Mechanical Tuner for SSR1

performance of prototype tuner

&

proposal for PXIE

presented by Yuriy Pischalnikov
in behalf of SSR1 team

SSR1 – cavity for HINS

- Coarse tuning (range ~200kHz & stiffness ~30kN/mm);

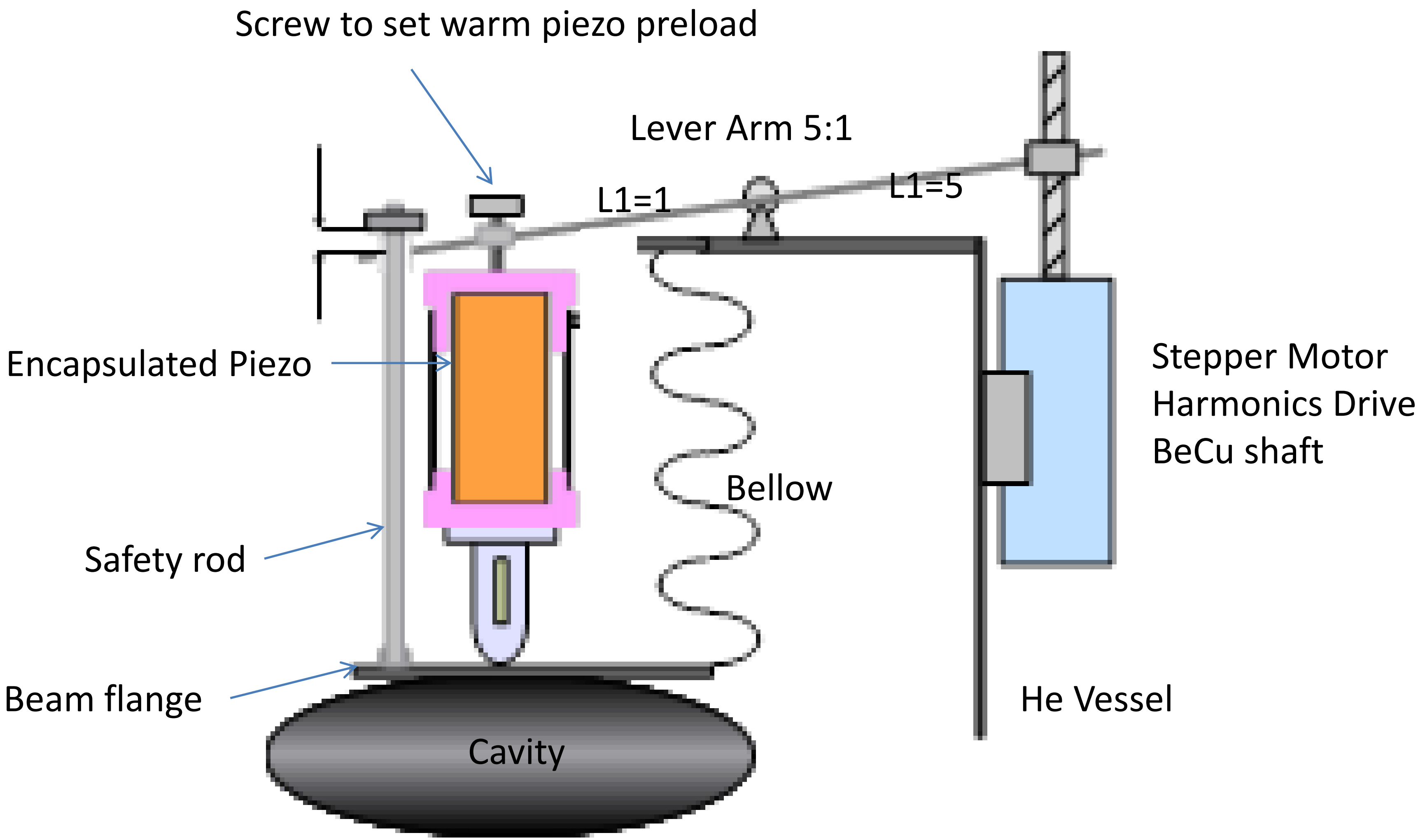
- operation at 4,5K & dF/dP ~140Hz/torr;

