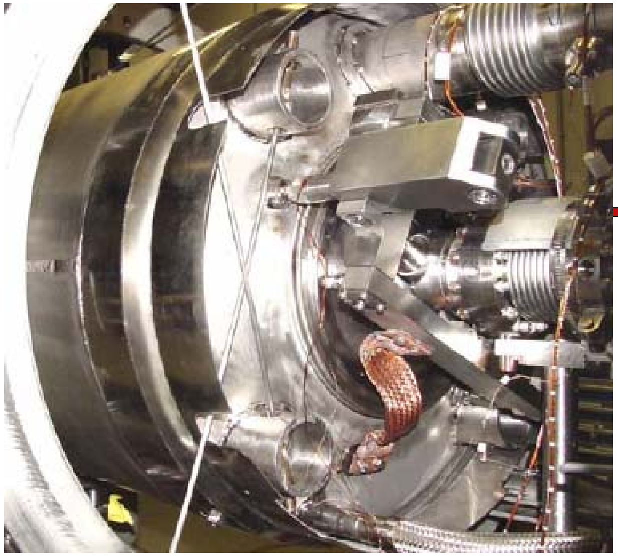
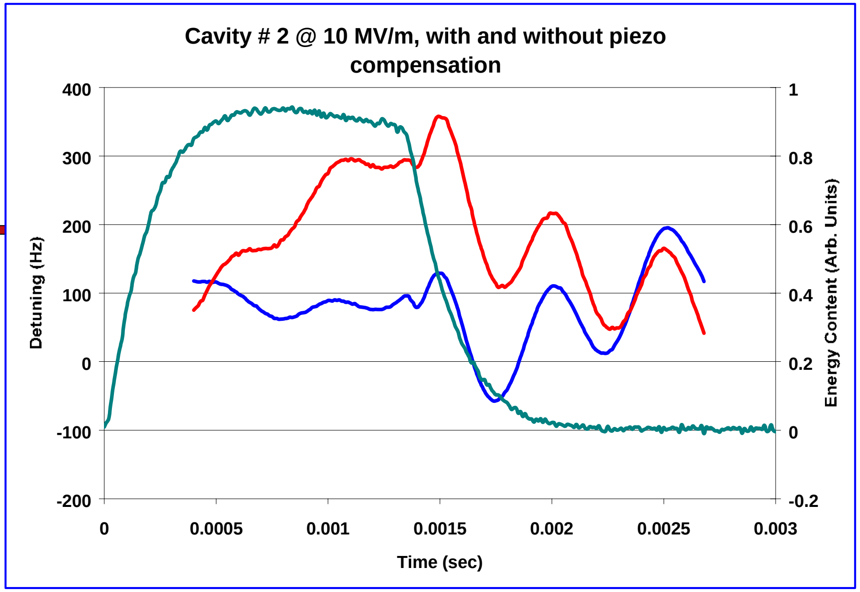
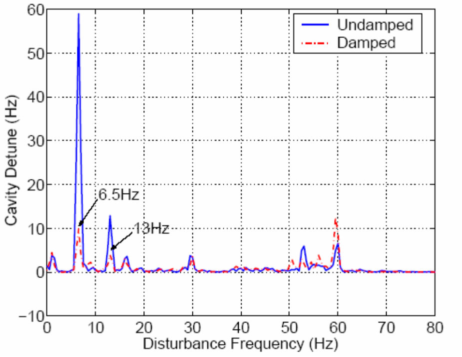
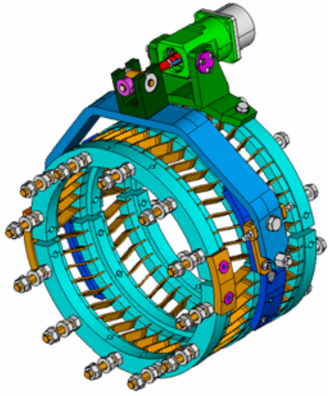




Overview of Existing Tuner Systems

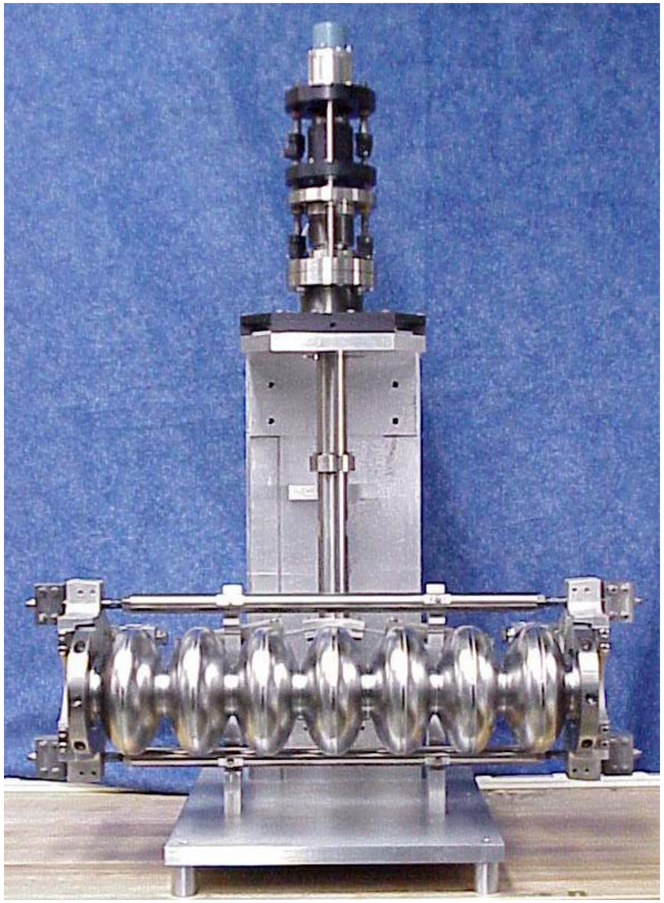


Edward Daly
Mechanical Engineering Group
Jefferson Lab



Outline

- Acknowledgements
- Introduction
- Requirements & Specifications
- Mechanical Design Descriptions
- Test Results / Operations
- Design Features and Impacts
- Summary



SL21/FEL03 Tuner Benchtop Test Rig

Acknowledgements

- Original CEBAF Tuner (JLAB nee CEBAF)
  - JLAB: J. Marshall, J. Preble, J. Fischer, W. Schneider, M. Wiseman, M. Drury, C. Mounts
- Upgrade Tuners for SL21, FEL03 and Renascence (JLAB 12 GeV Prototypes)
  - E. Feldl, W. Sachleben, M. Drury, P. Kneisel, J. Preble, K. Davis, R. Hicks, J. Fischer, A. Guerra, T. Rothgeb, W. Schneider, K. Wilson, M. Wiseman, K. Smith, J. Henry
- SNS Tuner - Original Design from Saclay via the TESLA collaboration
  - JLAB : J. Hogan, K. Smith, G. Ciovati, K. Davis, R. Getz, P. Kneisel, D. Machie, W. Schneider, K. Wilson, M. Wiseman, J. Delayen
  - SNS : S. Smee, M. Champion, LANL : R. Mitchell, K. Matsumoto
- RIA Tuner (MSU)
  - MSU: T. Grimm, M. Johnson
- TESLA Blade Tuner (INFN, DESY)
  - INFN: Danilo Barni, A. Bisotti, C. Pagani, DESY: R. Lange, H-B. Peters
- Energen Magnetostrictive Actuator
  - A. Mavanur, C. Joshi

Introduction – "Big Picture" for Tuners

- SRF/RF system should consume RF power efficiently
  - Minimizes klystron size and capital cost
  - Higher $Q_{external}$ (> 10^7) ←→ more efficient ER
  - Reduced Microphonics – actively controlled?
- RF Stability
  - Attained by controlling cavity RF phase (0.05°, RMS) and RF amplitude (2 x 10^{-4},RMS)
- Availability / Reliability / Maintainability
  - Use machine as scheduled
  - Operate machine as desired
  - Repair machine (if required) for use and operation

→ Examine what has been achieved on some existing systems to stimulate discussion

Introduction: Pertinent Cavity Info (ERL-compatible Parameters)

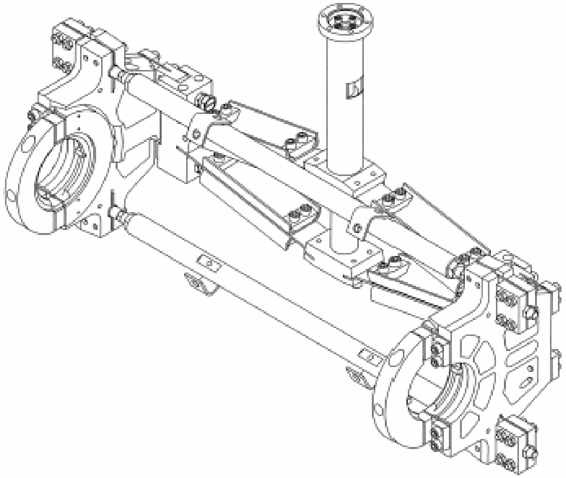
	CEBAF	CEBAF Upgrade (SL21,FEL03)	CEBAF Upgrade (Renascence)	RIA, β=0.47	SNS, β=0.61	SNS, β=0.81	TESLA 500
Frequency (MHz)	1497	1497	1497	**805**	**805**	**805**	1300
Gradient (MV/m)	5	12.5	**18**	10	10.3	12.1	**23.4**
Operating Mode	**CW**	**CW**	**CW**	**CW**	Pulsed, 60 Hz, 7%	Pulsed, 60 Hz, 7%	Pulsed, 60 Hz, 1%
Bandwidth (Hz) **$Q_{external}$**	220 6.6×10^6	**75** **2.0×10^7**	**75** **2.0×10^7**	**40** **2.0×10^7**	1100 7.0×10^5	1100 7.0×10^5	520 3.0×10^6
Lorentz Detuning (Hz)	75	312	324	1600	470	1200	434
Microphonics (Hz, 6σ)	-	**±10**	**±10**	**±10**	±100	±100	NA
Stiffness (lb/in)	26,000 (calc'd)	37,000 (calc'd)	20,000-40,000 (calc'd)	< 10,000	8,000 (meas'd)	17,000 (meas'd)	31,000 (est'd)
Sensitivity (Hz/μm)	373	267	~300 (calc)	> 100	290	230	315

