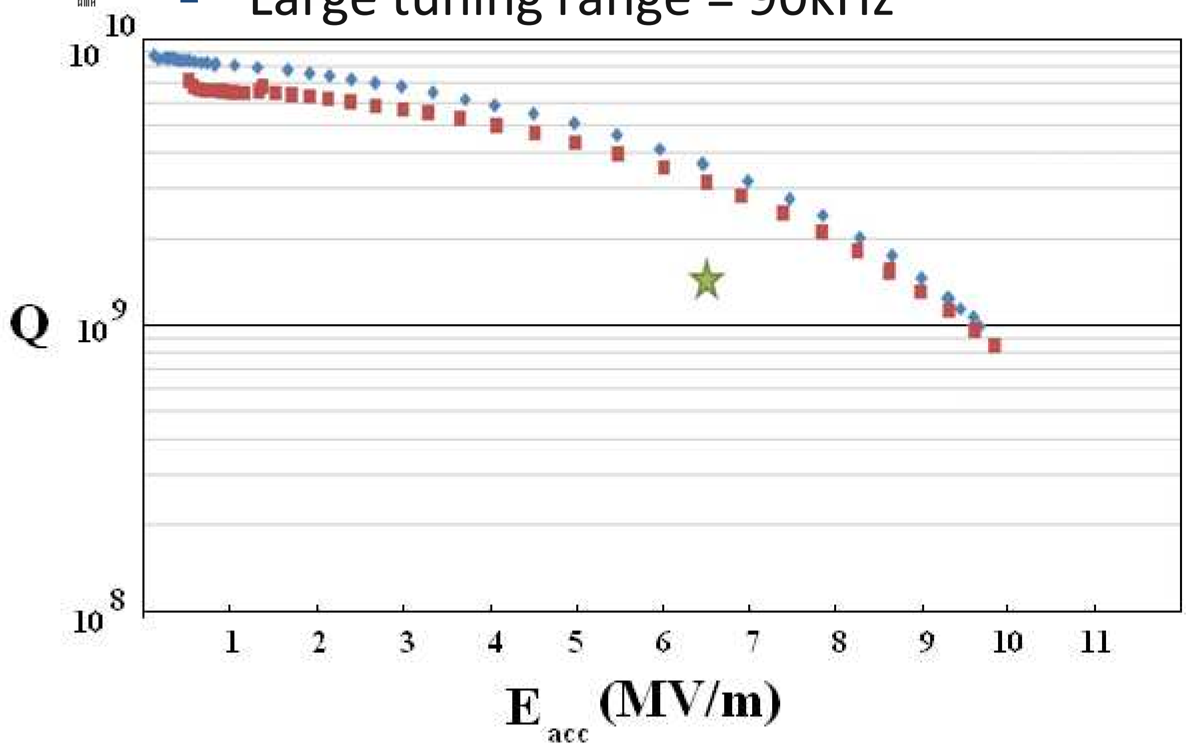
Plunger Tuner

Spiral2
IPN-Orsay



High RRR Niobium Plunger

- Can in principle be used on nearly any cavity with a properly placed port.
- Moveable niobium rod
- Cooled with helium bath
- Large tuning range = 90kHz



