CEBAF Tuners: 1980 - 2018

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MRCW18 – October 25th – 26th, 2018

Introduction

- A number of different cryomodules are (have been) in operation at CEBAF
  - C20/C50
  - Renascence (C100 Prototype)
  - C100
- The CMs have unique tuner styles
- Microphonics issues found during testing and operation have been solved by both design and retroactive modification

CEBAF Cryomodules

C20/C50

- Original CEBAF cryomodules (C20)
- Reworked to create C50 cryomodules

Renascence

- CEBAF Upgrade prototype

C100

- Upgrade CEBAF cryomodules

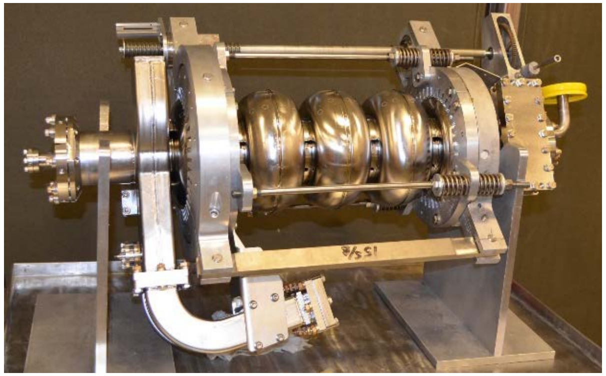
Overview

	CEBAF (C20/C50)	CEBAF Upgrade (Renascence)	CEBAF Upgrade (C100)
Cavity	5-Cell	7-Cell	7-Cell
Frequency (MHz)	1497	1497	1497
Gradient per Cavity (MV/m)	5	18	19.2
Operating Mode	CW	CW	CW
Bandwidth (Hz) $Q_{external}$	220 6.6×10^6	75 2.0×10^7	75 2.0×10^7
Lorentz Detuning (Hz)	75	324	312
Microphonics (Hz, 6σ)	-	±10	±10
Stiffness (lb/in)	26,000	20,000-40,000	37,000
Sensitivity (Hz/μm)	373 (calc)	~300 (calc)	267 (calc)

J.Delayen, *Tuning Systems,* USPAS 2008

C20/C50 Tuner specs

	C20/C50 Tuner
Coarse Range (kHz)	+/- 200
Coarse Resolution (Hz)	NA
Backlash (Hz)	> 100
Fine Range	None
Fine Resolution (Hz)	N/A
Tuning Method	Tension/Comp
Tuner Environment	Immersed (He)
Drive Environment	Vacuum/Warm
Motor Stoke (in)	0.25



P. Kneisel, J. Mamosser, *Mechanical Tuner for 5-Cell Cavity,* JLab Tech Note TN91-043

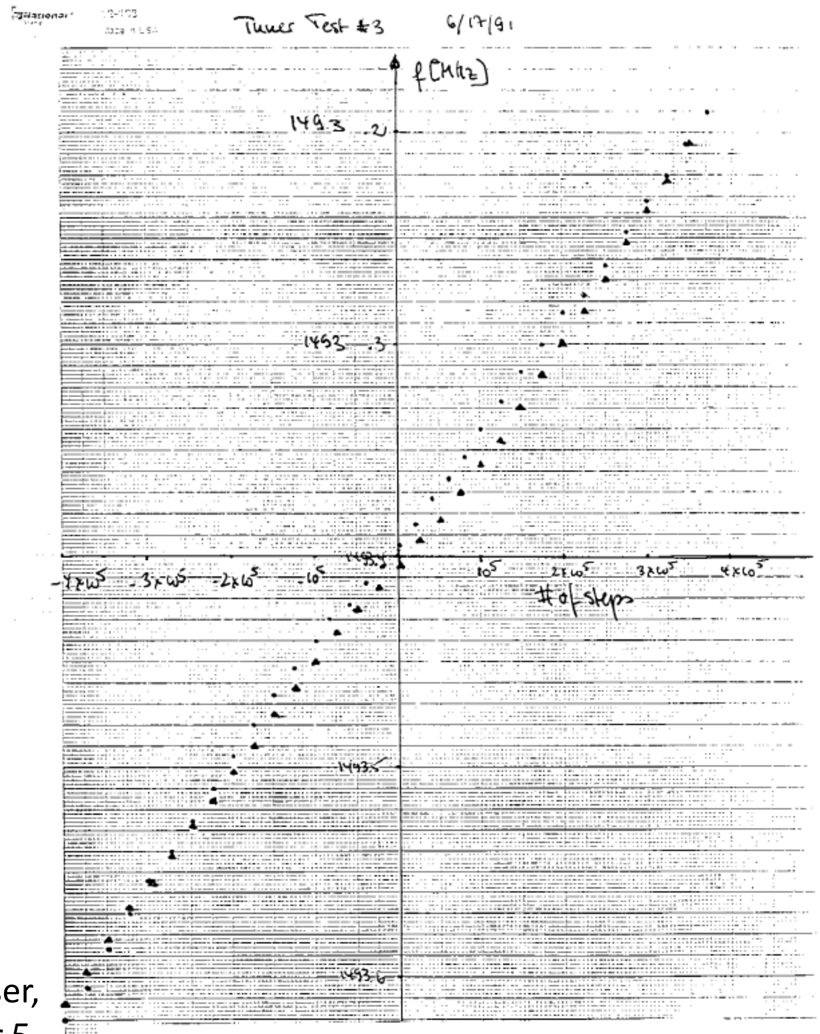
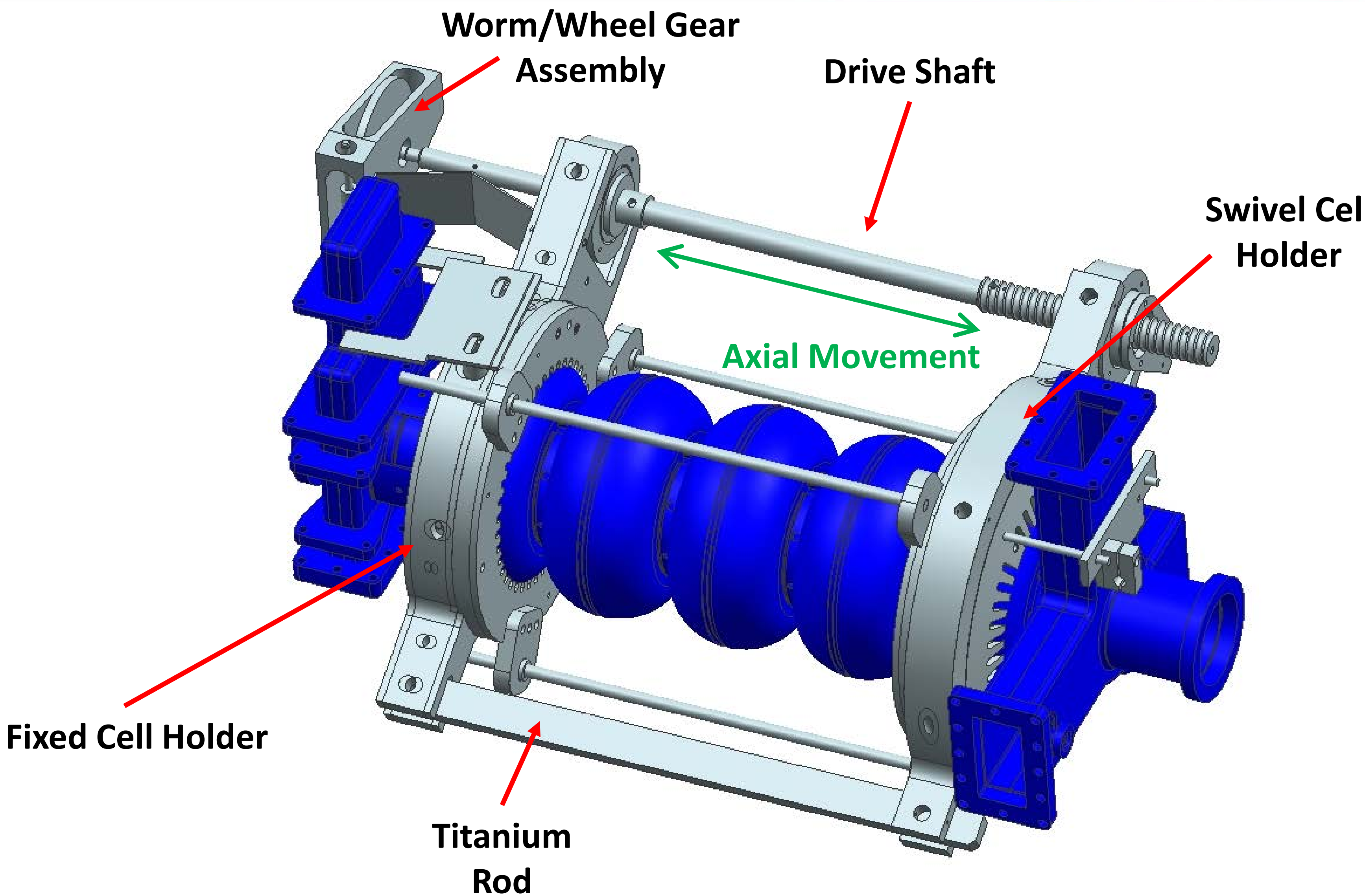