Tuner Requirements & Specifications (ERL-compatible Parameters)

	CEBAF	CEBAF Upgrade (SL21,FEL03)	CEBAF Upgrade (Renascence)	RIA, β=0.47	SNS, β=0.61	SNS, β=0.81	TESLA 500
Coarse Range (kHz)	±200	±200	±400	950	±245	±220	±220
Coarse Resolution (Hz)	NA	**< 2**	**2 - 3**	**< 1**	**2 - 3**	**2 - 3**	**< 1**
Backlash (Hz)	>> 100	**< 3**	**< 3**	NR	< 10	< 10	NR
Fine Range	No Fine Tuner	**> 550 Hz / 150 V**	**1.2 kHz / 1000 V 30 kHz / 30 A**	**11 kHz / 100 V**	**> 2.5 kHz / 1000 V**	**>2.5 kHz / 1000 V**	No Fine Tuner
Fine Resolution (Hz)	NA	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**	**< 1**
Demo of Active Microphonics Damped?	No	?	No	**Yes**	No	No	No
Tuning Method	Tens. & Comp.	**Tension**	**Tension**	NA	**Comp.**	**Comp.**	Tens. & Comp.
Mechanism, Drive Comp.	Immersed, **Vac/Warm**	Vacuum, **Vac/Warm**	Vacuum, Vac/Cold	Vacuum, **Vac/Ext**	Vacuum, Vac/Cold	Vacuum, Vac/Cold	Vacuum, Vac/Cold

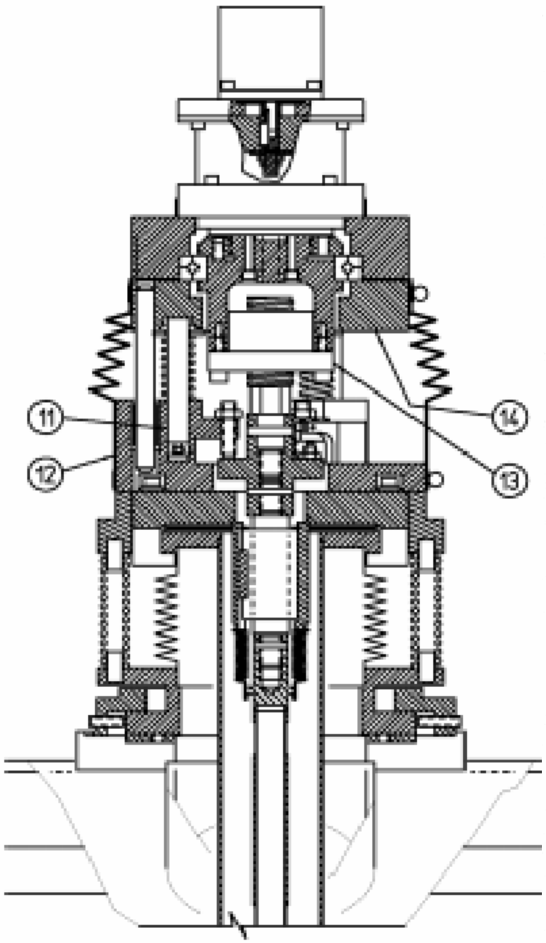
Upgrade Tuner for SL21 and FEL03 Cryomodules - Description

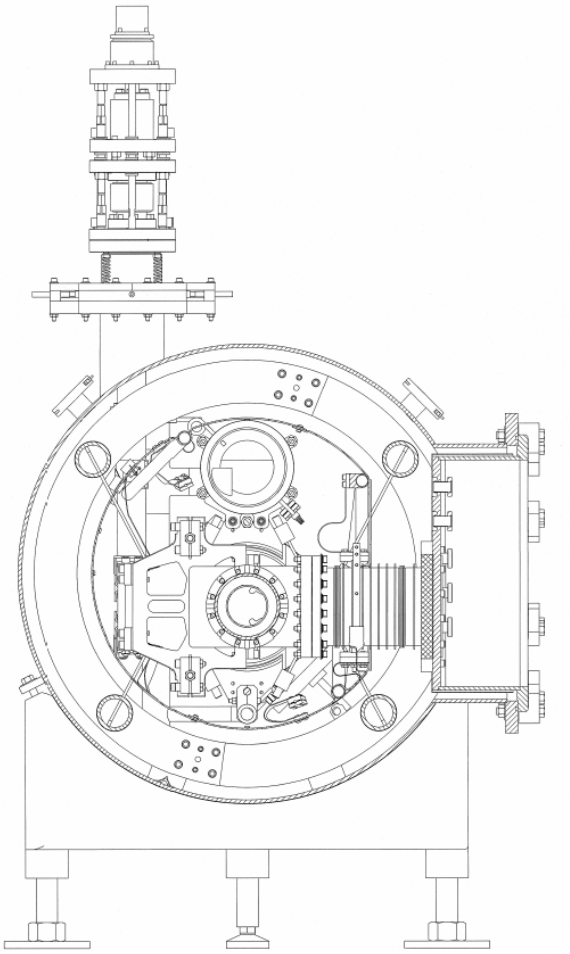
- Scissor jack mechanism
  - Ti-6Al-4V Cold flexures & fulcrum bars
  - Cavity tuned in tension only
  - Attaches on hubs on cavity
- Warm transmission
  - Stepper motor, harmonic drive, piezo and ball screw mounted on top of CM
  - Openings required in shielding and vacuum tank
- No bellows between cavities
  - Need to accommodate thermal contraction of cavity string
  - Pre-load and offset each tuner while warm



Warm Drive Components and Cross Section of Upgrade CM

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



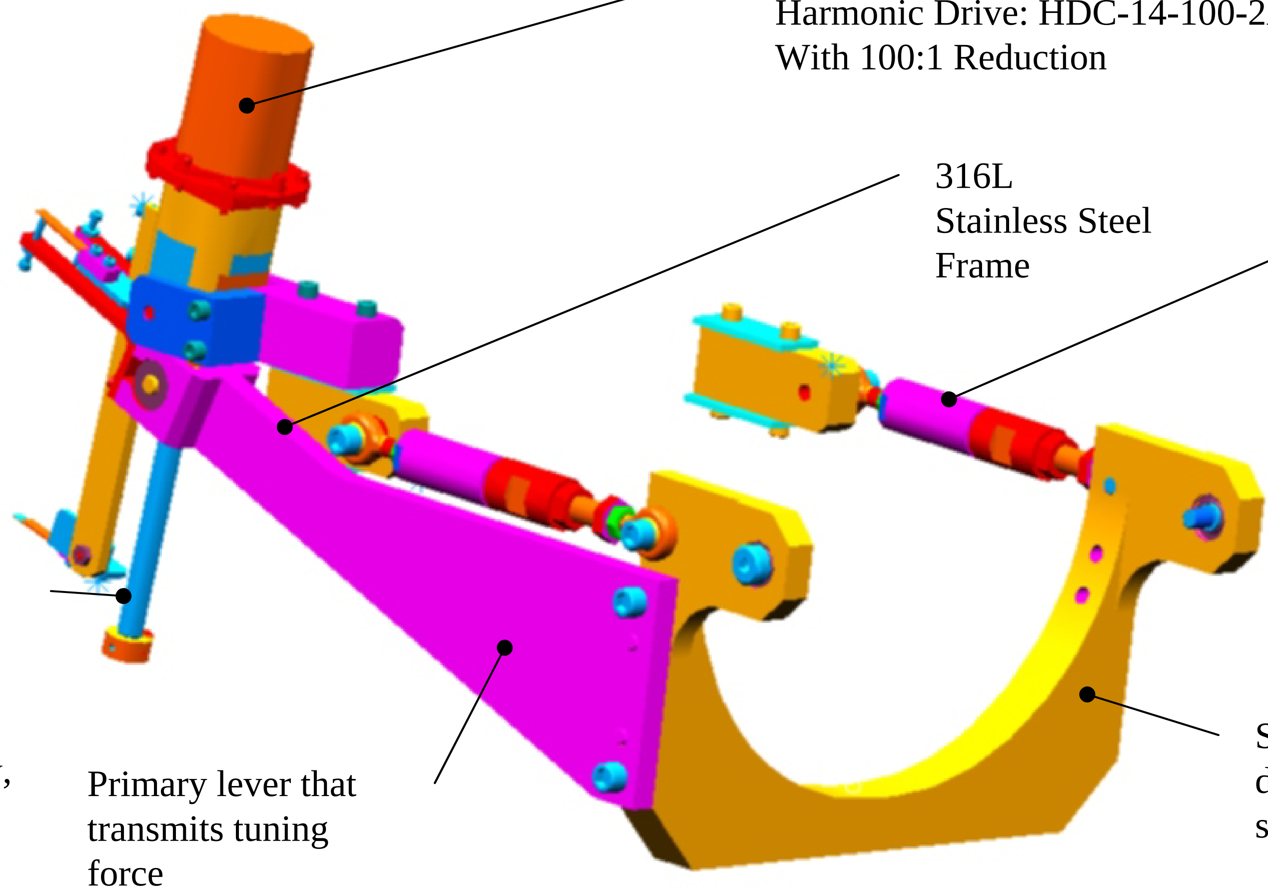


Renascence Tuner Assembly with Two Cold Piezo Actuators

Motor: Phytron VSS-52, 52 in*oz.,
Harmonic Drive: HDC-14-100-2ASP
With 100:1 Reduction