- RF pulse operation at Eacc~10MV/m == large detuning during by LF

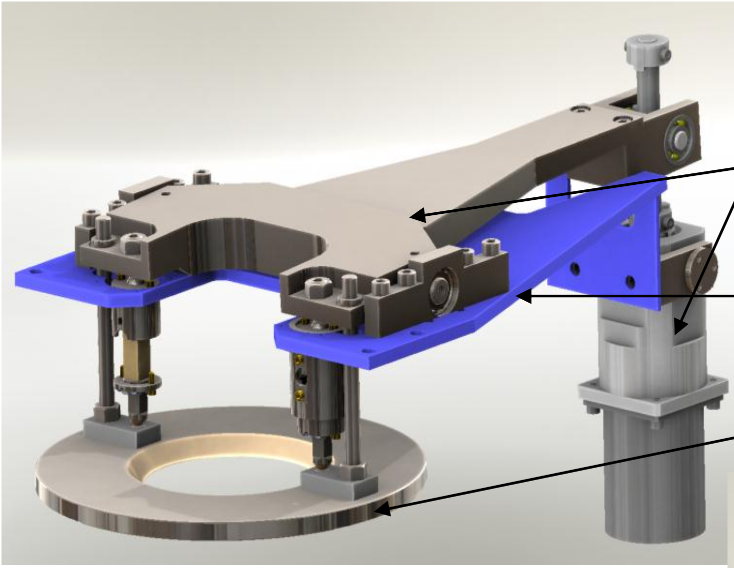
- Just 25mm space along the beam line

- Development started after Cavity and He vessel already designed and build

SSR1 tuner schematics



Designer - Evgeni Borrisov

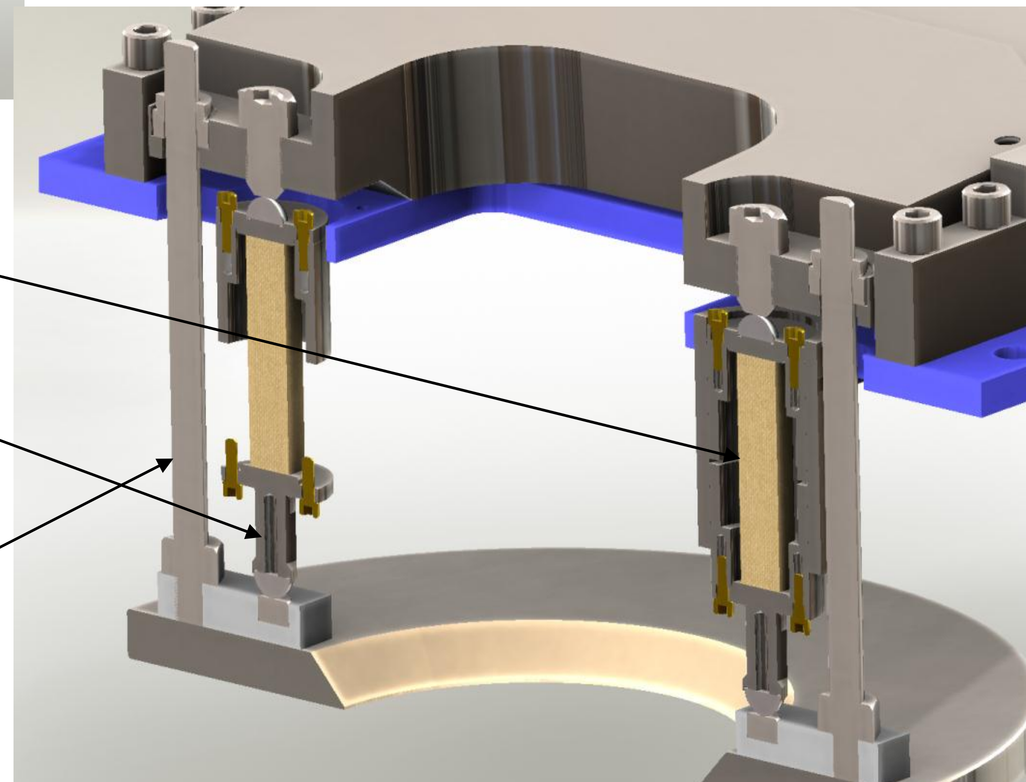


Stepper Motor & Harmonics Drive

Slow Tuner Arm

Assembly Flange attached to He Vessel Flange

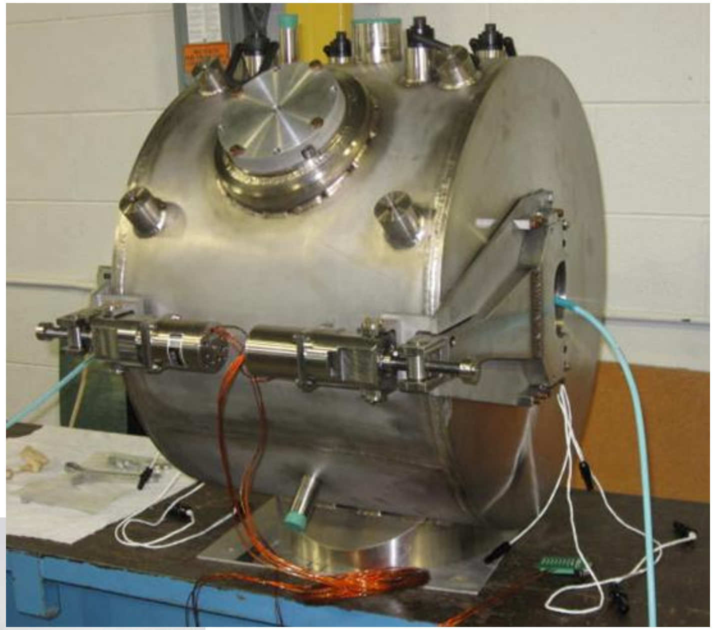
Cavity Flange

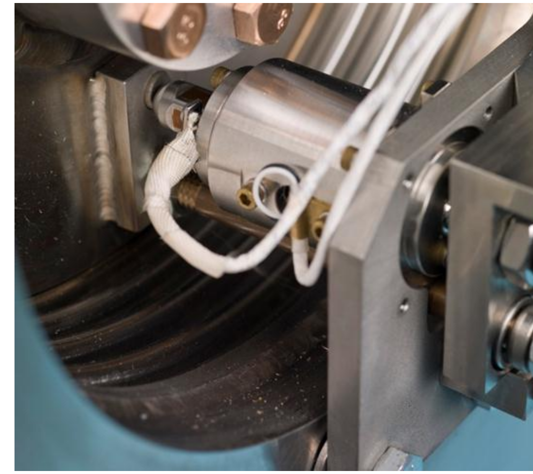


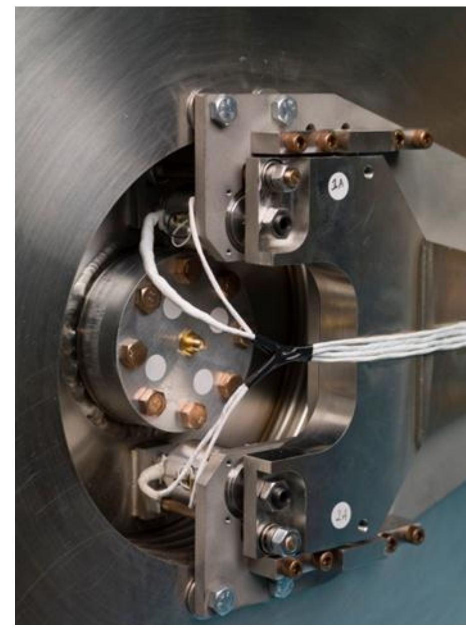
Piezo inside tube assembly
(to prevent shearing forces & keep piezo assembly attached)

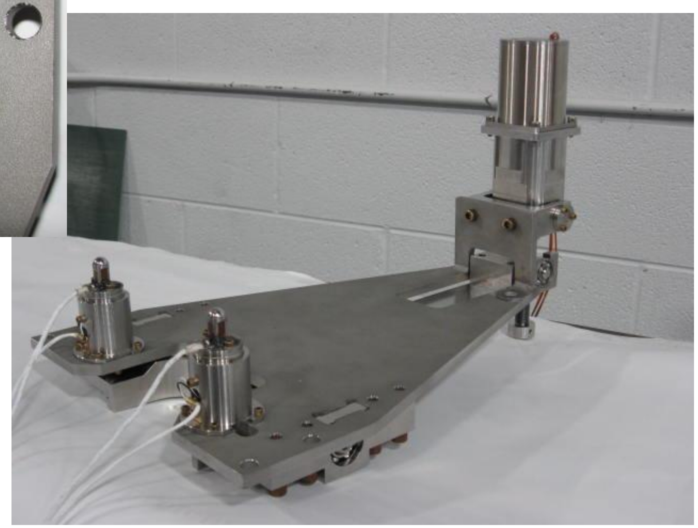
"Bullet" with SGs to monitor preload on piezo

"Safety rod" attached cavity flange to slow tuner arm to prevent cavity from permanent detuning during process of cooling cavity down to