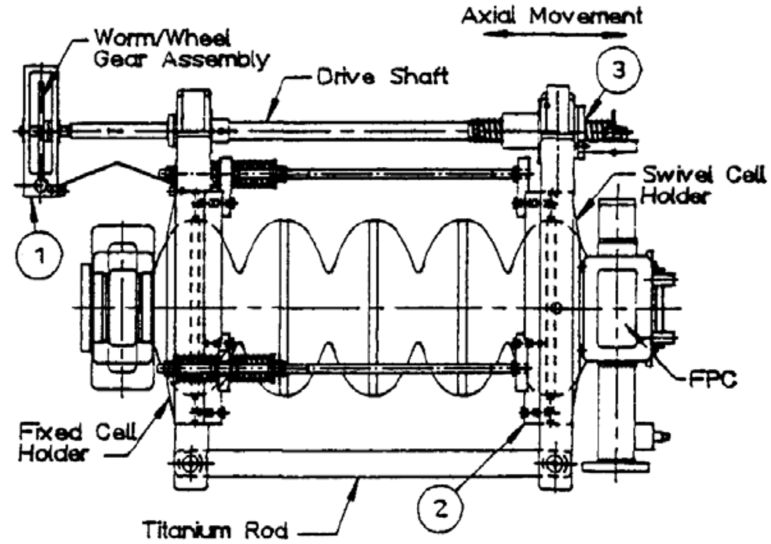
Fig. 2 : Frequency shift vs. axial displacement

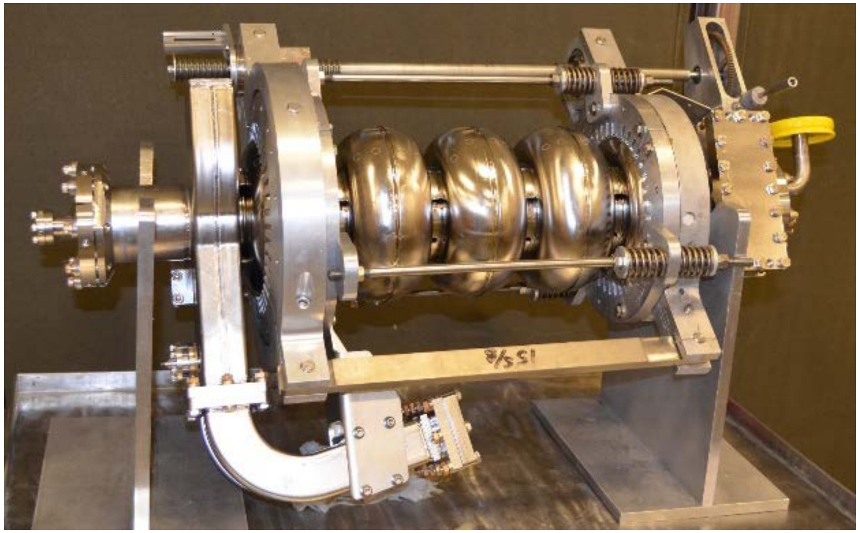
C20/C50 Tuner



C20/C50 Tuner

- The tuner is attached to the first cell with a fixed cell holder, and to the fifth with a swivel cell holder.
- 4 cells are tuned, with the 5th being fixed
- A rigid titanium rod connects the two holders at one end and a drive shaft assembly connects the two at the other end.
- Tuning is accomplished by translating rotational motion of the worm/wheel gear assembly into axial movement of the swivel cell holder

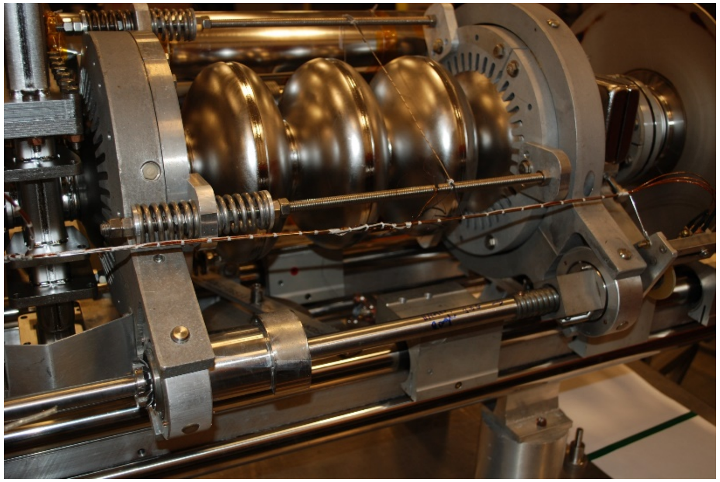




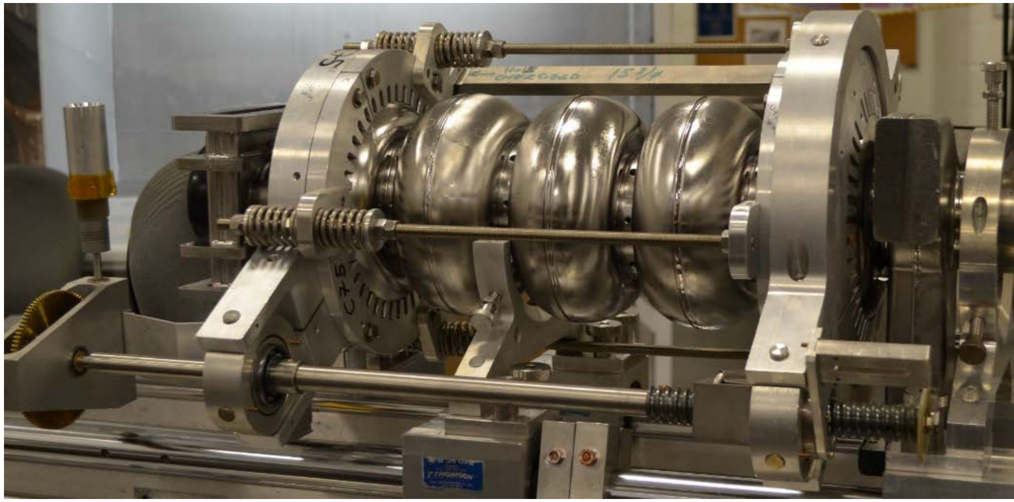
J. Marshall, J. Preble, W. Schneider, *Superconducting Cavity Tuner Performance at CEBAF,* PAC 1993

C20/C50 Tuner Performance

- Feedback control system measures the phase difference between the forward and transmitted power, calculates the tuning angle, and drives the tuner stepper motor
- 20 degrees of phase shift corresponds to 41 Hz of frequency shift
- Changes in angle results from fluctuations in helium bath pressure, where +/- 1 torr results in shift of 100 Hz
- At the design gradient of 5 MV/m, the frequency shifts ~75 Hz due to radiation pressure



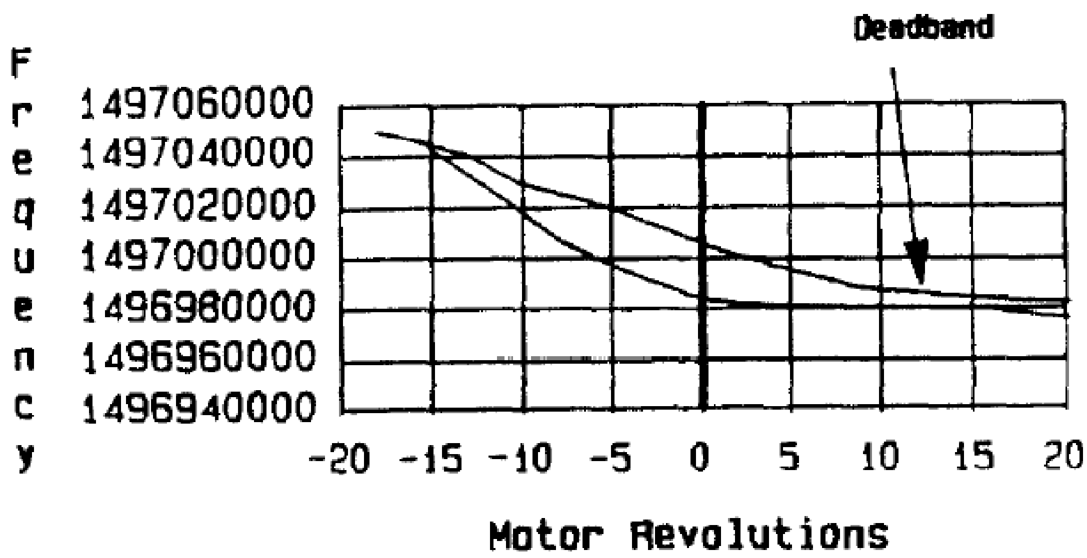
Tuner on original 5-Cell cavity (top) and an improved low loss 5-Cell cavity (bottom) for new C75 cryomodules



J. Marshall, J. Preble, W. Schneider, *Superconducting Cavity Tuner Performance at CEBAF,* PAC 1993

C20/C50 Tuner Issues

- Early production tuners had several functional issues (see below):
  a) Backlash caused by motor-to-tuner gear slop
  b) Cell/cell holder thermal mismatch
  c) Deadband due to lack of cavity/tuner pre-stress
- Hysteresis at resonance was +/- 10 kHz, mostly due to cell/holder gap
- Excessive motor operation could lead to repairs every 7 years against expected maintenance every 10 years