316L
Stainless Steel
Frame

Piezo Actuator in
SST Cartridge –
40mm Stack
(Model # PSt
1000/16/40 VS25)



Dicronite-
coated
Beryllium
Copper
Drive Screw,
M12 x 1.5

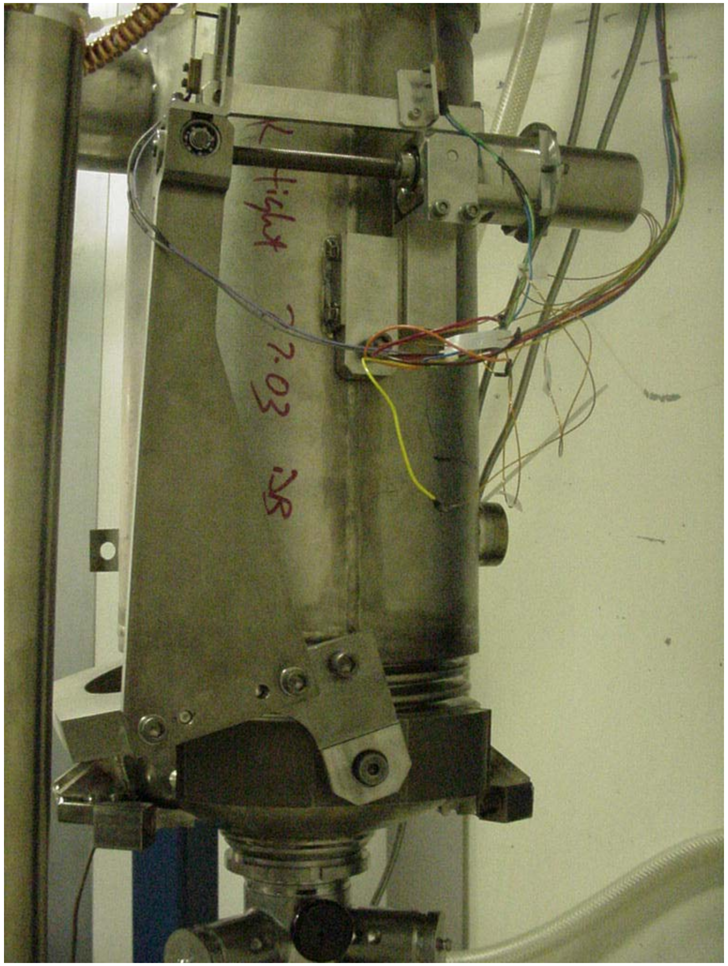
Primary lever that
transmits tuning
force

Secondary lever –
divides load
symmetrically

Renascence Tuner Description

- Mechanism – “Rock Crusher” – All cold, in vacuum components
  - Stainless steel frame
  - Attaches to chocks on cavity
  - Attaches via shoulder bolts to helium vessel head
  - Dicronite coating on bearings and drive screw
  - Cavity tuned in tension only

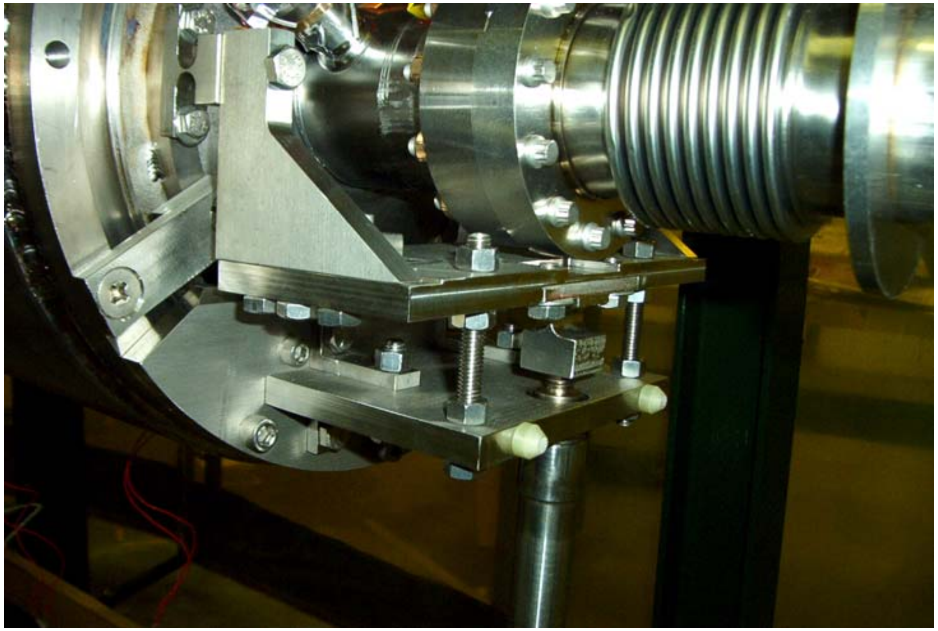
Shown hanging in VTA Test Stand, attached to EP3 cavity, ready for cold testing

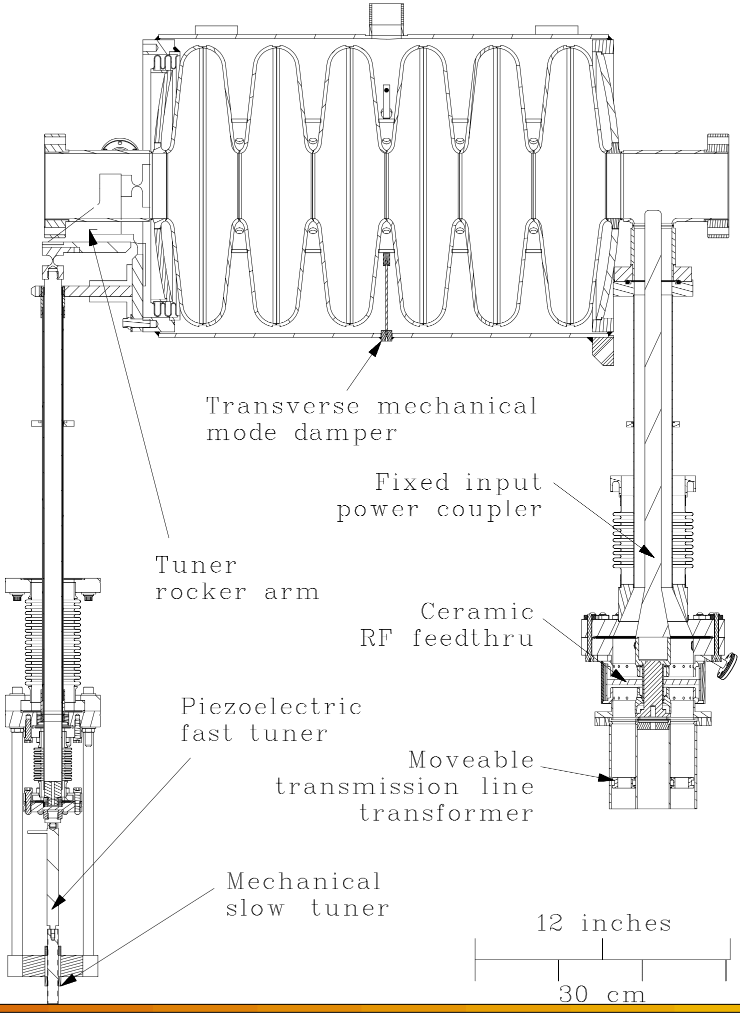


RIA Tuner - Description

- Mechanism
  - Stainless steel rocker arm and drive rod
    - Attaches to chocks on cavity
    - Attaches via flexures and threaded studs to helium vessel head
  - Cavity tuned in compression only(?)
- Cold transmission – compressive force on drive rod
- Stepper motor and piezo external to vacuum tank
- Bellows on vacuum tank
  - Need to accommodate relative thermal contraction of cavities
  - Allow tuner transmission to float (unlocked) during cooldown
  - Pre-load each tuner while warm, account for vacuum loading on bellows