Olry, SRF09, THOBAU04

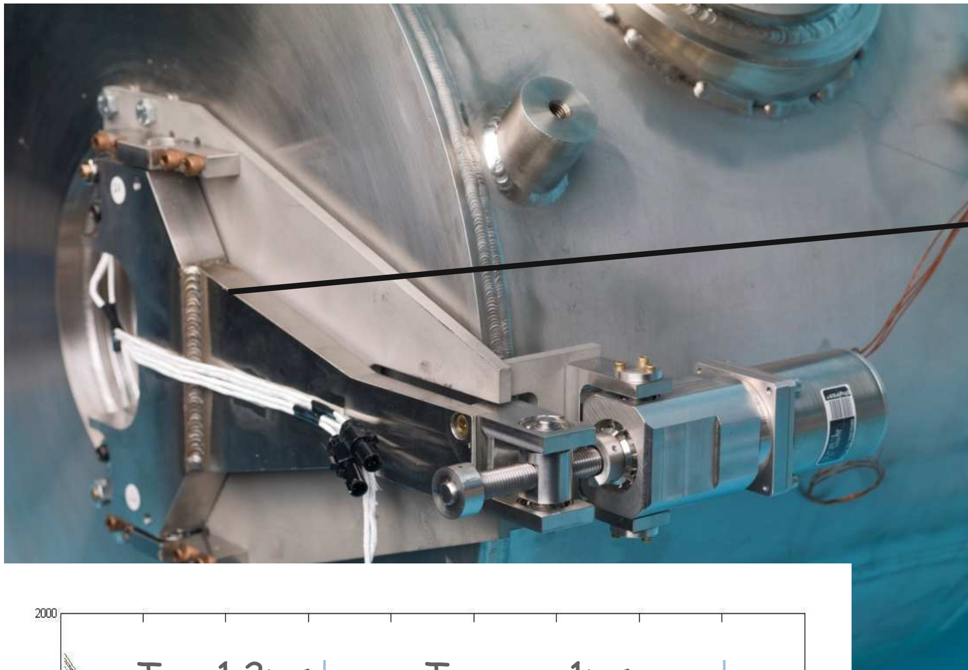
Example of Low-β Tuner For Pulsed Operation