J. Marshall, J. Preble, W. Schneider, *Superconducting Cavity Tuner Performance at CEBAF,* PAC 1993

C20/C50 Tuner Remedies

- Difference in thermal coefficients between aluminum and Nb results in inherent hysteresis
- Holders were manufactured as half-cells matching contours of the cavities
- Final assembly included the addition of shims (~0.010 thick)
- Deadband was shifted to 30 KHz under resonance
- Plots show +/- 50kHz and +/- 5kHz hysteresis loops
- Cell holder shapes have been modified for use in new C75 cryomodules

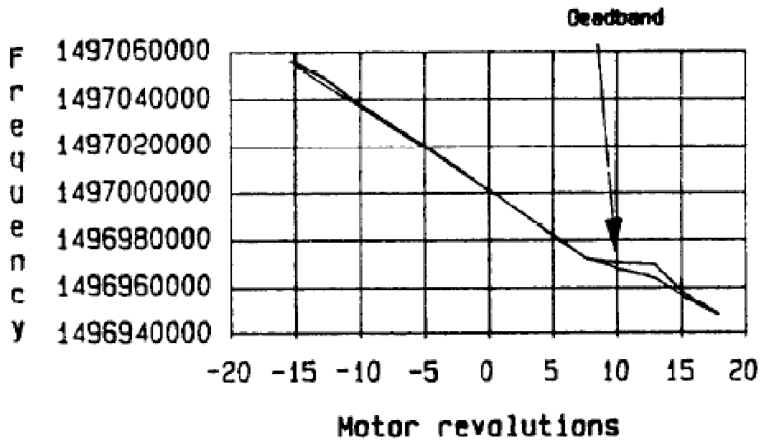
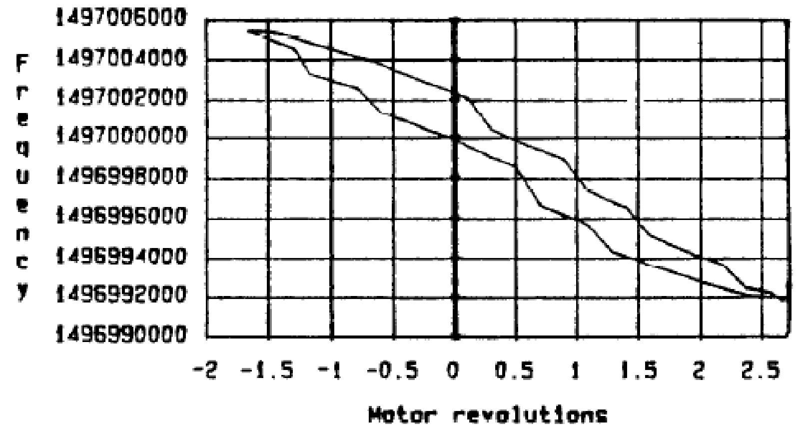
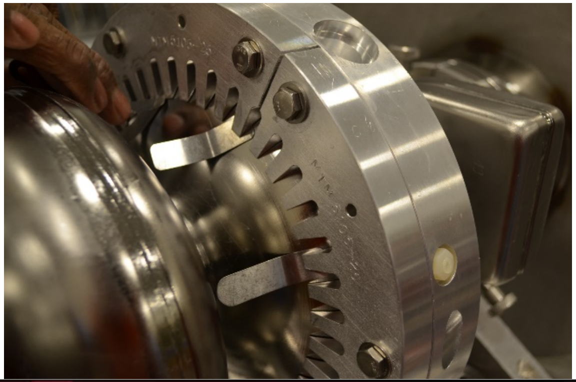


Figure 3. ±50 kHz hysteresis loop of a cavity-tuner assembly tested in the fall of 1992.

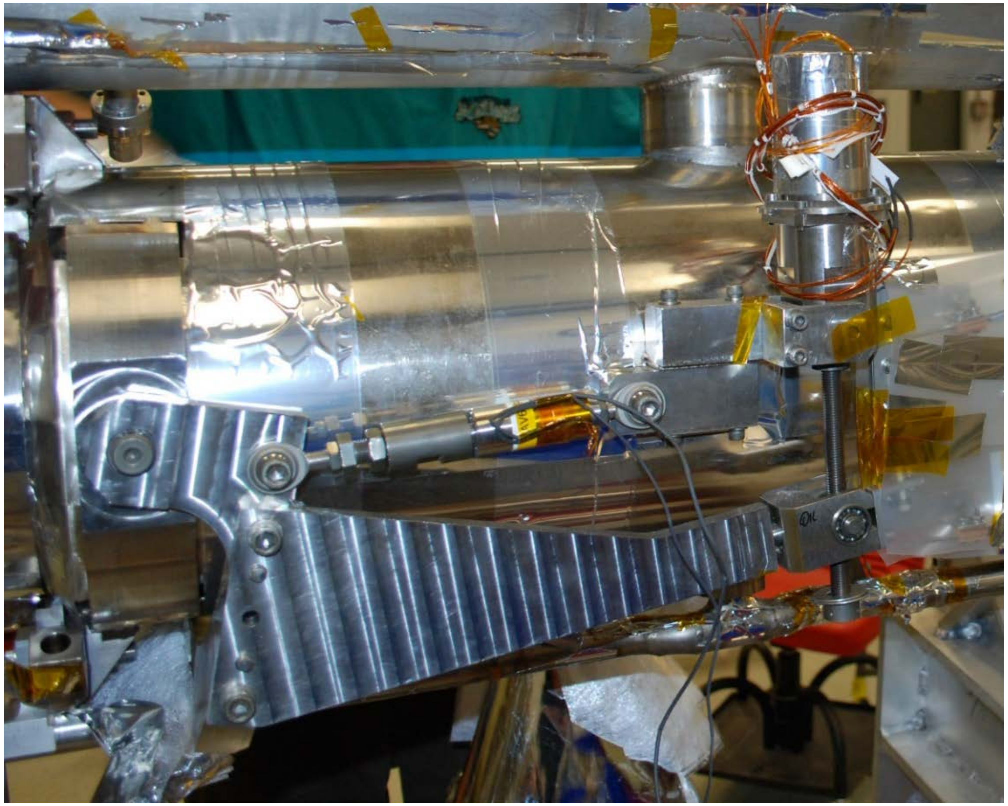




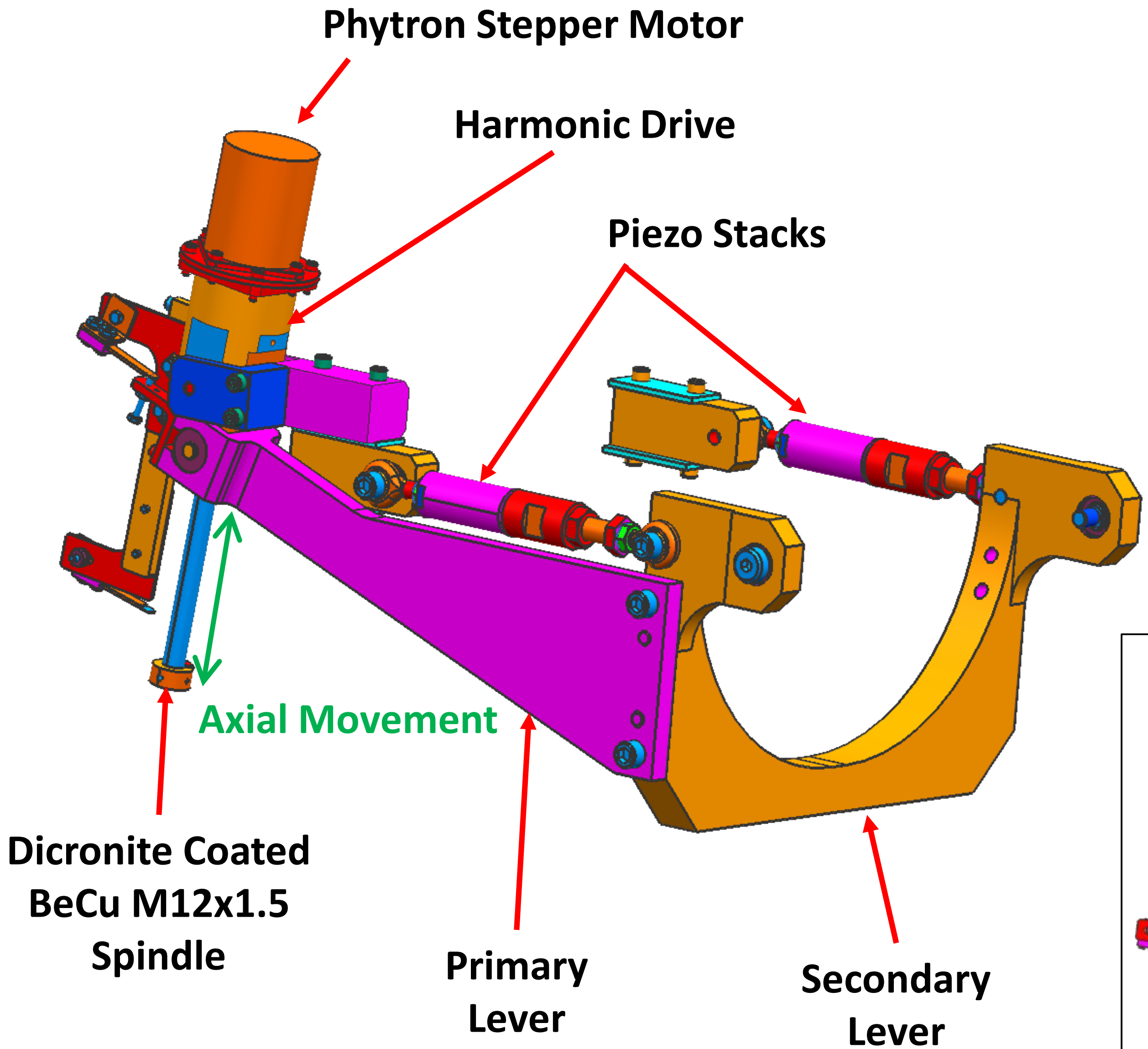
J. Marshall, J. Preble, W. Schneider, *Superconducting Cavity Tuner Performance at CEBAF,* PAC 1993