RIA Tuner – Rocker Arm / Schematic

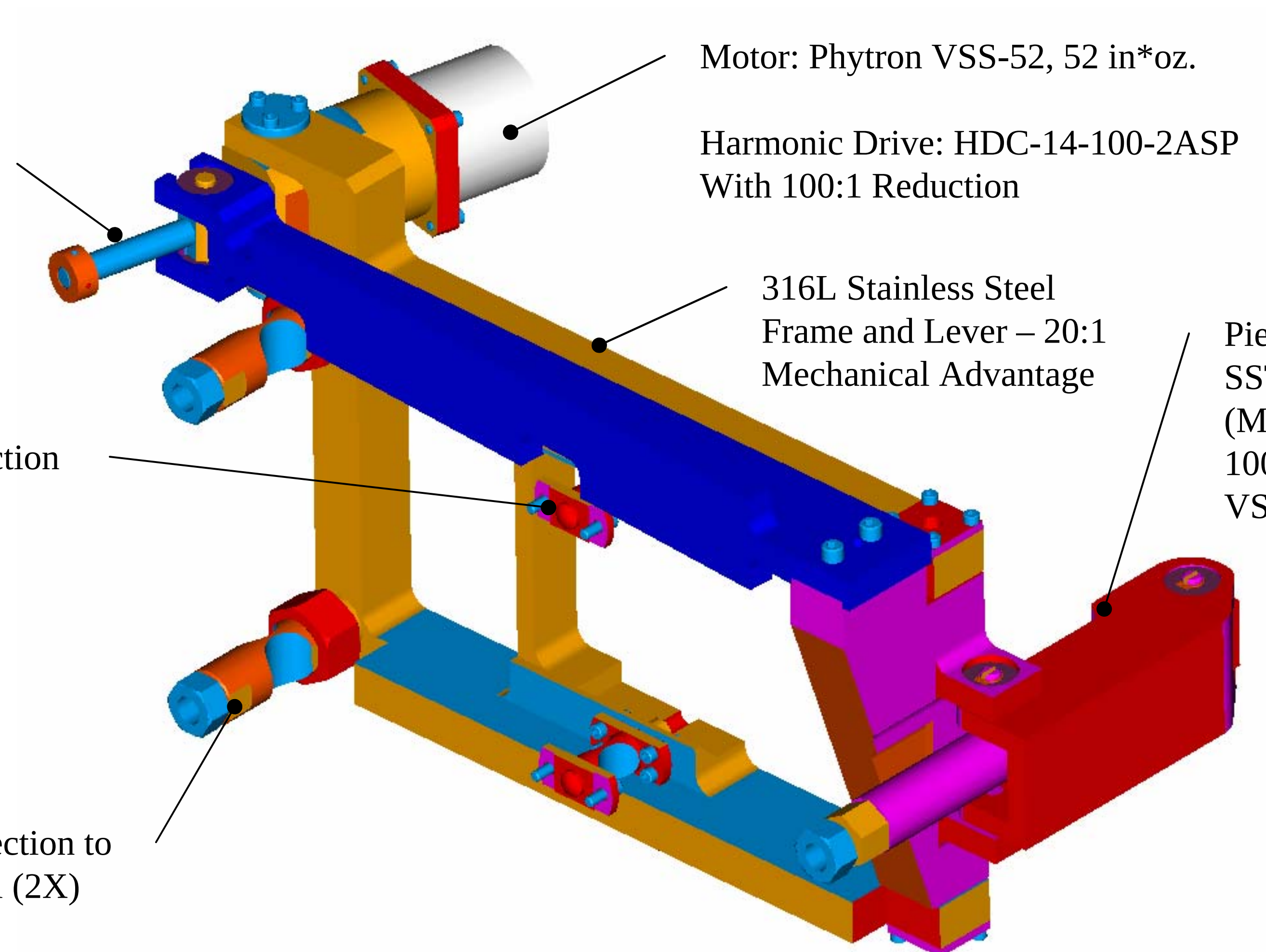




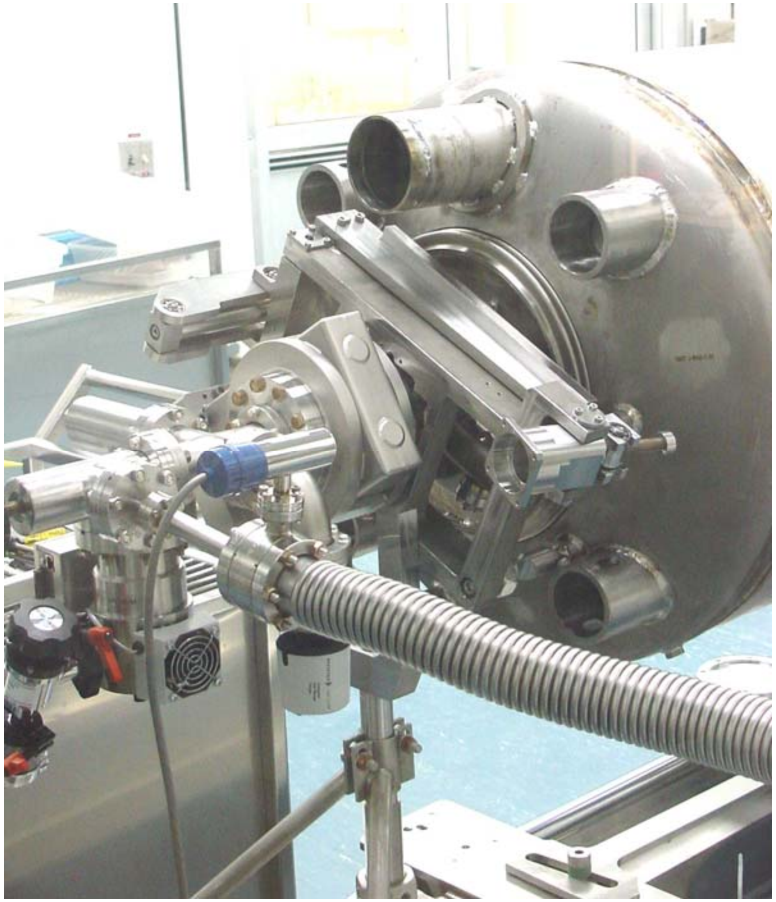
SNS Tuner - Description

- Mechanism scaled from original DESY/Saclay design
  - Stainless steel frame
    - Attaches to chocks on cavity
    - Attaches via flexures and threaded studs to helium vessel head
  - Dicronite coating on bearings and drive screw
  - Cavity tuned in compression only
- Cold transmission
  - Components in insulating vacuum space
  - Stepper motor and harmonic drive rated for UHV, cryogenic and radiation environment
- Bellows between cavities
  - Need to accommodate relative thermal contraction of cavities
  - Pre-load each tuner while warm

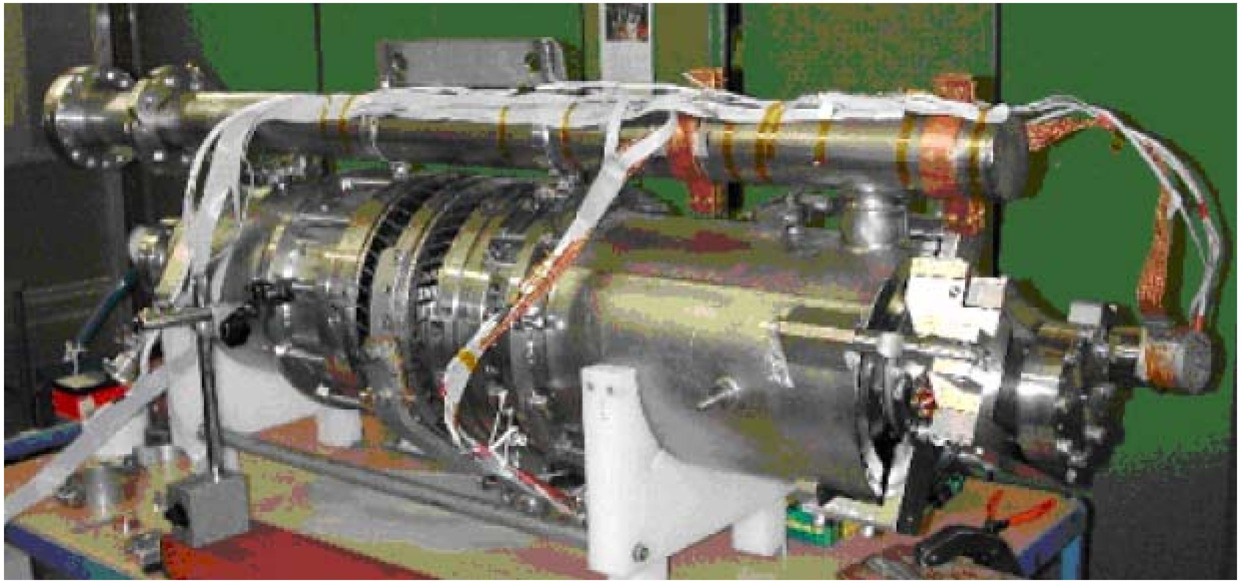
SNS Tuner Assembly w/ Piezo Actuator

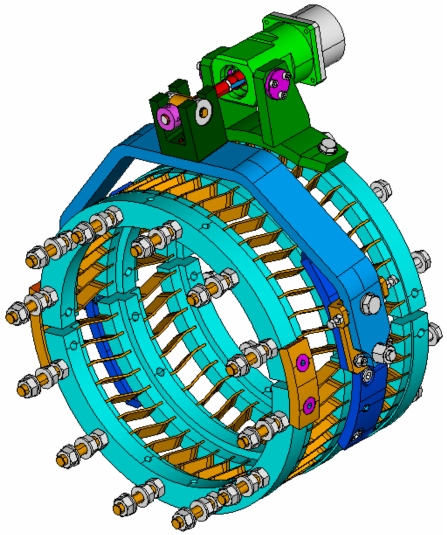


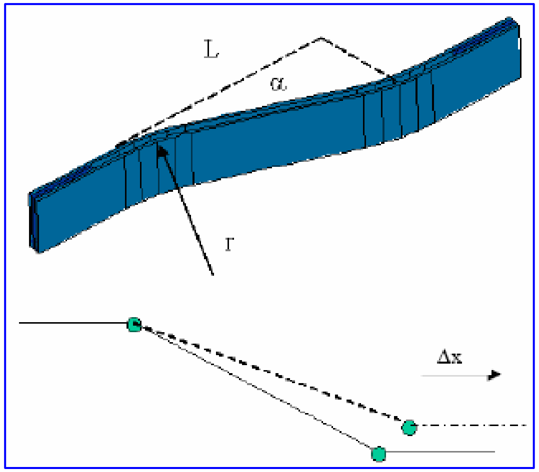
SNS Tuner with Piezo Actuator Installed on Helium Vessel & Cavity