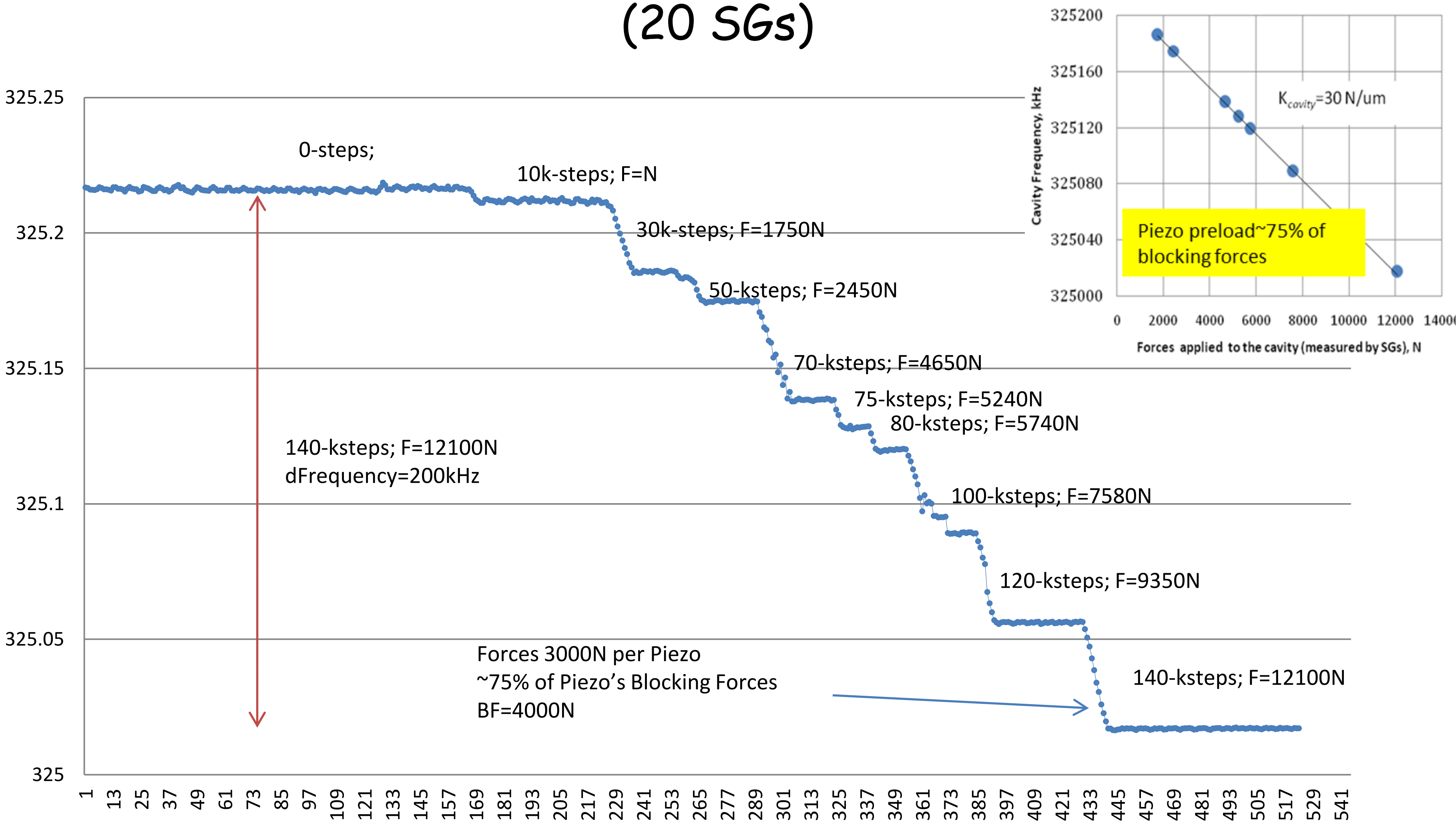




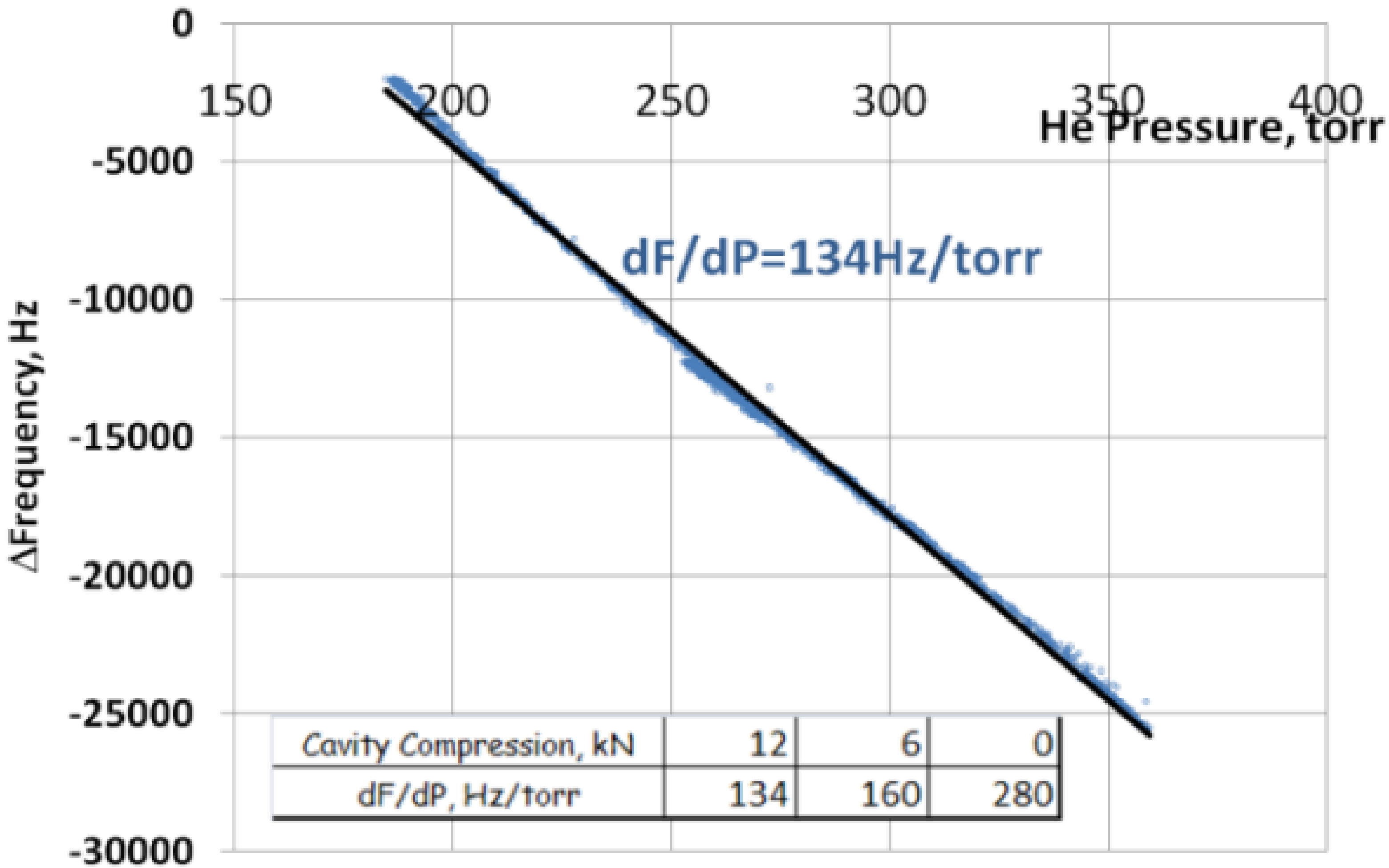




SSR1 tuning with Slow Tuner
Forces applied to cavity/Piezos measured with Strain Gauges (20 SGs)