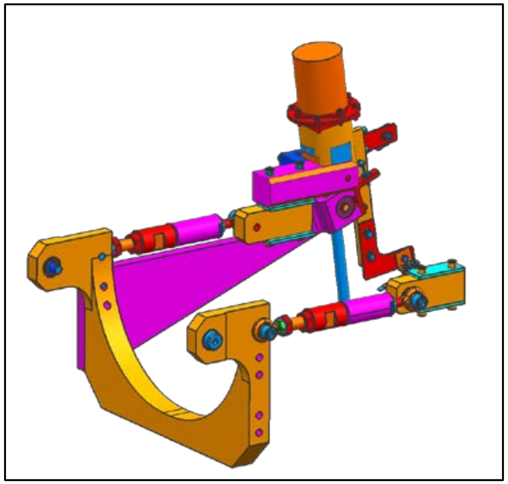
Renascence Tuner Specs

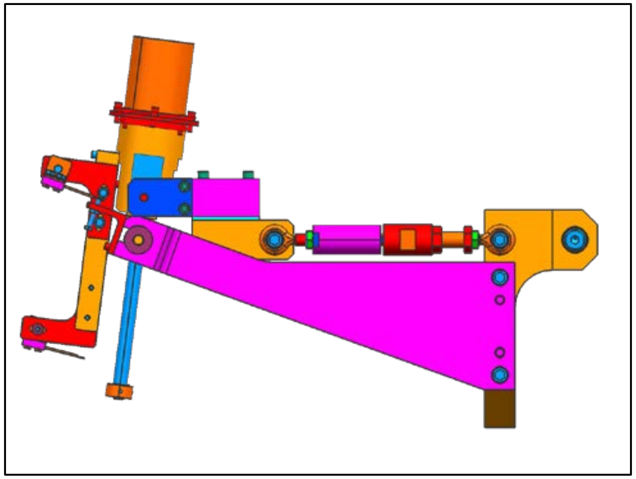
	Renascence Tuner
Coarse Range (kHz)	> 400
Coarse Resolution (Hz)	< 100
Backlash (Hz)	< 25
Fine Range (kHz)	1.0
Fine Resolution (Hz)	< 1
Tuning Method	Tension
Tuner Environment	Vacuum
Drive Environment	Vacuum/Cold



Renascence Tuner

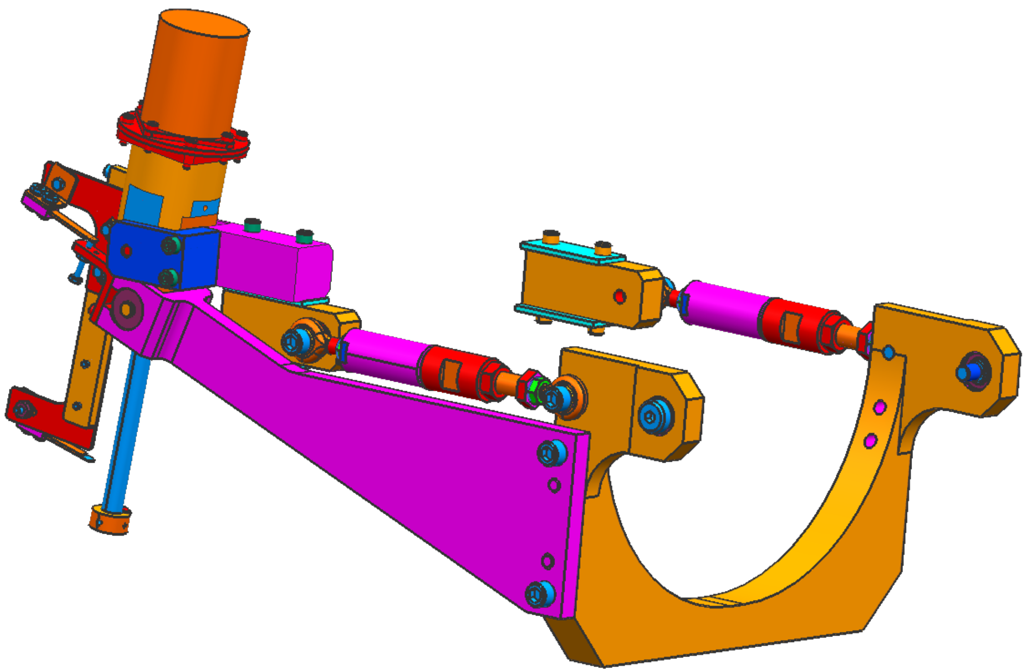






Renascence Tuner Features

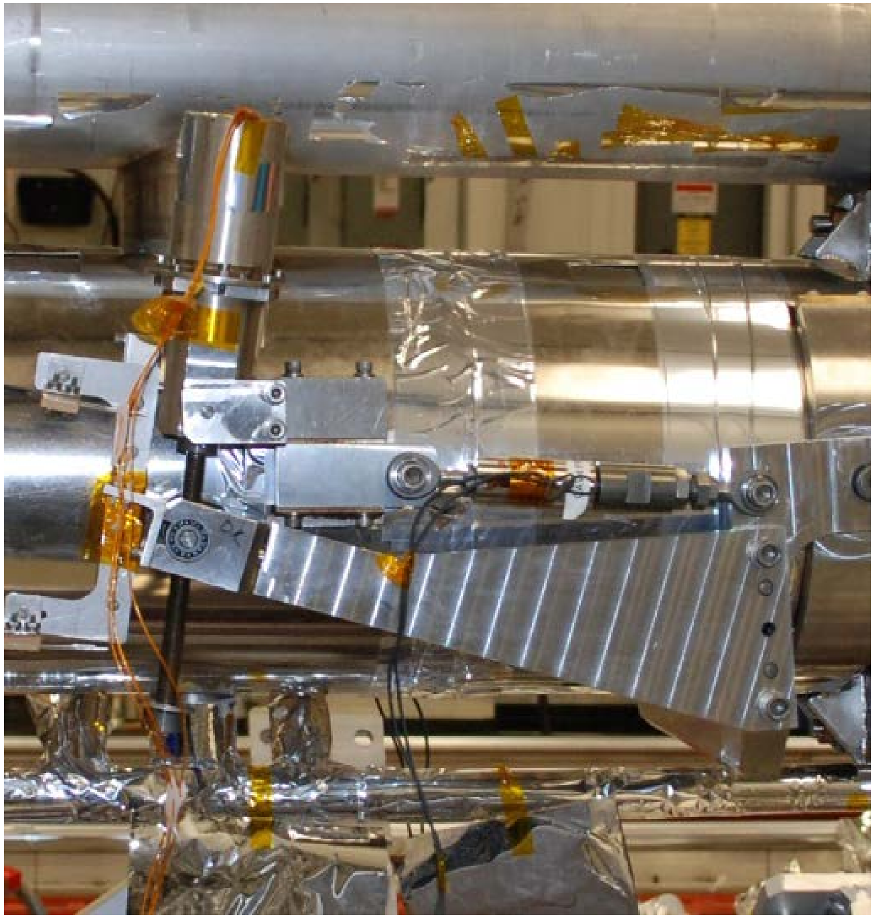
- New HOM design for upgrade cavities left no beamline space for cavity tuner
- Renascence tuner is designed to apply a large force over a relatively short distance; it has a mechanical advantage of 30:1
- Coarse tuning is via a Phytron stepper motor (200 steps/rev) attached to a Harmonic Drive (Ratio 100:1)
- Fine tuning is via a 40mm Piezo stack
- Components are in insulating vacuum and operate cold
- Vacuum vessel included flange ports to allow for motor and piezo replacement



E.Daly, G.K. Davis, W.R. Hicks, *Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities,* PAC 2005