TESLA - Blade Tuner

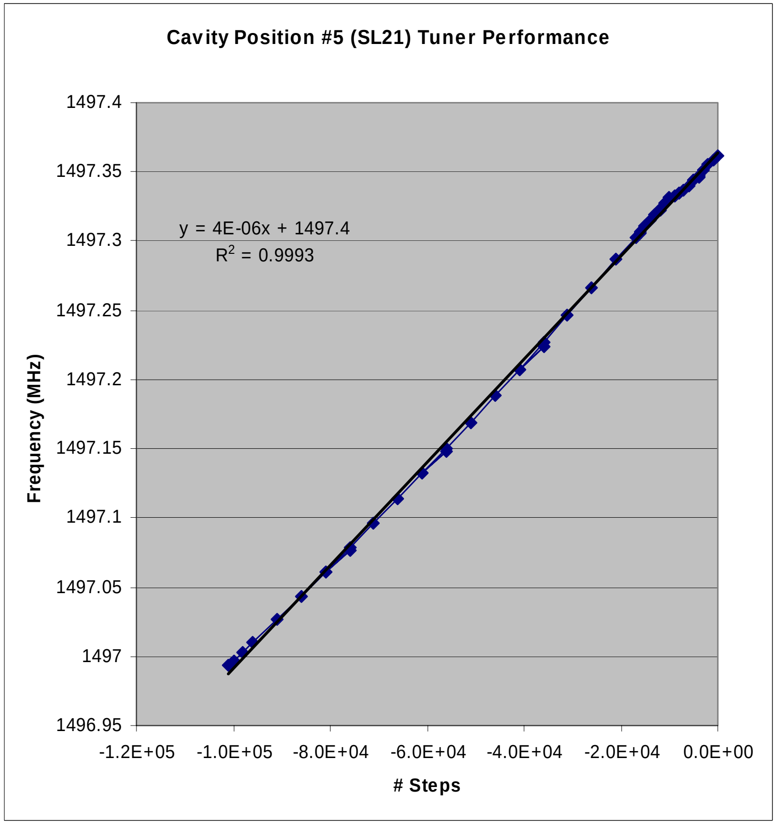


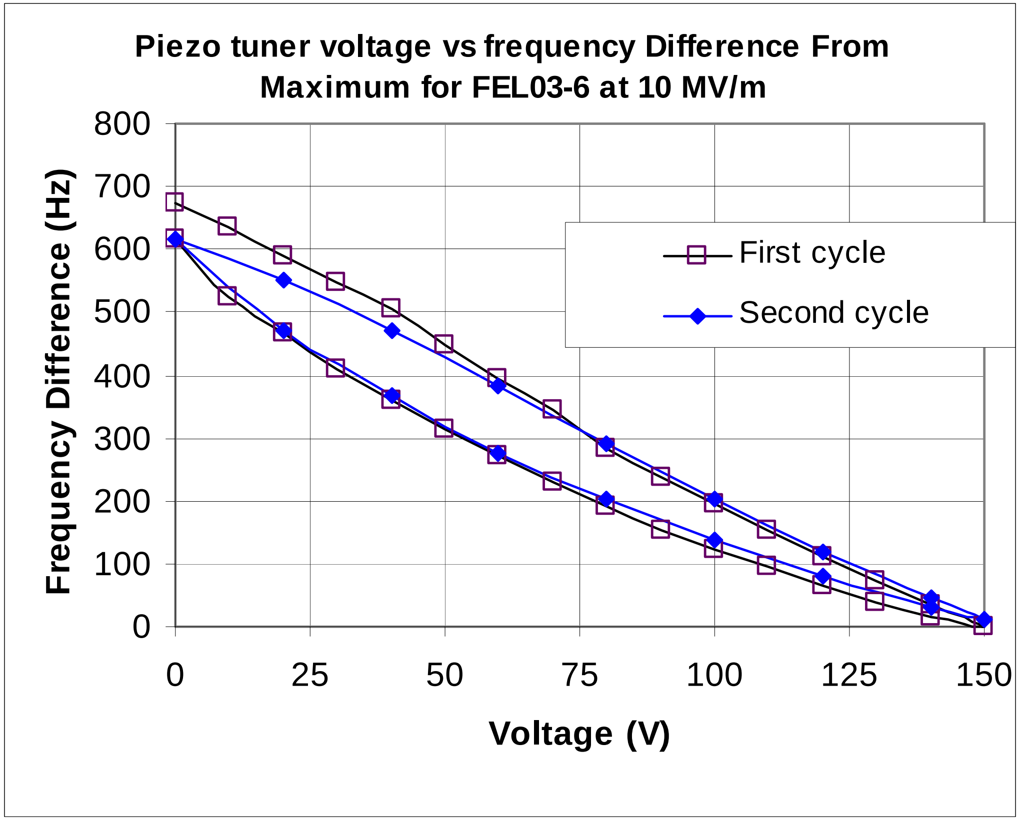




- Mechanism – All cold, in vacuum components
  - Titanium frame
  - Attaches to helium vessel shell
  - Pre-tune using bolts pushing on shell rings
  - Dicronite coating on bearings and drive screw
  - Cavity tuned in tension or compression – blades provide axial deflection

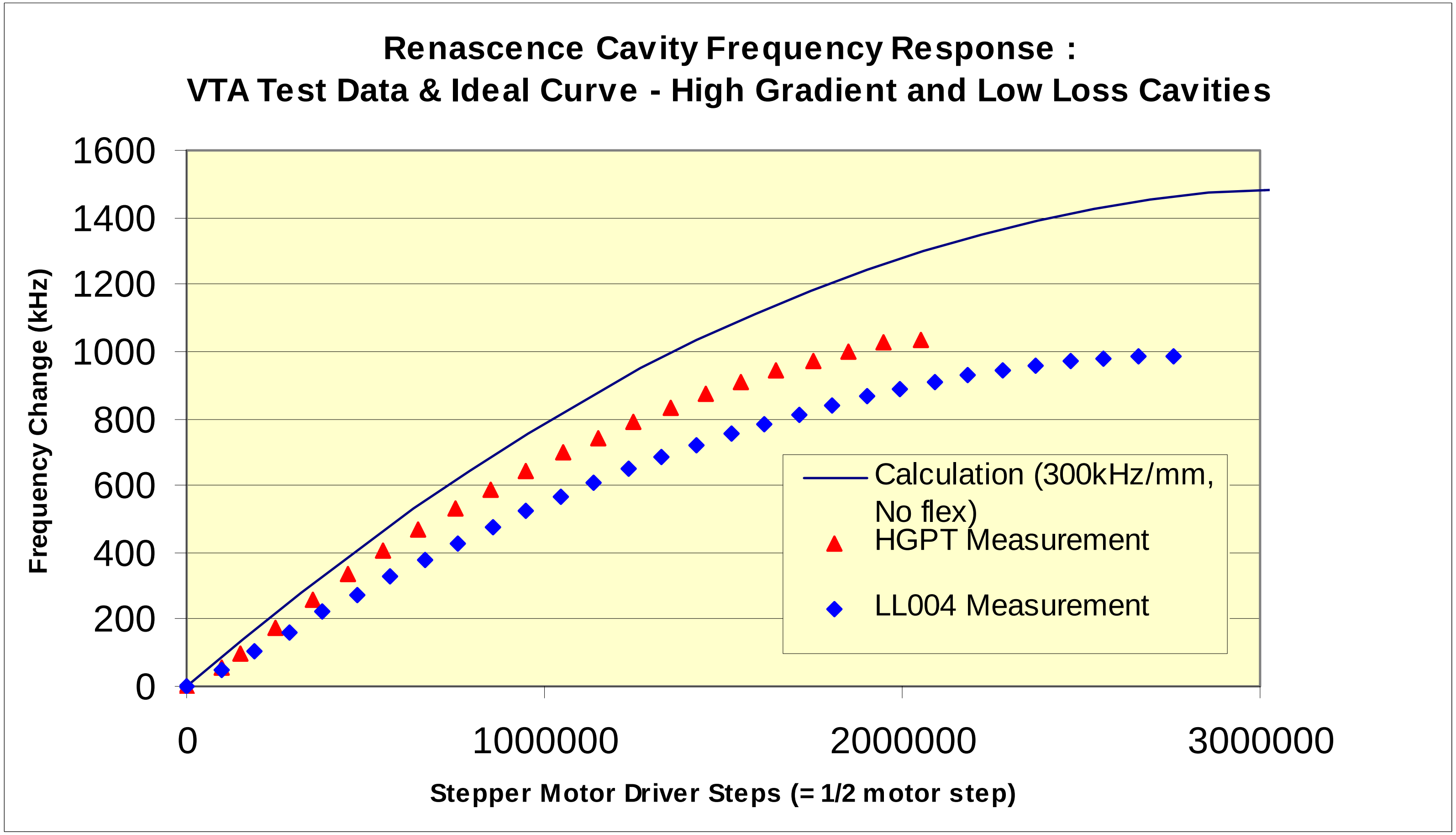
Upgrade Tuner – SL21 / FEL03 :
Range and Resolution (Piezo Hysteresis)