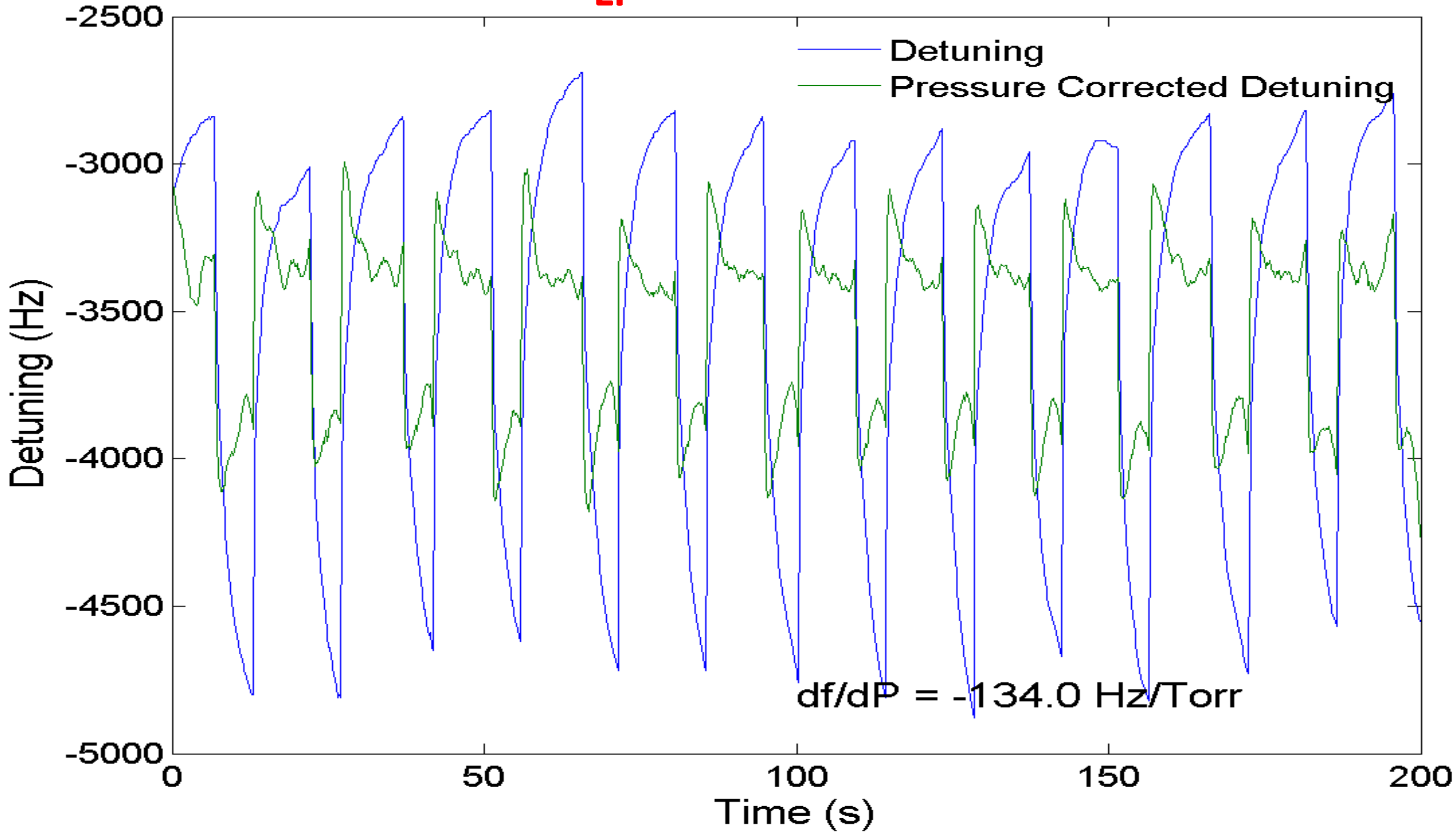


Cavity frequency sensitivity to He bath pressure (dF/dP). The inset shows the dF/dP value for different load applied by the tuner to the cavity beam flanges.



Static Lorentz Force Detuning in the SSR1 Prototype.

$K_{LF}=1.5$ (for 12kN preload)



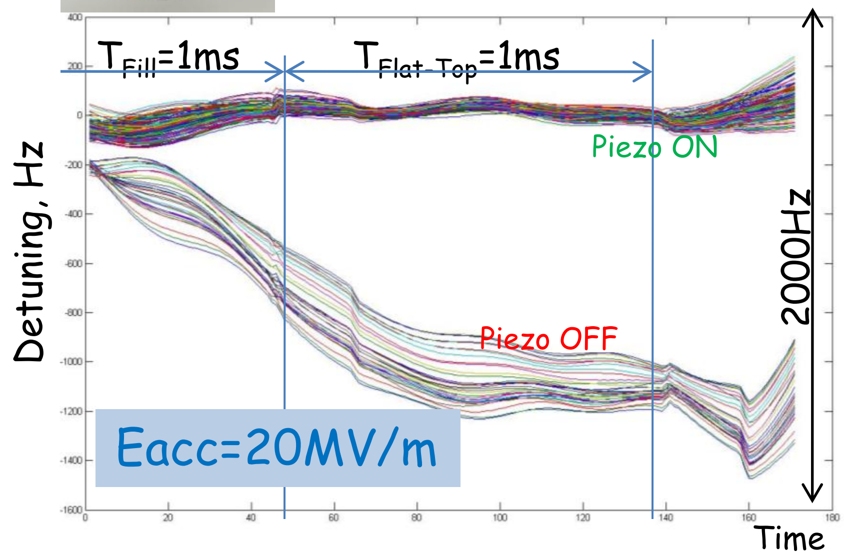
The blue line shows the change of cavity frequency due to the combination of the static Lorentz Force and changes in the He pressure as the gradient was cycled between 3 and 20 MV/m. The green line shows the frequency shift following corrections for variations in the He pressure.

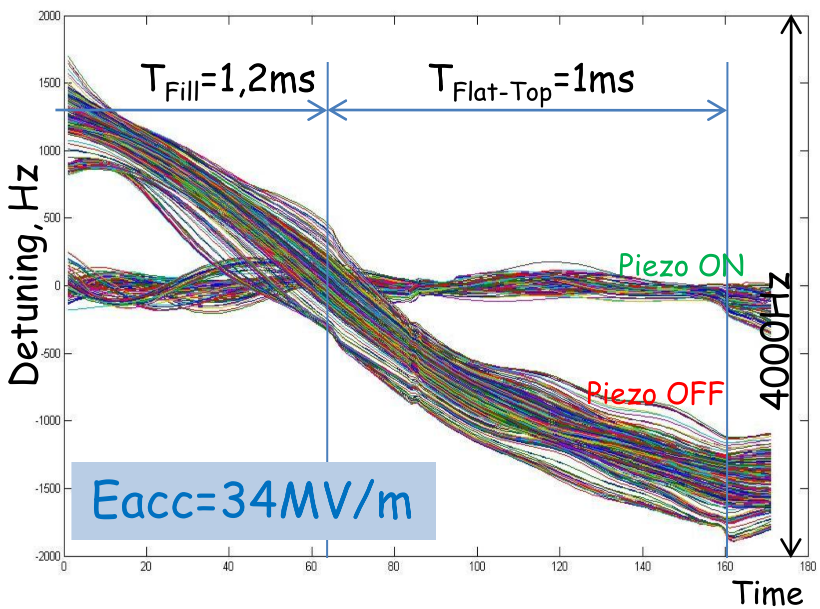
325MHz Spoke Cavity (SSR1)

(designed for HINS: 4,5K & 10MV/m ; RF-pulse 1ms-FlatTop)