Renascence Tuner Operation

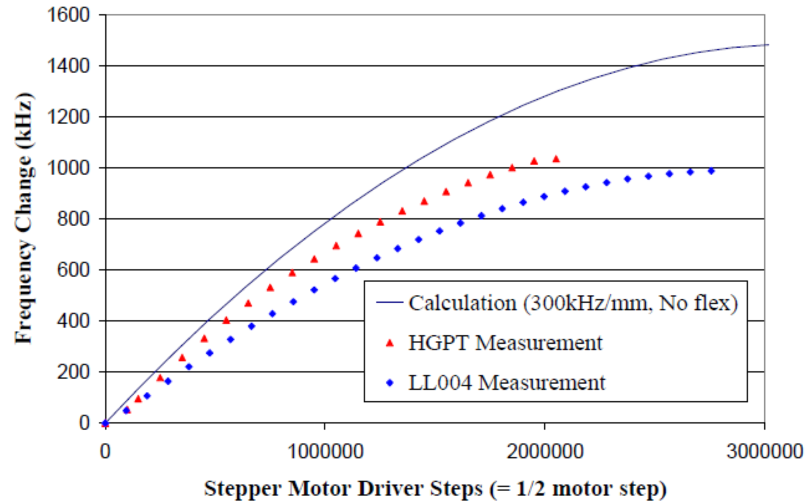
- Tuner is installed on individual cavity helium vessels
- Cavities tuned in tension by stepper motor and harmonic drive (ratio 100:1)
- Motor pushes one end of the primary lever downwards
- Primary lever motion causes secondary lever to rotate about pins and stretch cavity in tension
- Secondary lever ensures even load distribution on cavity
- Piezo actuator stacks are compressively loaded as motor is actuated
- Piezos can compress or expand to provide fine tuning

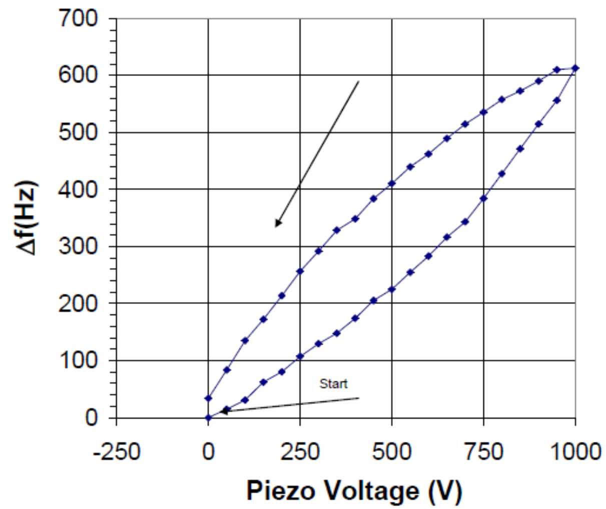


E.Daly, G.K. Davis, W.R. Hicks, *Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities,* PAC 2005

Renascence Tuner Performance

- Tuner was tested on Low Loss (LL004) and High Gradient (HGPT) cavities
- Tuner range:
  - o 1000 kHz (spec 400kHz)
- Tuning sensitivity (top graph):
  - o 0.73 Hz per step for HGPT
  - o 0.57 Hz/step for LL004
- Decrease in frequency change is due to tuning mechanism following cosine function
- Piezo response:
  - o 0.35 – 0.60 Hz/volt (bottom graph)
- Possible reliability issues with cold motor/piezos caused this tuner design to be scrapped for future C100 cryomodules

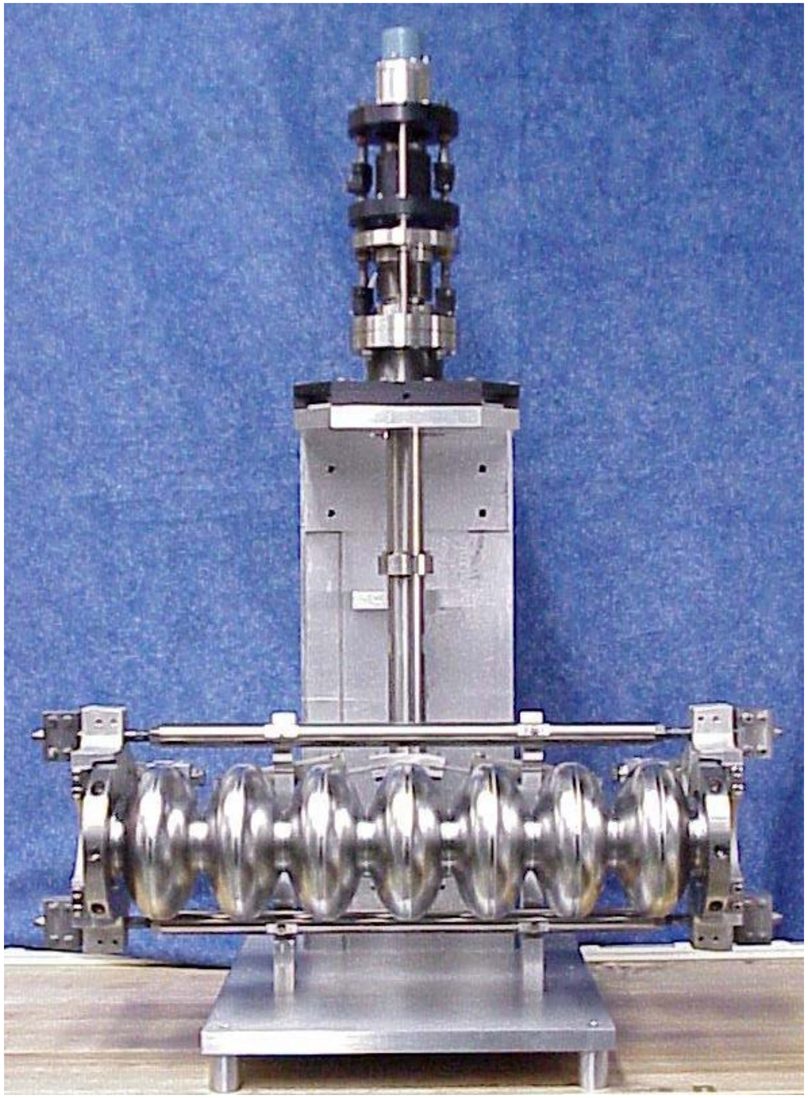




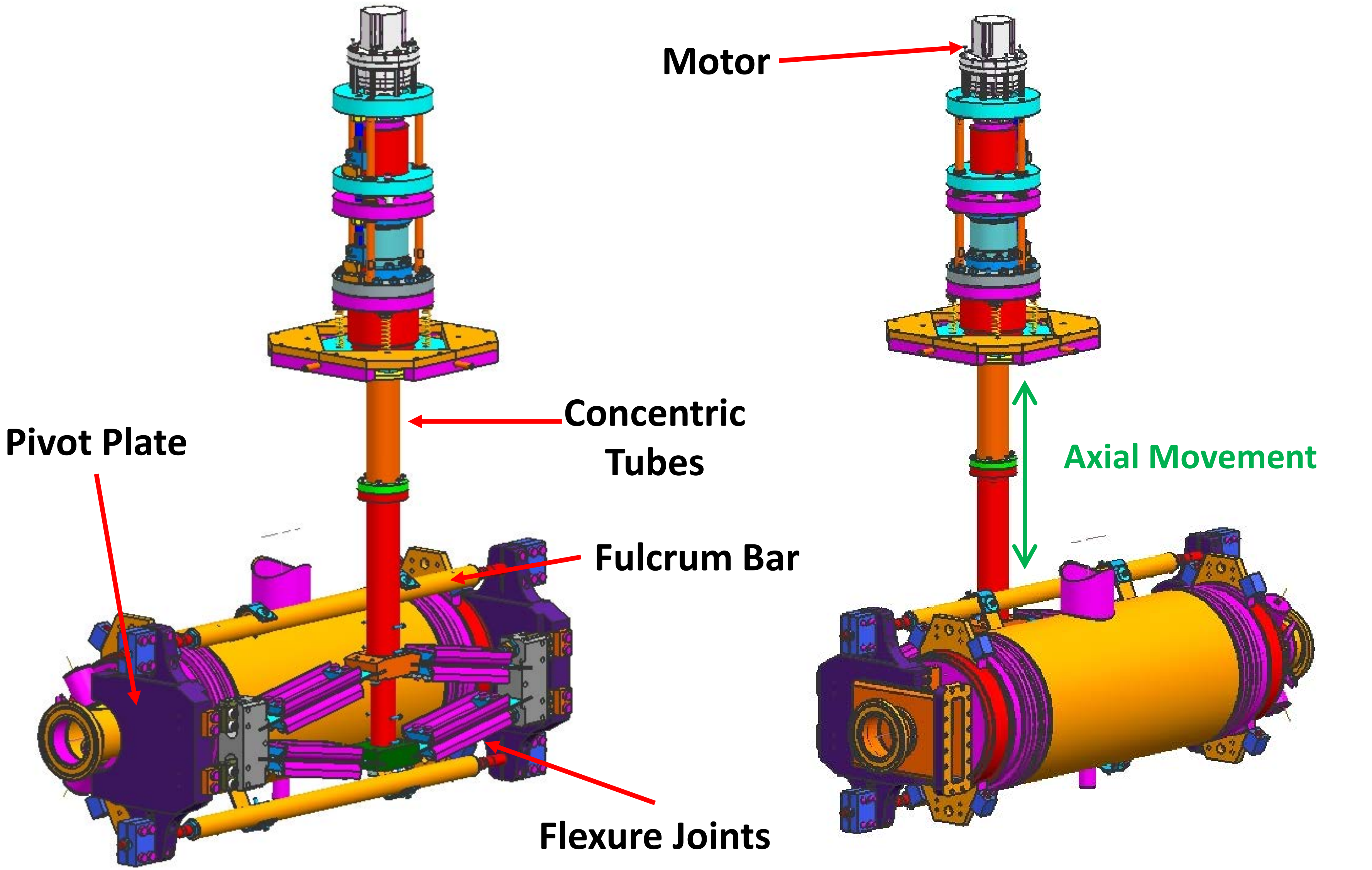
E.Daly, G.K. Davis, W.R. Hicks, *Testing of the New Tuner Design for the CEBAF 12 GeV Upgrade SRF Cavities,* PAC 2005