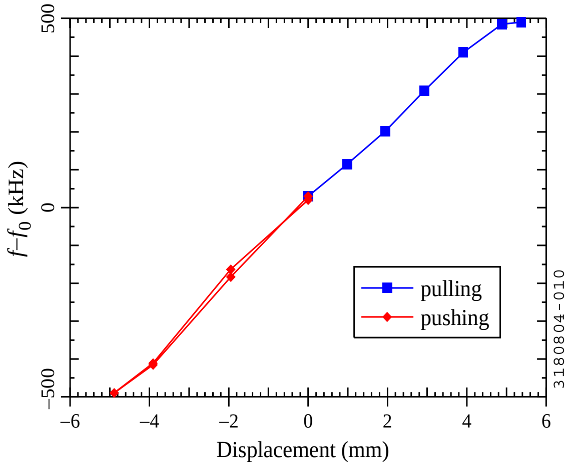
Renascence Tuner – VTA Testing :

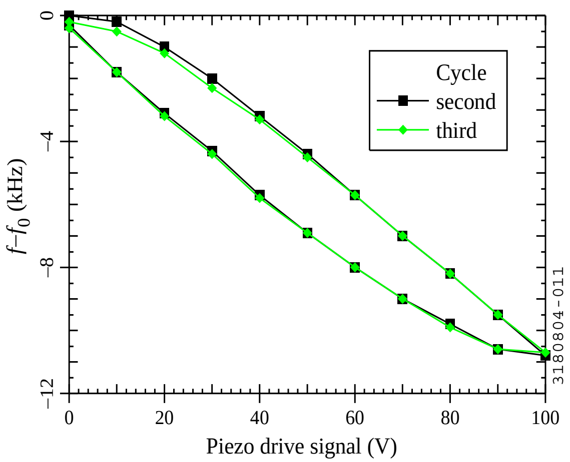
Range (Helium vessel compliance reduces actual stroke)

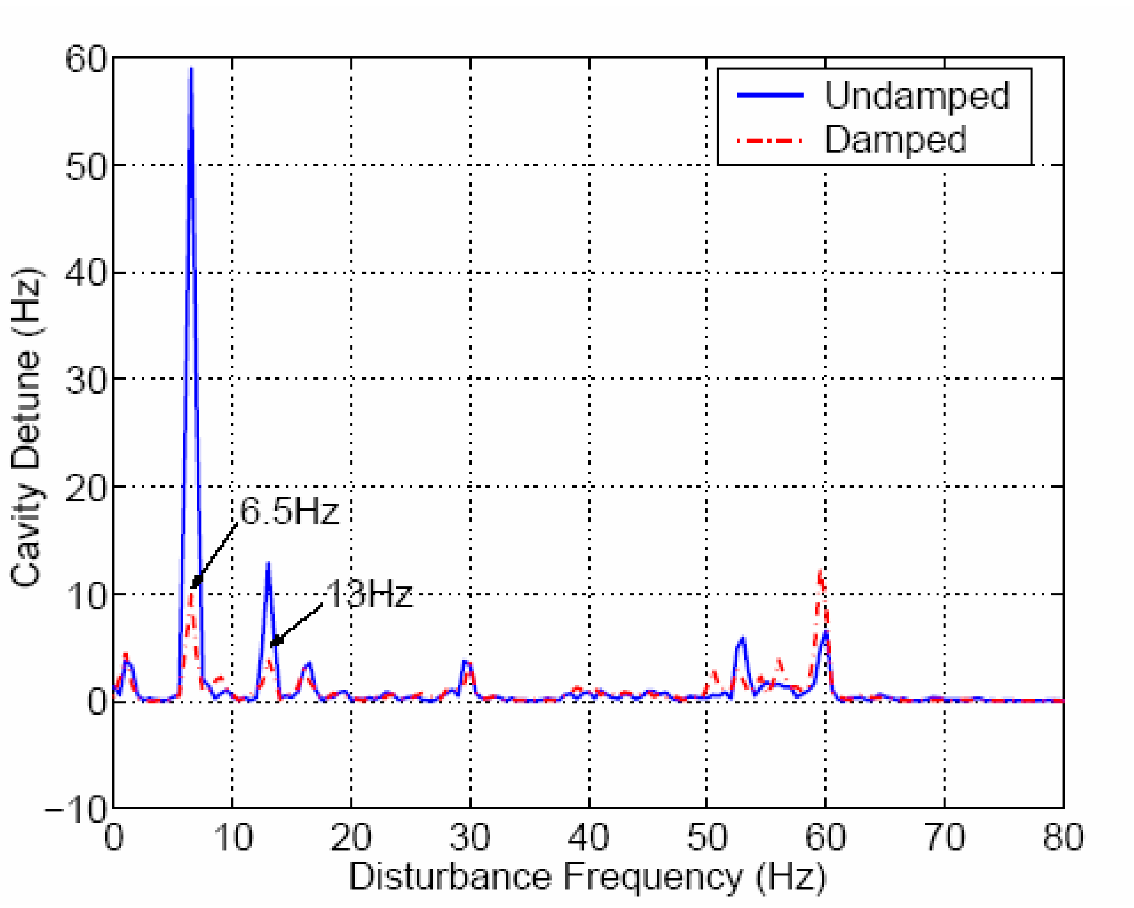


RIA Tuner – Test Results:

Coarse and Fine Tuner Range; Active Feedback Control

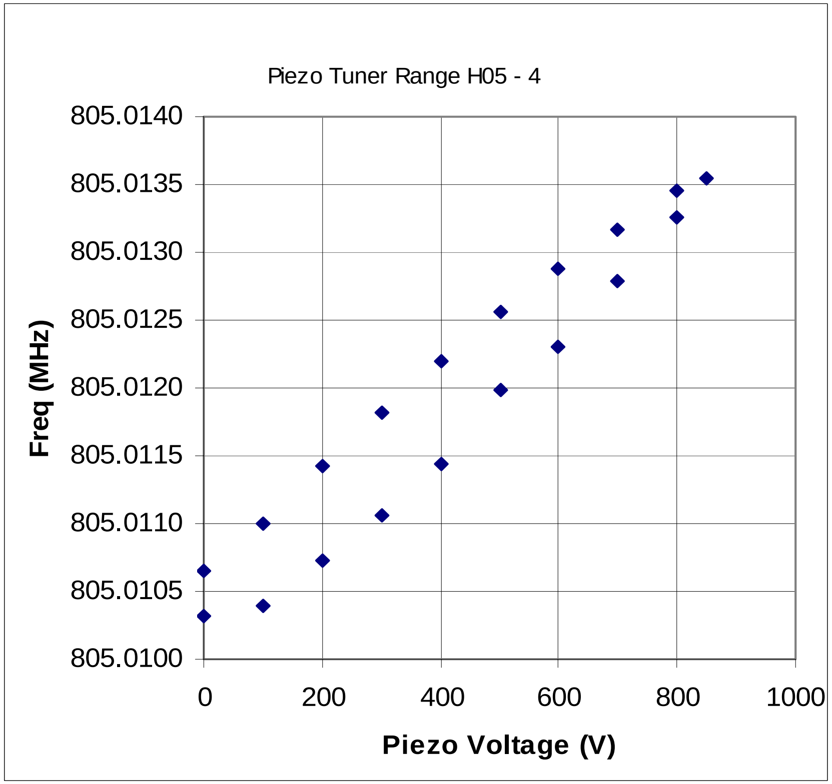


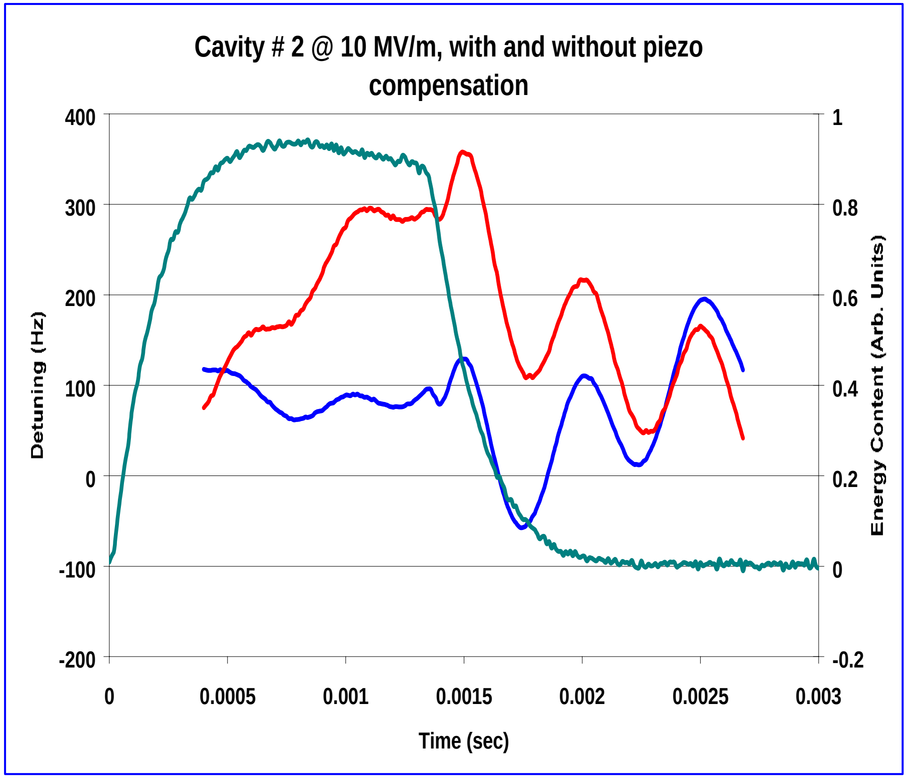




SNS Tuner – CMTF Test Results:

Fine Tuner Range and Hysteresis; Piezo Compensation



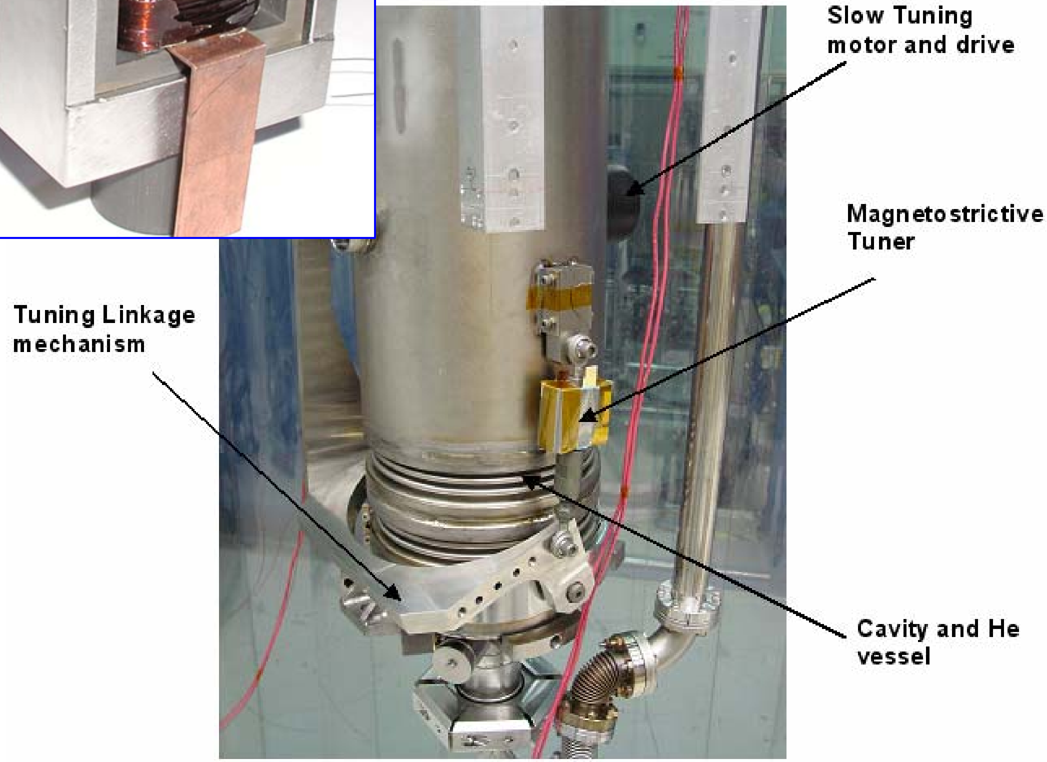


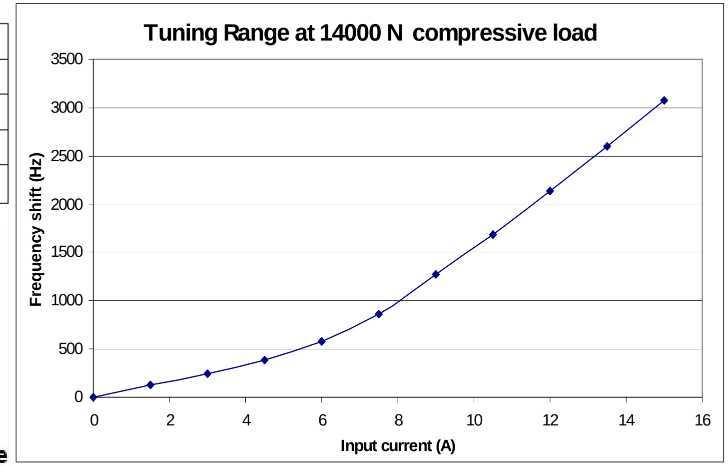
Renascence Cavity – VTA Test Results:

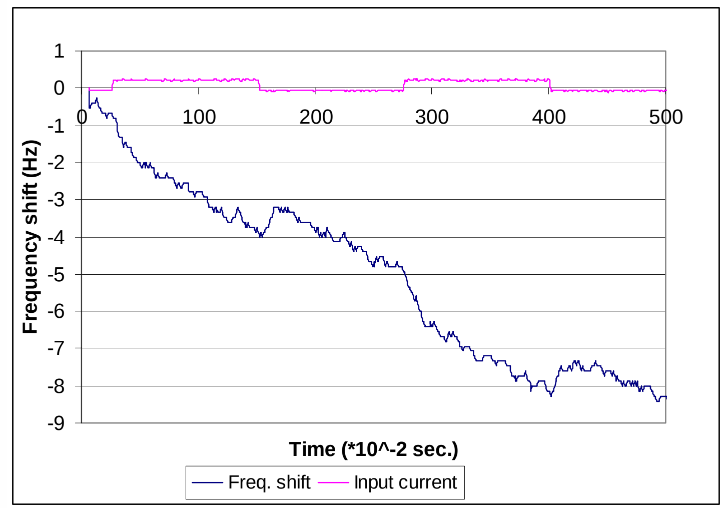
Magnetostrictive Actuator on Tuner

RANGE OF THE MAGNETOSTRICTIVE TUNER AT DIFFERENT LOADS

Compressive Load (N)	Max. Tuning Range (Hz)
No Load	2,600
7100	5,892
10,200	3,423
14,000	3,088