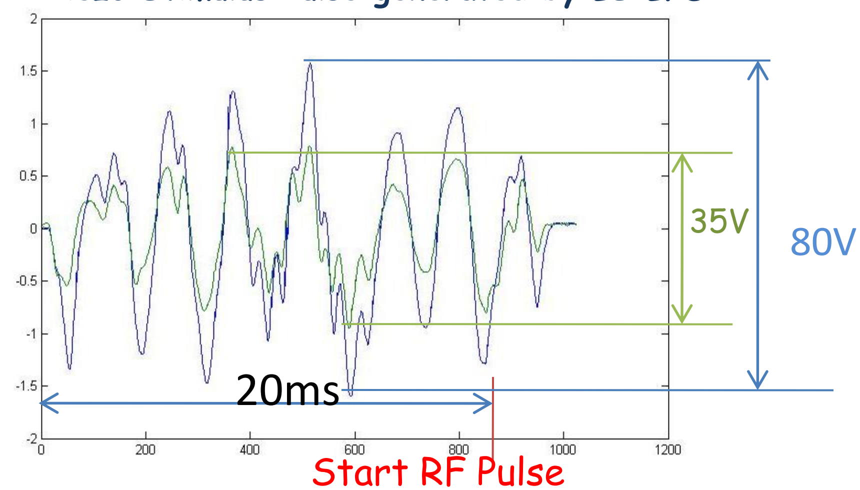
Eacc	Piezo OFF	Piezo On	(ApiezoV)
20MV/m	500Hz(1000Hz)	30Hz	35V(18%)
34MV/m	1500Hz(3500Hz)	75Hz	80V(40%)

$\Delta F = -kE_{acc}^2$ K~1,2Hz/(MV/m)²



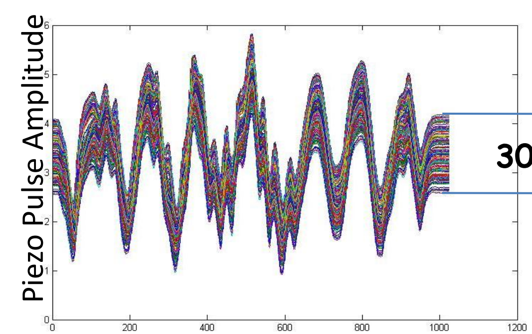


Piezo Stimulus Pulse generated by LS LFD



4,5 K LiqHe bath pressure compensation

Piezo Stimulus pulses Eacc=34MV/m during 180sec operation Bias changed on 30V (dV=30V → dF=600Hz)



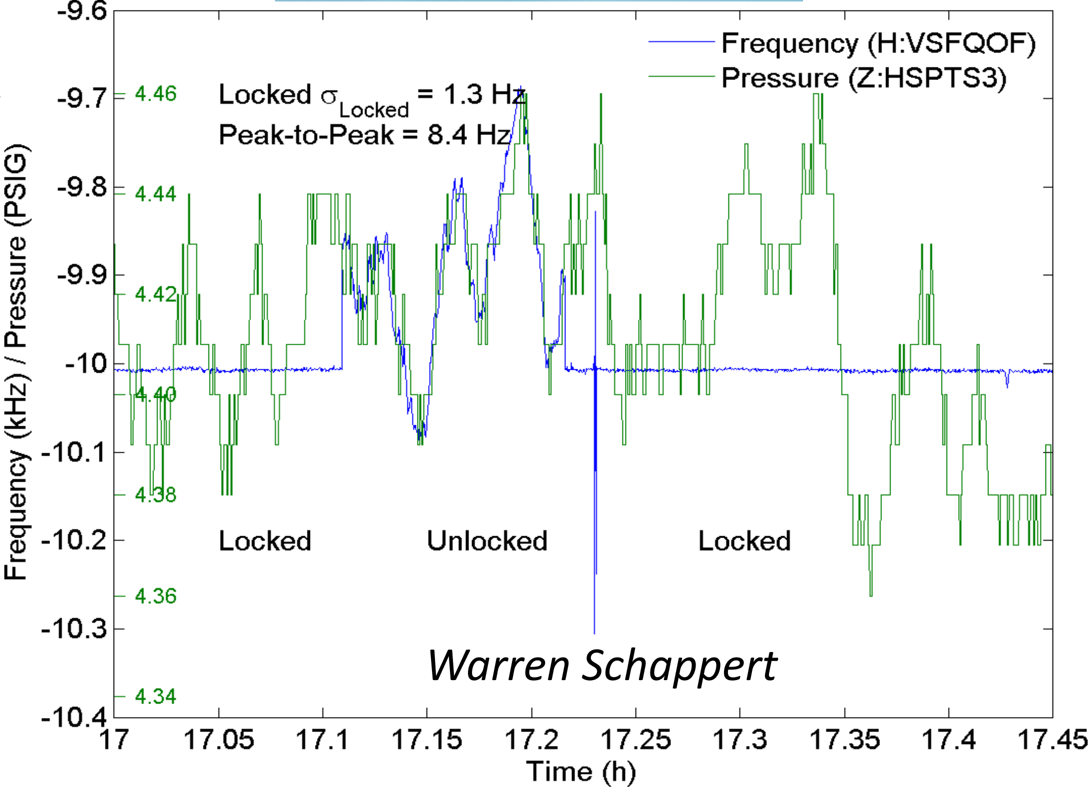
PAC2011 poster TUP080

Compensation of fluctuations in the pressure of the surrounding helium bath;

SSR1 with Narrow Bandwidth Coupler

- Initial cold tests of SSR1 using CW provided an opportunity to gain experience with a very narrow bandwidth cavity
  - Test Conditions
    - 4.5K
    - Cavity bandwidth of about 1.5 Hz
    - df/dP ~= **140 Hz/torr**
    - dP_{PTP}~=**5 torr**
    - LLRF tracking resonant frequency of cavity
  - Detuning control system
    - 100 kHz digitizer measured RF frequency offset from an arbitrary set point
    - FPGA fed Δf back to fast tuner
- Reduced pressure related variations in cavity frequency from several hundreds Hz to

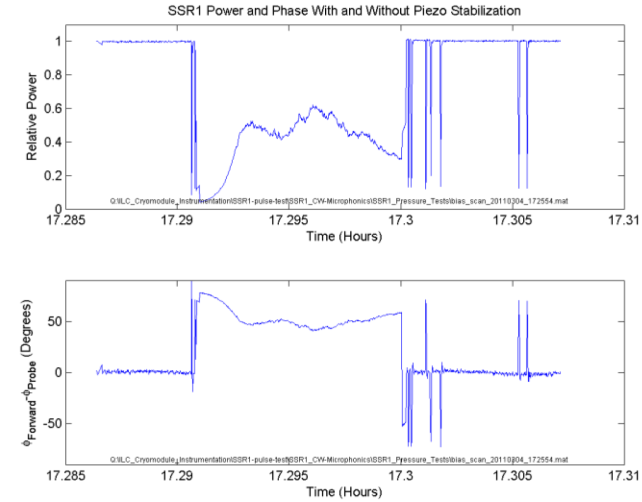
Δf <= 1.3 Hz RMS



Warren Schappert

SSR1 with Wide Bandwidth Coupler

- Second round of CW tests provided an opportunity to gain experience with a wider bandwidth cavity and fixed RF drive frequency
  - Test Conditions
    - 4.5K
    - Cavity bandwidth ~100 Hz
    - RF drive frequency fixed ~325 MHz
  - Detuning control system
    - 104 MHz digitizer measured RF phase difference between forward and probe signals
    - CPU fed $\Delta\phi$ back to fast tuner
- Able to limit pressure related variations
  - Gradient <= 0.2% RMS
  - Phase <= 1.2° RMS