C100 Tuner Specs

	C100 Tuner
Coarse Range (kHz)	+/- 200
Coarse Resolution (Hz)	< 2
Backlash (Hz)	< 3
Fine Range	550 Hz (150V)
Fine Resolution (Hz)	<1
Tuning Method	Tension
Tuner Environment	Vacuum
Drive Environment	Vacuum/Warm



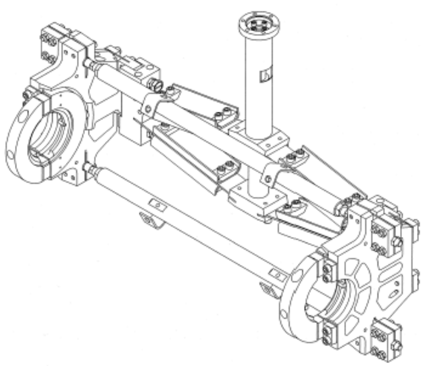
C100 Tuner

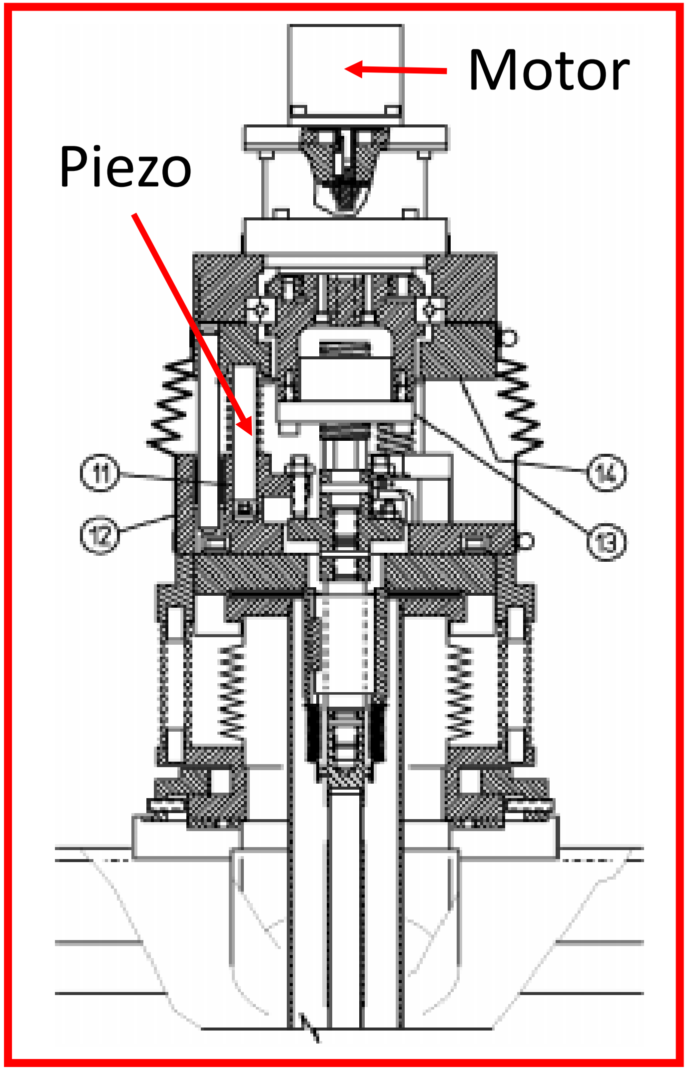


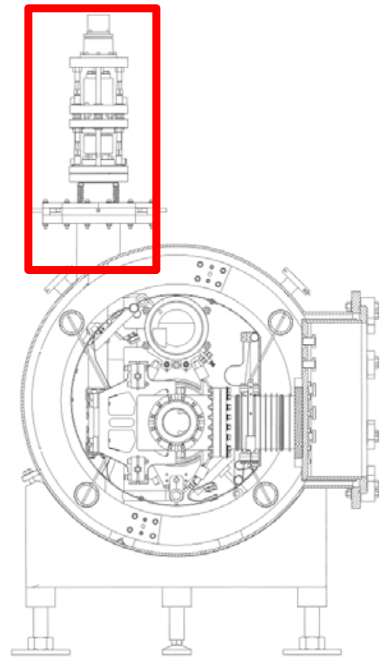
Motor
Concentric
Tubes
Pivot Plate
Axial Movement
Fulcrum Bar
Flexure Joints

C100 Tuner

- Stepper Motor
  - 200 step/rev
- Harmonic Drive
  - Gear Reduction = 80:1
- Low voltage piezo
  - 50 μm stroke (150 V)
- Ball screw
  - Lead = 4 mm
  - Pitch = 25.75 mm
- Bellows/slides
  - axial thermal contraction



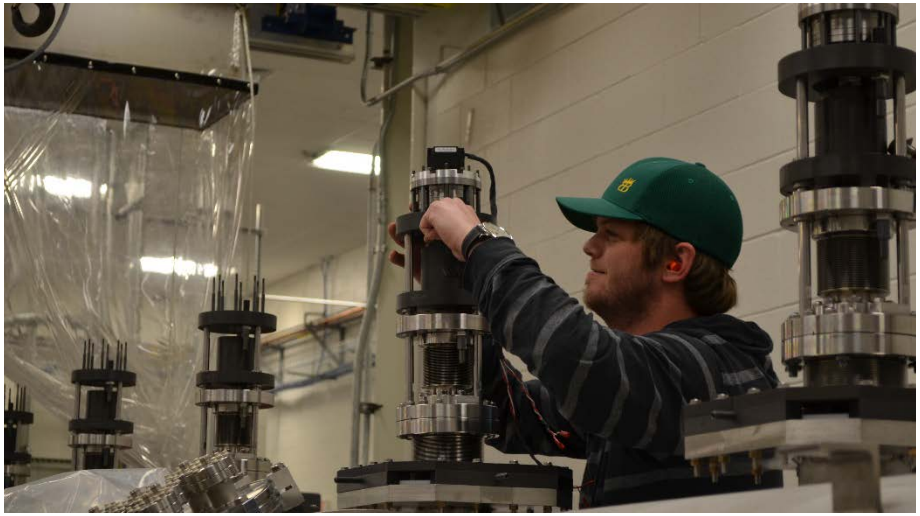




J.R. Delayen, L. Doolittle, E. Feldl, V. Nguyen, W. Sachleben, *Frequency Tuning of the CEBAF Upgrade Cavities,* PAC 1999, New York

C100 Tuner Features

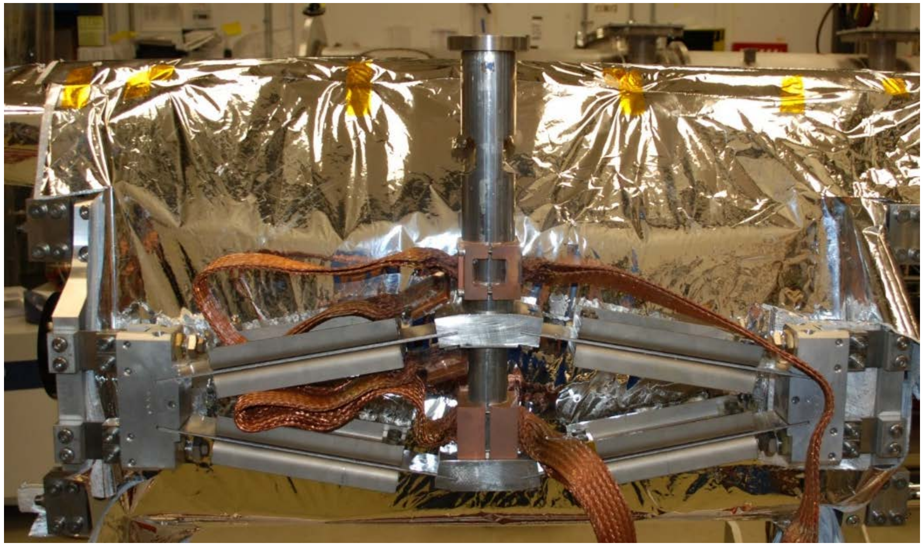
- Scissor jack mechanism
  - Ti-6Al-4V Cold flexures & fulcrum bars
  - Cavity tuned in tension only
- Warm transmission
  - Stepper motor, harmonic drive, piezo and ball screw mounted on top of CM
  - Openings required in shielding and vacuum tank
  - Originally due to a lack of confidence in the reliability of cold motor systems