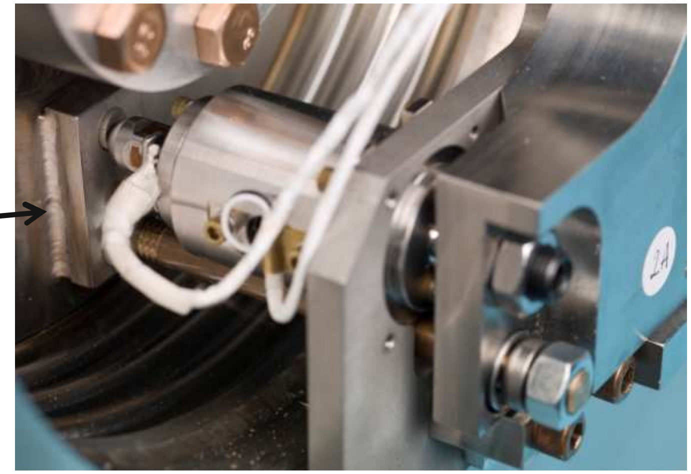
FNAL's Single Spoke Cavity Tuning

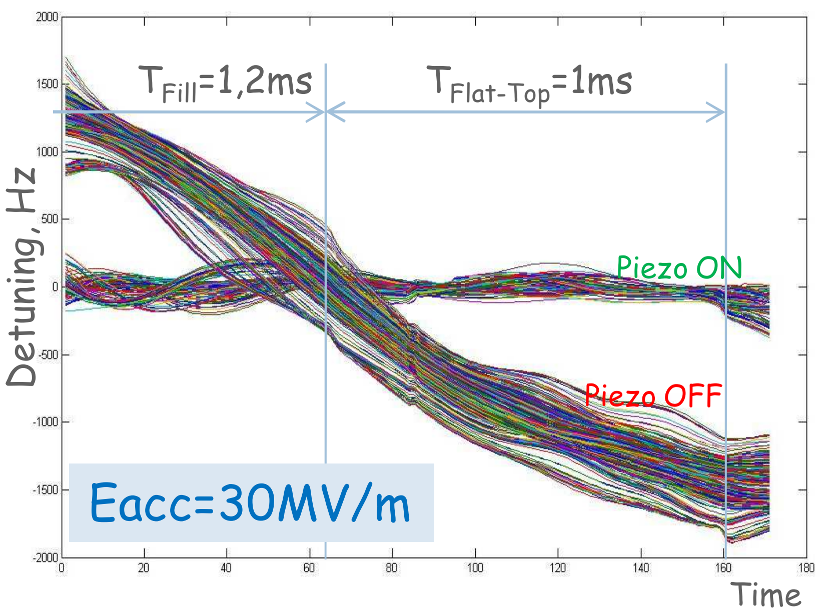
325 MHz Single-Spoke

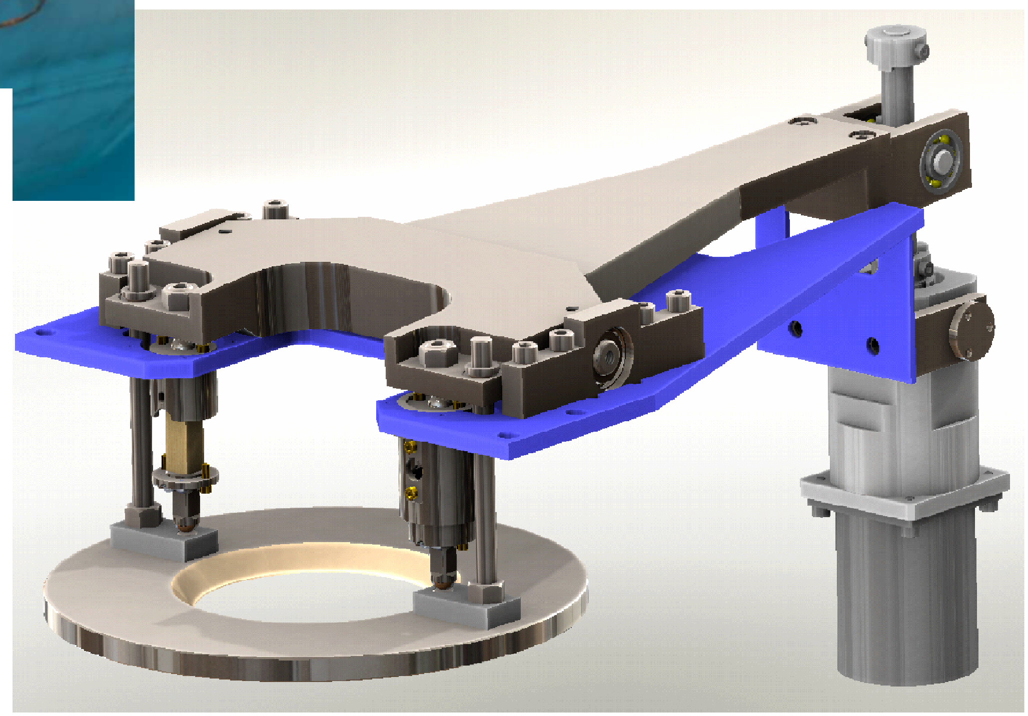
- FNAL developed spoke cavities for a pulsed high-intensity proton accelerator
- The cavities are reinforced, increasing their rigidity and minimizing Lorentz detuning, I. Gonin (FNAL)
- G. Apollinari, SRF'05, TUP34

FNAL's Single Spoke Cavity Tuner









Schappert, Pischalnikov, FRIOA01

Summary

- When designing your cavity it pays to couple your electromagnetic with your mechanical simulations

  Majority of frequency detuning effects can be minimized or even eliminated by design (neglect can lead to an unusable system)

- Tuner designs should be tailored to applications; many designs work but vary in cost, complexity and flexibility

Thank You

- Scott Gerbick, Mark Kedzie, Mike Kelly, Peter Ostroumov, Sergey Sharamentov Ken Shepard, and Gary Zinkann (ANL)
- Jean Delayen (ODU)
- Alberto Facco (MSU/INFN-LNL)
- Robert Laxdal (TRIUMF)
- Yuriy Pischalnikov and I. Gonin (FNAL)
- John Rathke and Tom Schultheiss (AES)