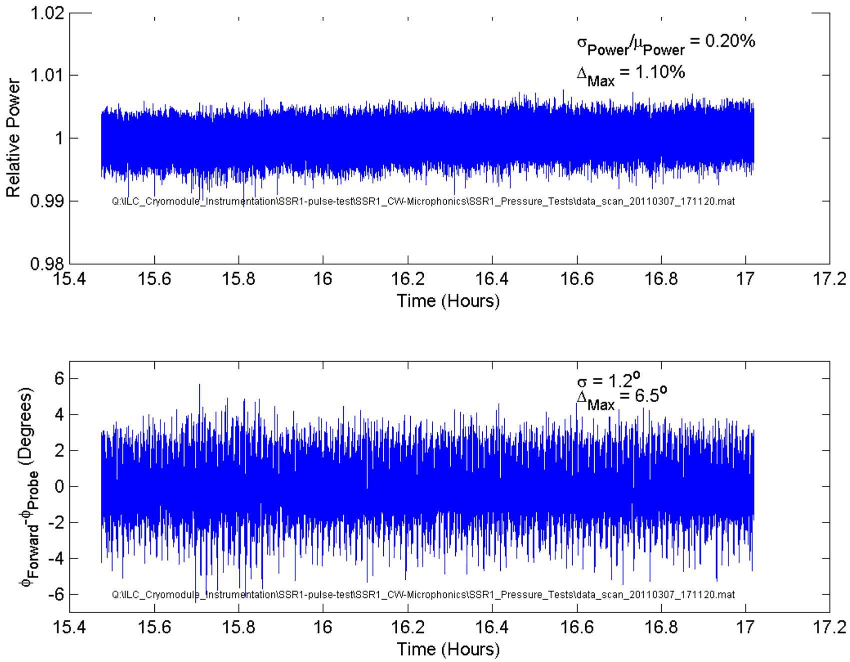


Table 1: A Comparison of the Measured Cavity and Tuner Performance Parameters to the Design Values

Parameter	Units	Measured	Design
Slow Tuning Range	kHz	-220kHz/ +20kHz	-250kHz/ +25kHz
Force on Cavity	kN	13	14
Force on each Piezo Actuator	kN	3	3.5
Fraction of Piezo Blocking Force	%	75	15-85
Cavity Spring Constant	(N/um)	30	20
Cavity Tuning Sensitivity	(Hz/um)	550	500
Unloaded dF/dP	Hz/torr	-280	-360
Loaded (13kN) dF/dP	Hz/torr	-137	-210
Unloaded K_{LF}	$Hz/(MV/m)^2$	2.0	----
Loaded (13kN) K_{LF}	$Hz/(MV/m)^2$	1.5	3.8

Summary

Performances of Prototype Tuner

- Developed for SSR1 Tuner exceed performance requirements (for HINS project):
  - Slow/coarse tuner range -200kHz;
  - Fast/fine tuner capable to compensate ~3500Hz of LFD & 600Hz of pressure related microphonics with just 80V (200V max) in feed-forward loop
  - In CW mode with Feed-back loop (at 4.5K) microphonics can be control below 1.5Hz (rms) level

Tuner Proposal for SSR1

- New SSR1 Tuner design use prototype tuner as a base
  - lever arm;
  - cold slow tuner transmission (motor/harmonics drive/CuBe)
  - cold fast/fine tuner;

- Proposed modifications (work in-progress):
  - Access port inside cryomodule to replace tuner (SNS, JLAB);
  - Increase stiffness of the tuner;
  - Optimization of the slow tuner transmission & piezostack L&S
  - Tune cavity from one side; one flange fixed to He Vessel
    - pros: lower dF/dP;
    - cons: one motor-no redundancy
  - Move piezo assembly away from beam pipe-close to motor
    - pros: decrease rad. exposure for piezostacks; ability to replace; less piezo load during cavity tuning (depend on lever design);
    - cons: less stroke transfer to the cavity (depend on lever design);
  - Dedicate special efforts for tuner subsystem reliability study

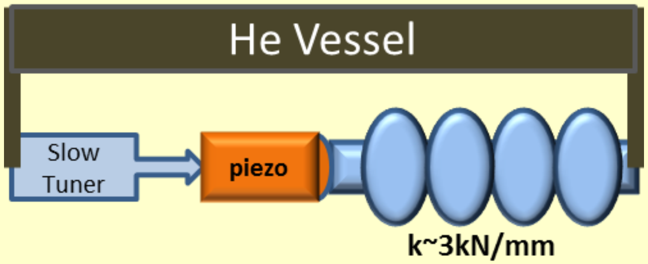
What other options have been considered?

- Different types of tuners kinematics
- Motor & Piezostack warm - outside of cryomodule;
- Slow tuner and piezo in parallel configuration/ instead of in-serious (piezoactuator stroke applied to the side of the cavity not to the beam flange/low dF/dL & complexity to keep piezo preload);
- Tuner located inside spoke…

Different Slow/Fast Tuner Configuration

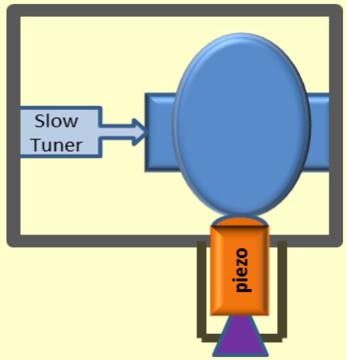
MOTOR/ Harmonics Drive	PIEZO	*CONS*	*PROS*	Tuners
WARM/ outside cryomodule	**WARM/ outside cryomodule**	larger heat load: penetration in He Vessel; usually more complicated design; slower time response of fast tuner (LFDC)	maintanability/reliability (motor&piezo); large stroke of piezo/fine tuning range.	JLAb Upgrade; FRIB;
WARM/ outside cryomodule	**COLD/ inside insulated vacuum**	larger heat load; penetration in He Vessel; usually more complicated design; shrot piezo stroke; difficult(in some design impossible to replace piezoactuator without dis-assembly of cryomodule	maintanability/reliability (for motor- but NOT piezo); fast traslation of tuner stroke to the cavity.	Slide-Jack(KEK)
COLD/ inside insulated vacuum	**COLD/ inside insulated vacuum**	maintanability/reliability is questinoable: if there are no special port in cryomodule to replace motor/piezo (SNS) failure of tuner will lead to removing/dis-assembly whole cryomodule	lower heat load: NO-penetration in He Vessel; usually more simple(less expensive) design;better coarse/fine tuning capability; fast response of cavity to peizo tuner.	SACLAY-I (TTF/XFEL); SACLAY-II; SNS; Blade Tuner (INFN/FNAL); SSR1 (Project X);