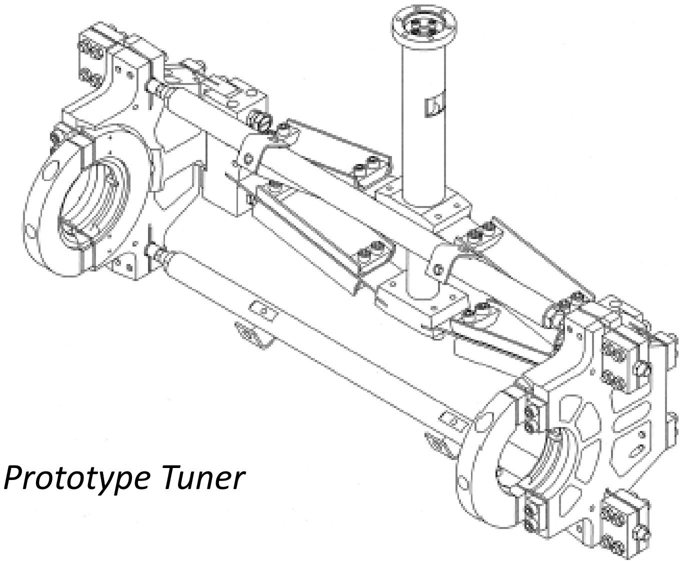


E.F. Daly, *Overview of Existing Tuner Systems,* ERL Workshop 18-23 MAR 2005

C100 Tuner Operation

- Motion transferred through concentric tubes moving axially, relative to one another
- Tubes engage scissor-jack assembly
  - Attached to hubs on cavity
  - Pivots against fulcrum bars
  - Downward motion of ball-screw causes cavity stretch
- Piezo stacks originally installed as back-up for coarse tuner not being able to fine tune
- No bellows between cavities
  - Need to accommodate thermal contraction of cavity string
  - Pre-load and offset each tuner while warm

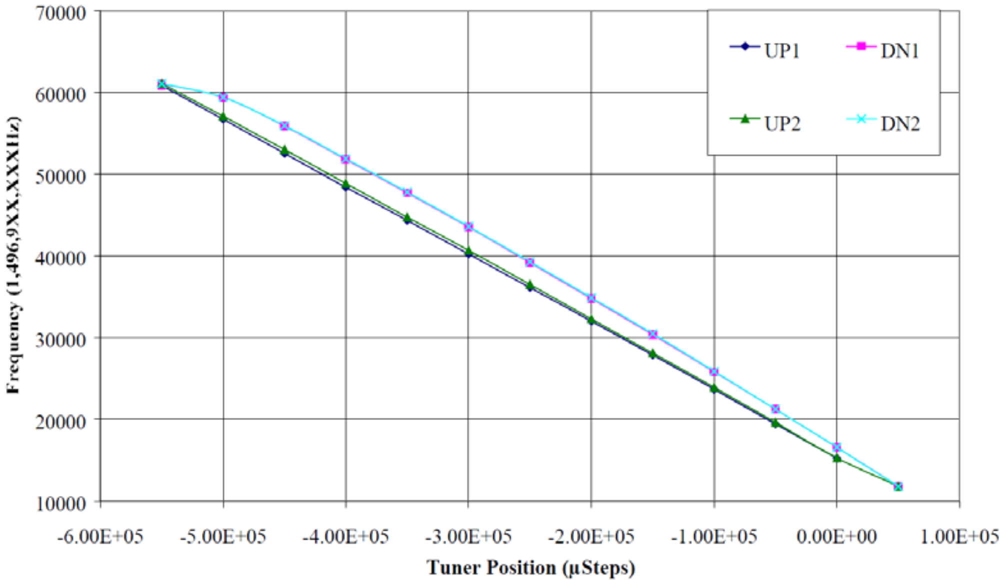




G. Davis, J. Delayen, M.Drury, E. Feldl, *Development and Testing of a Prototype Tuner for the CEBAF Upgrade Cryomodule*

C100 Tuner Performance

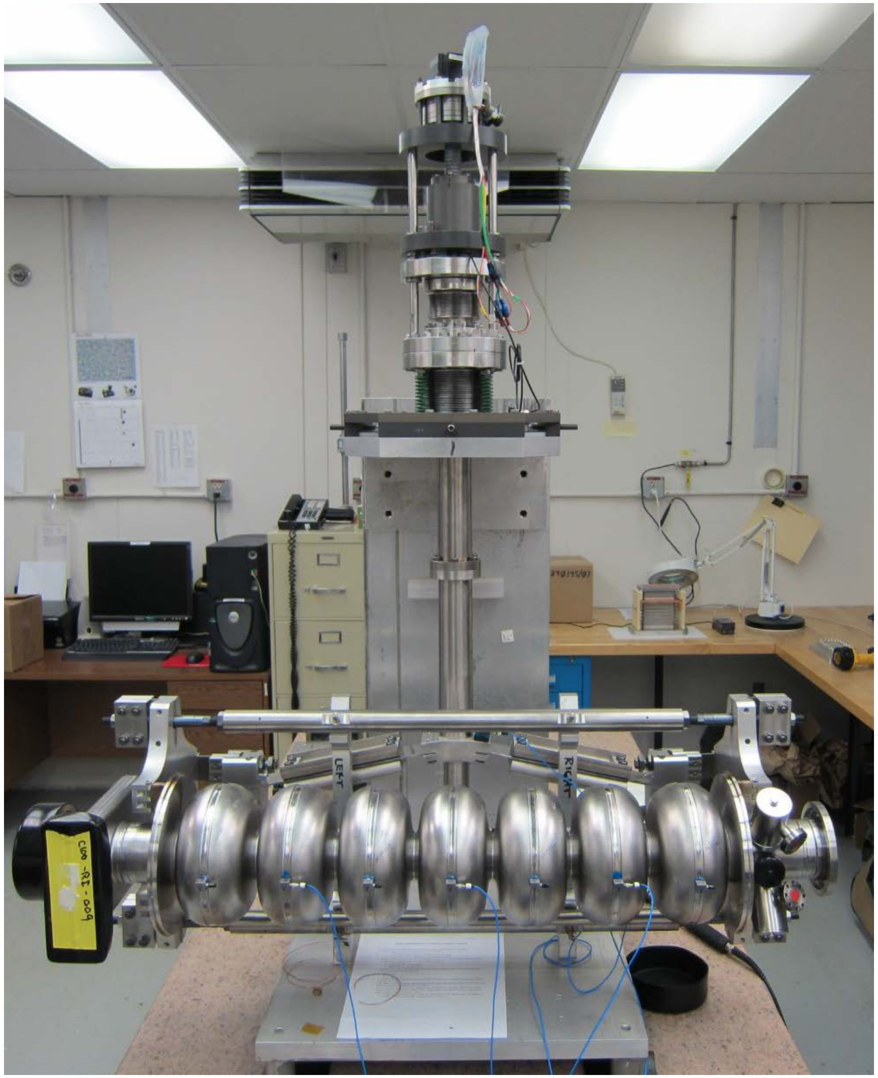
- Coarse Tuner:
  - Range: 343 kHz
  - Resolution: < 2 Hz
  - Hysteresis (at 700 Hz): 153 Hz
  - Repeatability (at 700 Hz): 37 Hz
- Fine Tuner (Piezo):
  - Range: 2.4 kHz
  - Resolution: 1 Hz
  - Hysteresis (at 2.5 kHz): 933 Hz
  - Repeatability (at 2.5 kHz): 329 Hz
- Note: Piezo stacks are currently only installed on one C100 in the CEBAF tunnel



G. Davis, J. Delayen, M.Drury, E. Feldl, *Development and Testing of a Prototype Tuner for the CEBAF Upgrade Cryomodule*

C100 Microphonics

- Operational microphonics were found to be higher than the 10 Hz spec
- The cause was determined to be cost-saving measures that reduced the stiffness of the tuner/cavity
- Thicker Pivot Plates were proposed as the simplest solution
- New setup tested warm on test bench, and on C100-5 in the tunnel
- New design (C100-4 onwards) showed marked improvement
- Retrofits applied to C100-1 to C100-3
  - Stiffen tuner stack
  - Bracing for waveguides
  - Bricks and bags (see T.Powers talk)