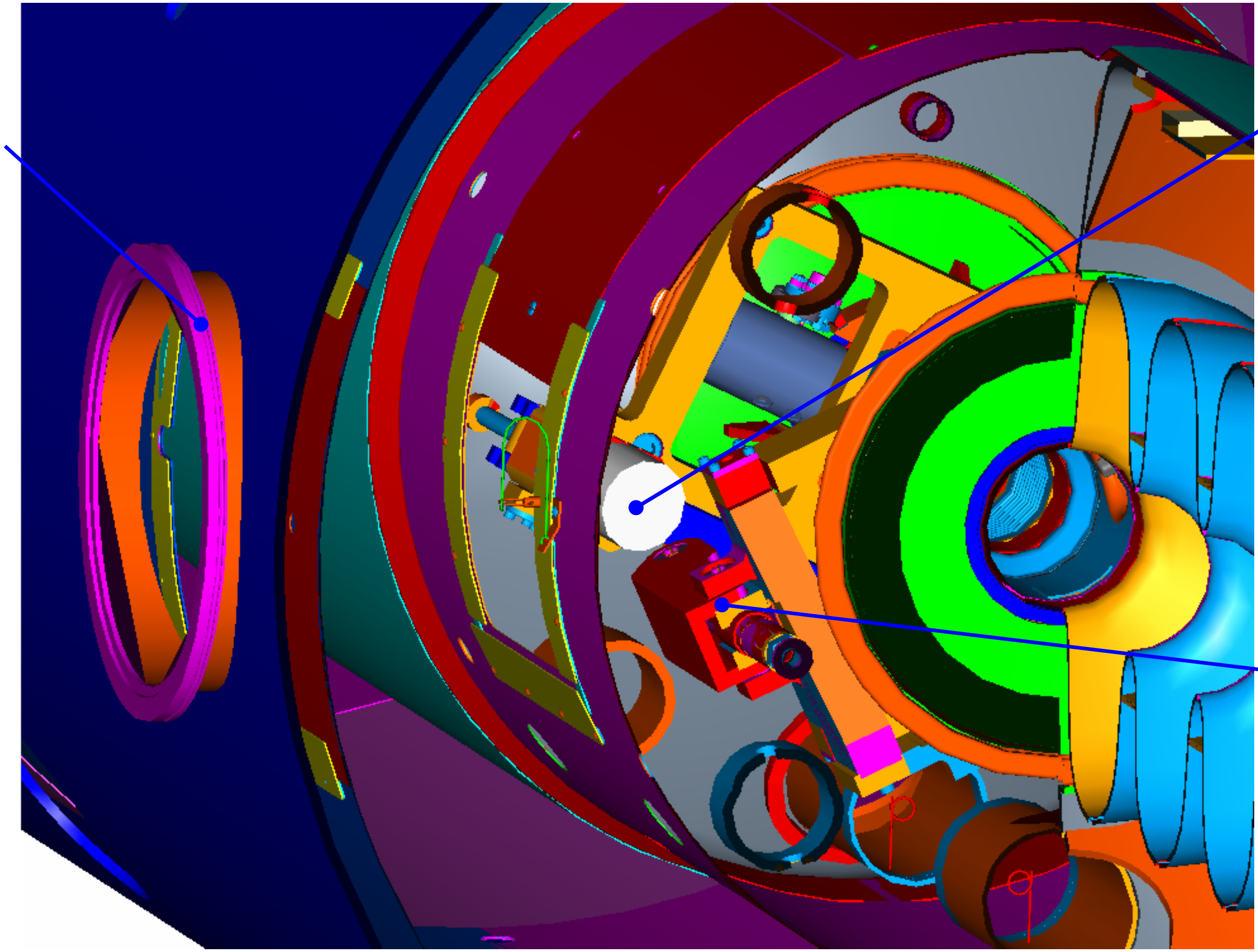




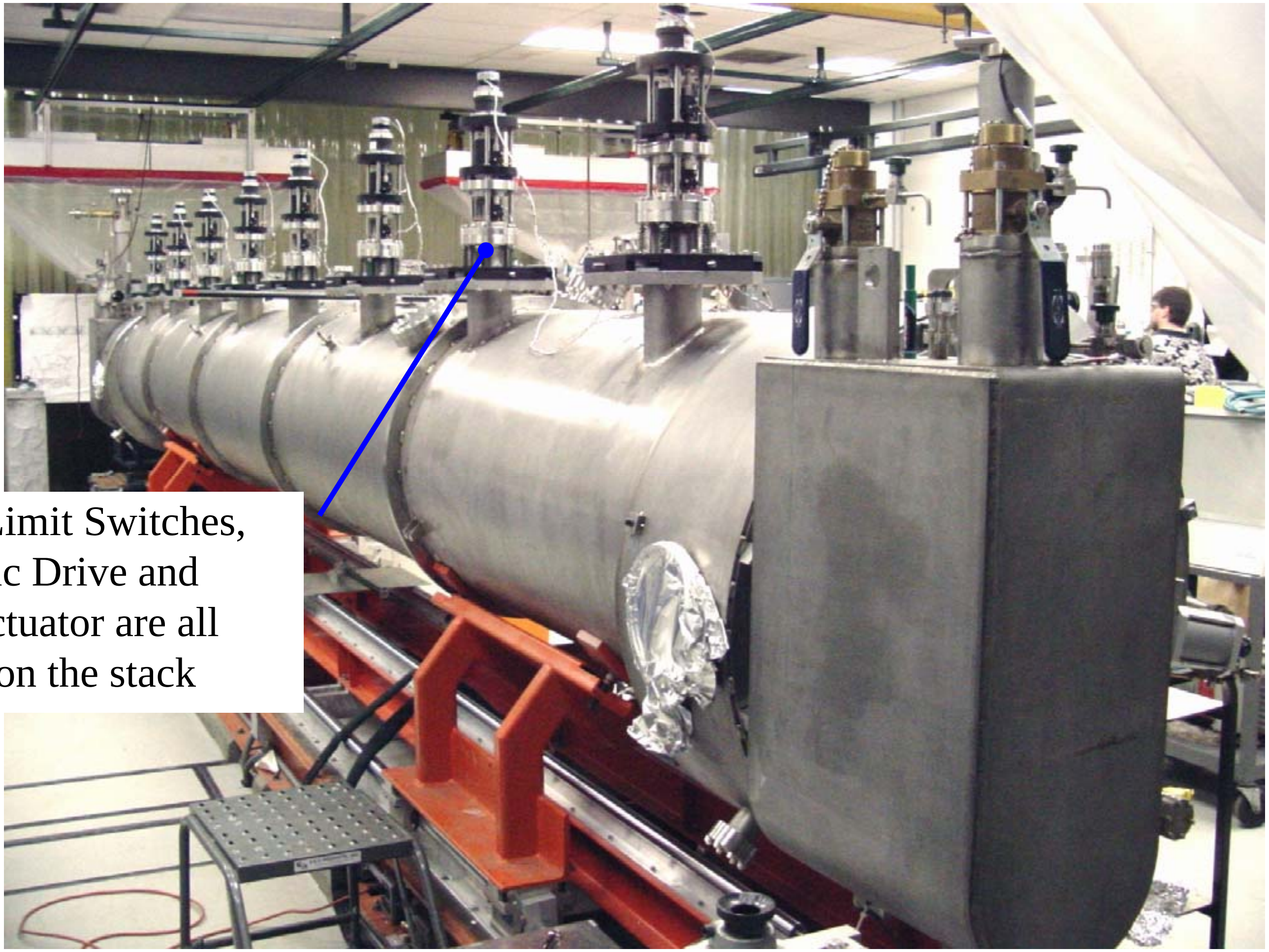


SNS Cryomodule:

Current Openings for Access to Tuner Components – CM CutAway

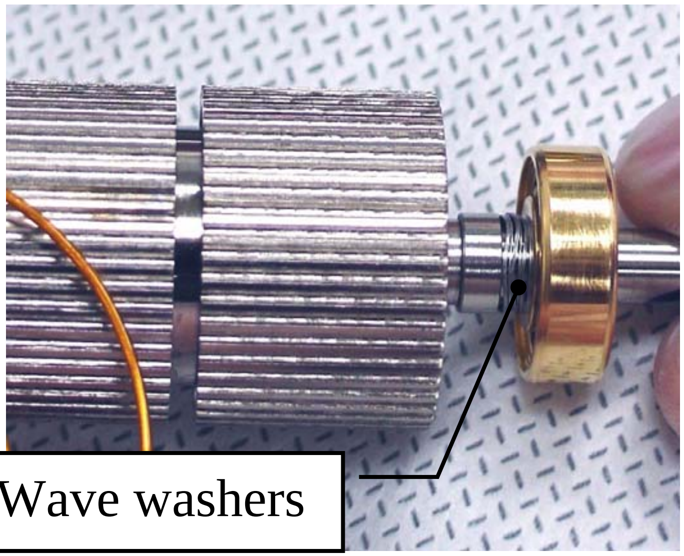


Upgrade Cryomodule –
Access to Tuner Drive Components



Comparing SNS Tuner Motor Rotor/Shafts: Prototype (left) and Production (right)

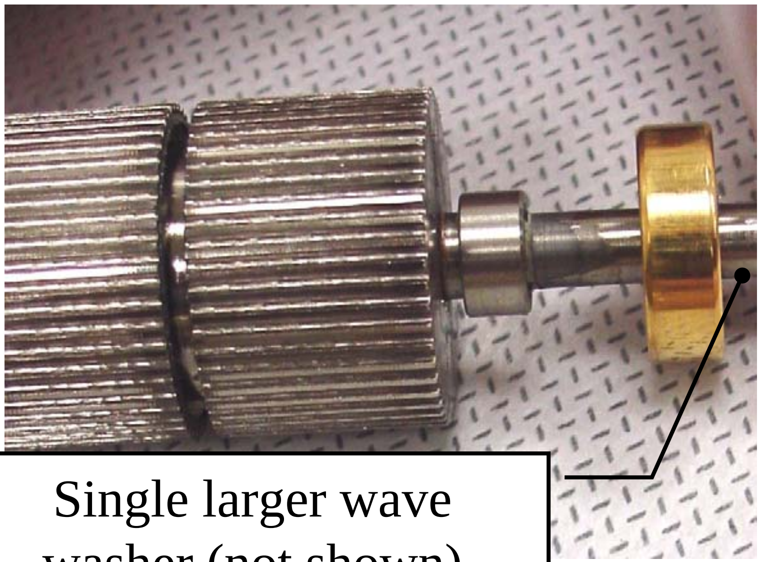
Rotor from accelerated life test motor



Wave washers

- Series of wavy washers provides pre-load on the shaft while allowing compliance during cooldown and operation at 4K.
- Accelerated Life Testing → > 20 yrs

Rotor from M-01 Cav. #2 Tuner



Single larger wave washer (not shown)

- Single wavy washer to the right of the bearing provides pre-load and compliance – cost reduction by vendor
- Pass vendor acceptance testing
- Compliance drastically reduced
- Motors bound up and didn't work!!

Closing / Summary :
Comparison of Tuner Features

- Coarse Tuning Mechanism
  - Typically cold, must be reliable and maintainable → access ports
  - Direct cavity drive reduces stiffness requirements on helium vessel
  - Tuner/HV stiffness > 10x cavity
  - Flexures exhibit reduced backlash
- Fine Tuning Actuators
  - Piezo – operate in compression, warm range 5-10x > cold range, capacitive device, minimize voltage, consider hysteresis
  - MST – must operate cold, consider lead thermal design, inductive element, minimize current, consider hysteresis
- Transmission Location (maintainability)
  - Cold placement requires proper materials, cyclic life testing and access for repair or replacement, electrical feedthroughs
  - Warm placement requires cooldown/tuning compliance, access ports, bellows
- Testing (minimizes risk associated with reliability and availability)
  - Perform accelerated life tests on critical components
  - Feedback results into design **prior** to production
  - Develop thorough acceptance tests to verify operation