Slow-fast tuner in-serious



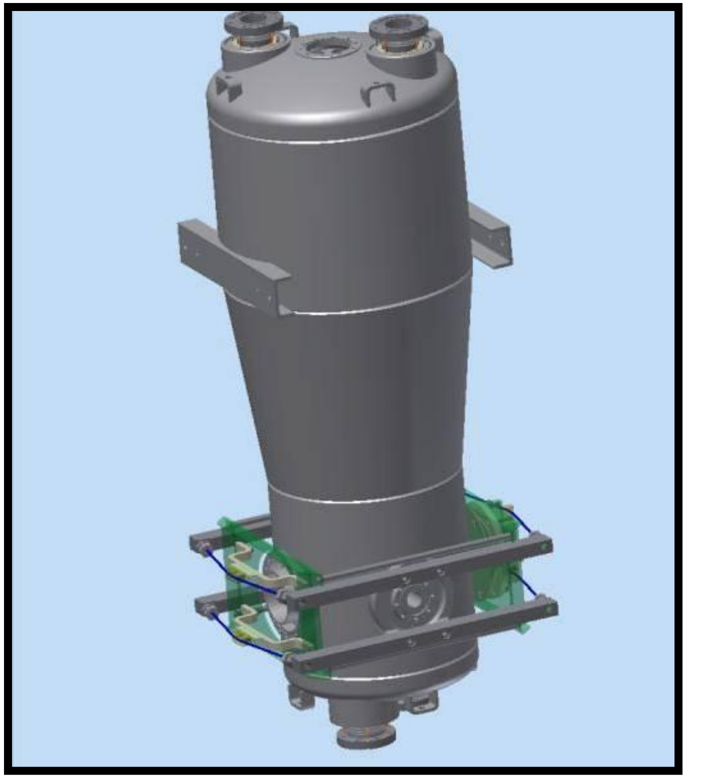
Piezo preload/unload is results of cavity tune range ΔL & K_{cavity}

Slow-fast tuner in-parallel

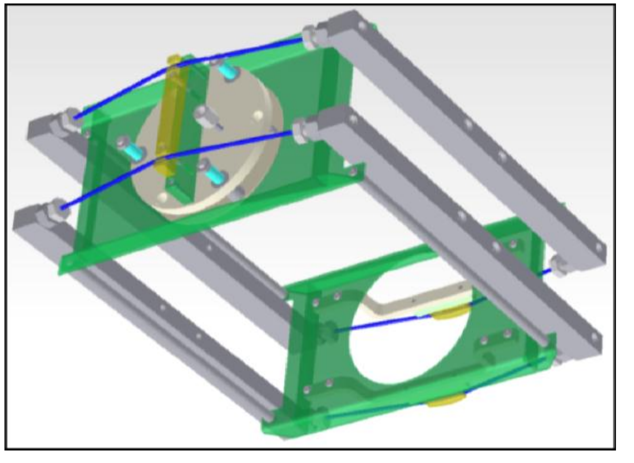


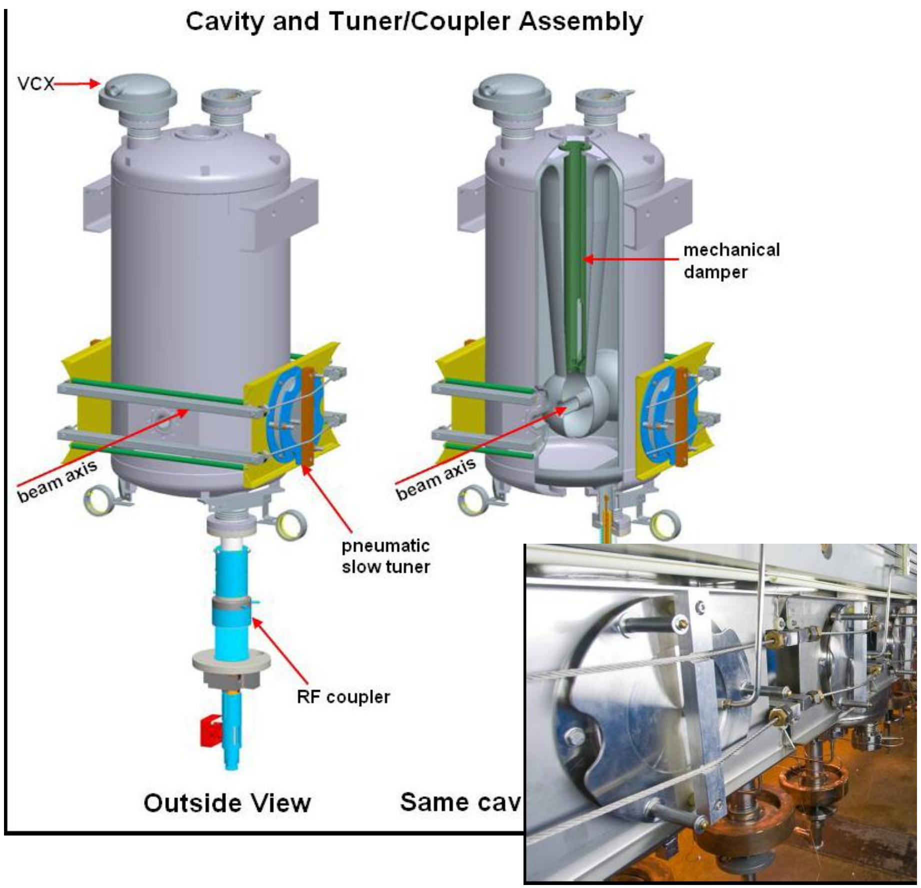
Piezo preload independent from cavity tuning range and K_{cavity}

ANL Pneumatic



- No hysteresis
- No backlash
- No vibration; does not excite microphonics
- **Operates in a continuous feedback mode ????**
  - **(is this cons or pros for slow/coarse tuner ?? ?)**
- Bellows is the only *moving part*
- 109 MHz quarter wave cavity 32kHz tuning window ~1000 Hz / sec slew rate
- Over 5X10^6 integrated operating hours with only 77.82 hours of downtime (downtime records are from 1994 to 2011)
- Can be easily applied for HWRs





Compensation of slow time varying frequency shifts (~1 Hz or slower) is done by deforming the cavities along the beam axis using a pneumatically operated stainless steel bellows (see Figure 3). The bellows are pressurized using helium **gas at 77 K and a maximum pressure of 0.6 bar.** The 30 kHz tuning range corresponds to a 2.5 cm bellows stroke and a 4 mm cavity length change along the beam axis.

30kHz for 4mm → 7.5Hz/um

For SSR1 → 500Hz/um

(67 times more sensitive) ---- this is related to accuracy of Pressure control

Lets assume that we use 2atm to tune cavity for 200kHz.
We will need pressure transducers with resolution of better than 10e-5 bar to control cavity frequency within 1Hz.