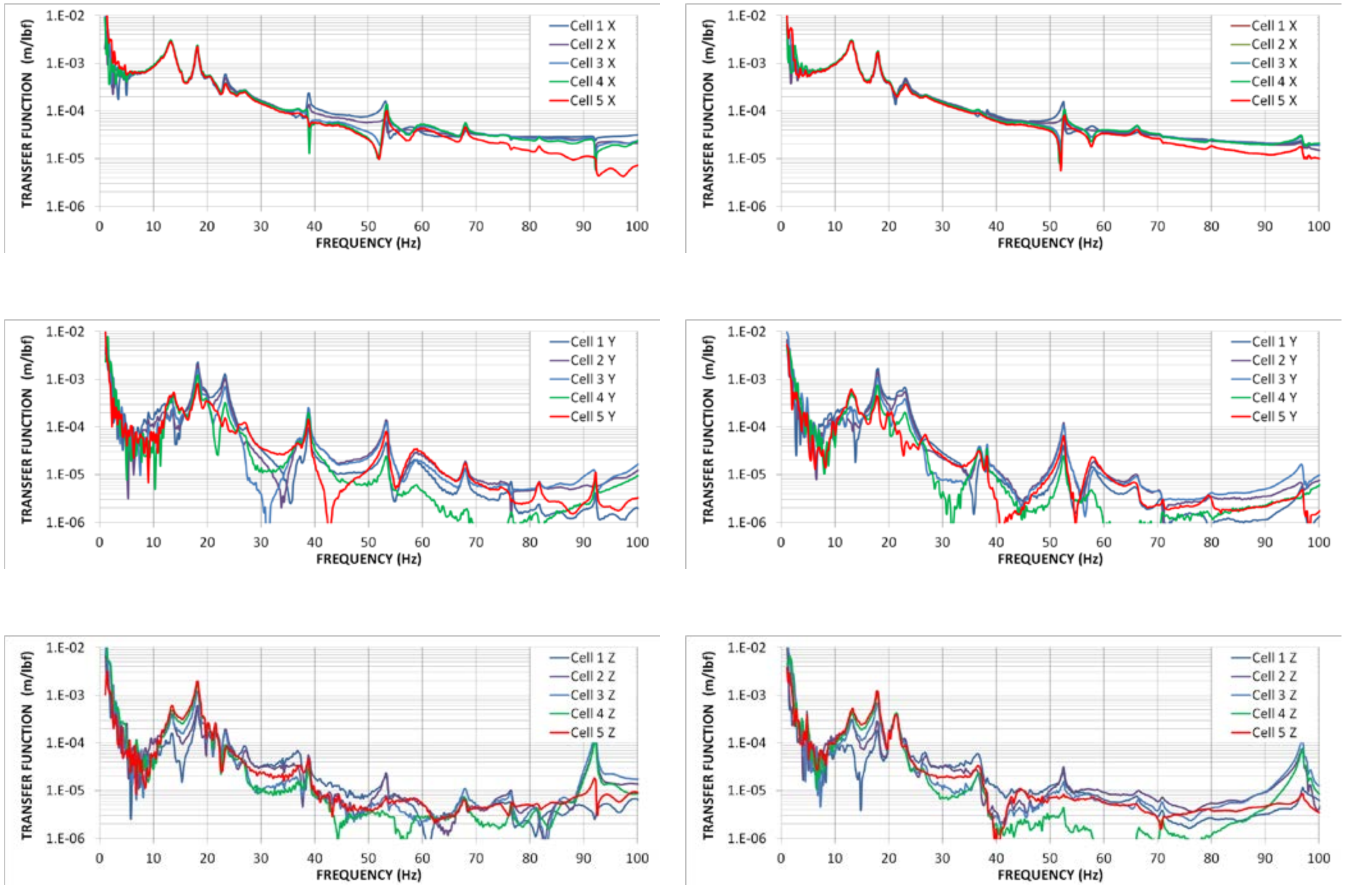


K. Davis, J. Matalevich, T. Powers, M. Wiseman, *Virbation Response Testing of the 12GeV Upgrade Cryomodule,* LINAC 2012

C100 Microphonics

Warm Transfer Function Measurements

- Improvements to the tuner stiffness did not significantly affect the axial vibrational response of the cavity
- Improvements to the tuner stiffness did reduce the lateral, bending, modes of the cavity. It also reduced cavity response to the 10 Hz rigid-body mode of the entire 8-cavity string.

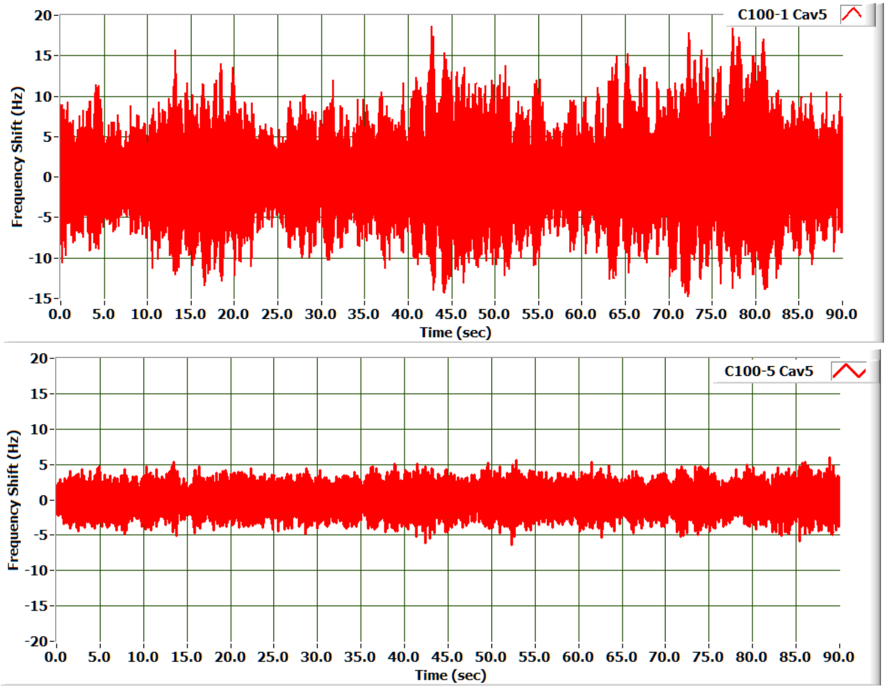


Original Tuner **Stiffened Tuner**

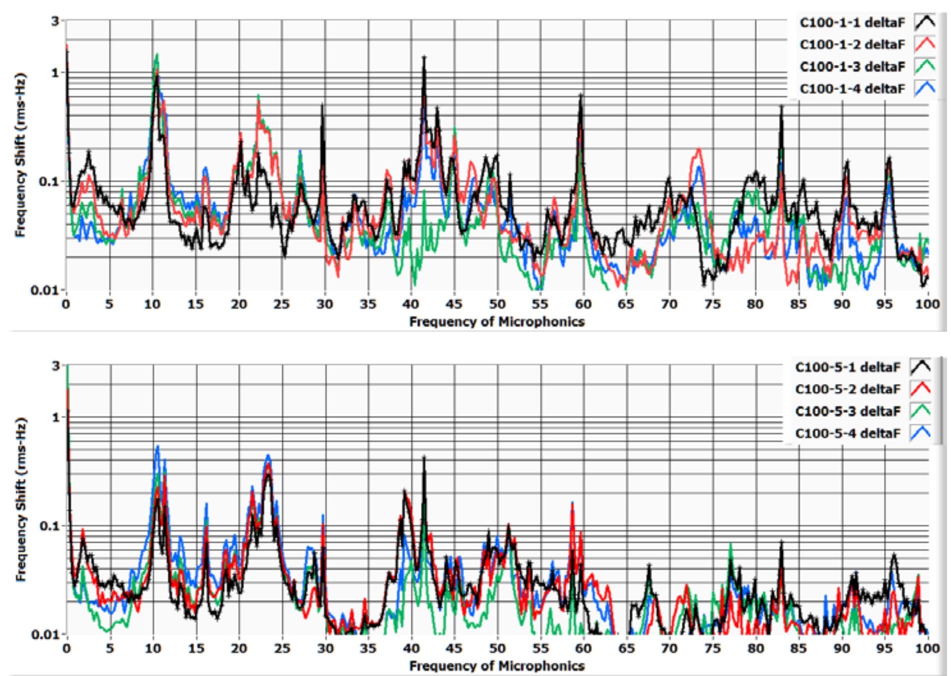
K. Davis, J. Matalevich, T. Powers, M. Wiseman, *Virbation Response Testing of the 12GeV Upgrade Cryomodule,* LINAC 2012

C100 Microphonics

Comparison of C100-1 (Original Tuner) and C100-5 (Stiffened Tuner)



Original Tuner (Top) and Stiffened Tuner (Bottom)



Original Tuner (Top) and Stiffened Tuner (Bottom)

K. Davis, J. Matalevich, T. Powers, M. Wiseman, *Virbation Response Testing of the 12GeV Upgrade Cryomodule,* LINAC 2012

C100 Microphonics

- The microphonics are substantially smaller in the cryomodule with stiffened tuners.
- The harmonics at 10 Hz and 45 Hz were substantially reduced in the cryomodule with the stiffened tuners.
- The 25 Hz component in C100-1 was not reduced substantially in C100-5. However, it was shifted up in frequency slightly as predicted by the modeling and warm tests.
- Operational testing in the CEBAF LINAC show an average of 47% improvement for ambient microphonic detuning for C100-5 (modified tuner) vs C100-1 (baseline tuner).
- Studies ongoing to use piezos to control microphonics

Cryomodule	C100-1 (baseline)	C100-5 (modified)	% Improved
Cavity 1	11.8 Hz	5.1 Hz	57%
Cavity 2	12.8 Hz	6.7 Hz	48%
Cavity 3	13.7 Hz	5.6 Hz	59%
Cavity 4	13.5 Hz	7.4 Hz	46%
Cavity 5	18.0 Hz	9.6 Hz	46%
Cavity 6	9.1 Hz	8.5 Hz	8%
Cavity 7	9.7 Hz	5.6 Hz	42%
Cavity 8	8.9 Hz	5.8 Hz	35%

Operational Microphonics in the CEBAF Tunnel, Baseline vs Modified Design (Peak Detuning)

K. Davis, J. Matalevich, T. Powers, M. Wiseman, *Virbation Response Testing of the 12GeV Upgrade Cryomodule,* LINAC 2012

Summary

- Unique tuners are in operation on several cryomodule/cavity types in the CEBAF tunnel
- C20/C50 tuners and C100 tuners are in current operation, and the Renascence-style tuner was also tested in the tunnel
- Lessons from testing and operations lead to improvements in design

Questions?