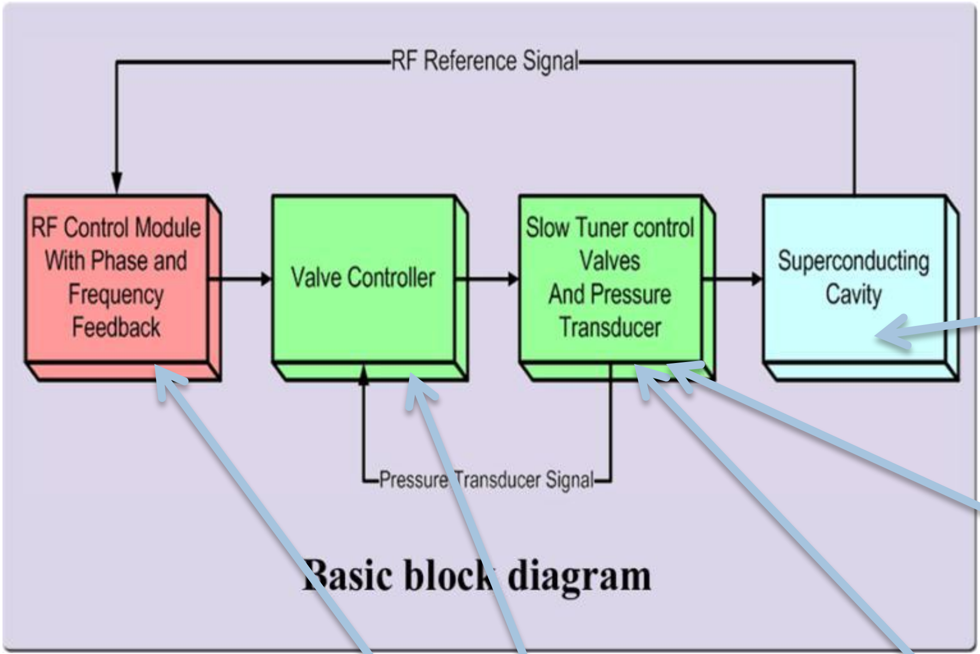
Kinematics and Forces

SSR1 stiffness is ~30kN/mm

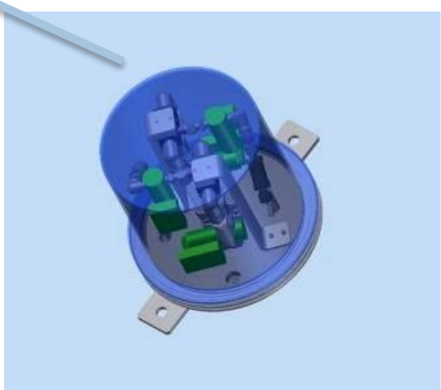
~12000N required to tune SSR1 for 200kHz

Stiffness of ANL cavity =???

Slow Tuner Block Diagram and Components



97 MHz cavity unit



109 MHz cavity unit

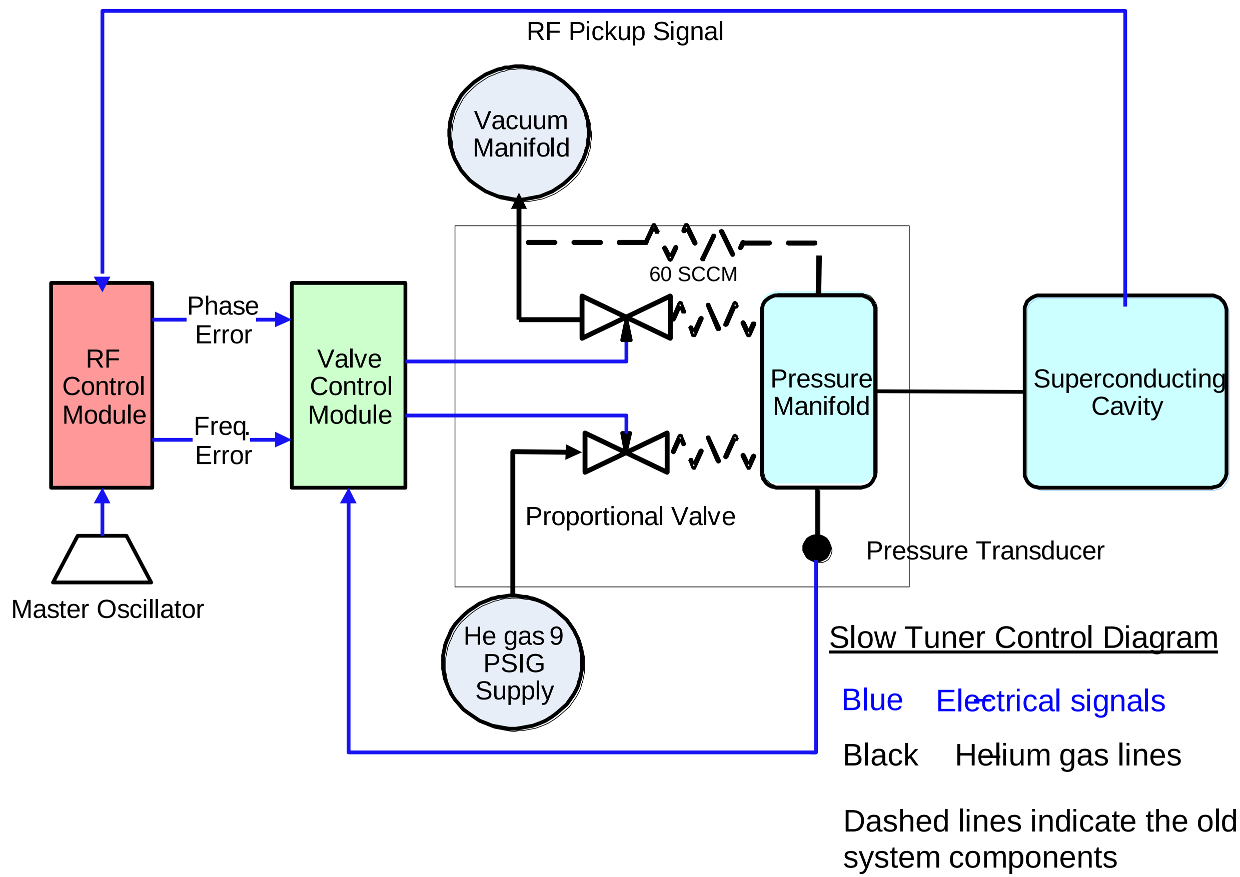
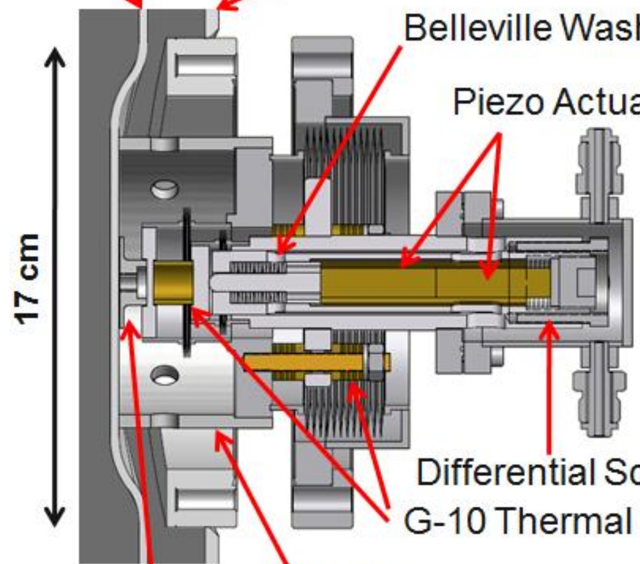


Figure 2. Slow tuner system detailed diagram. Flow restrictors and bypass leak shown in dashed lines.

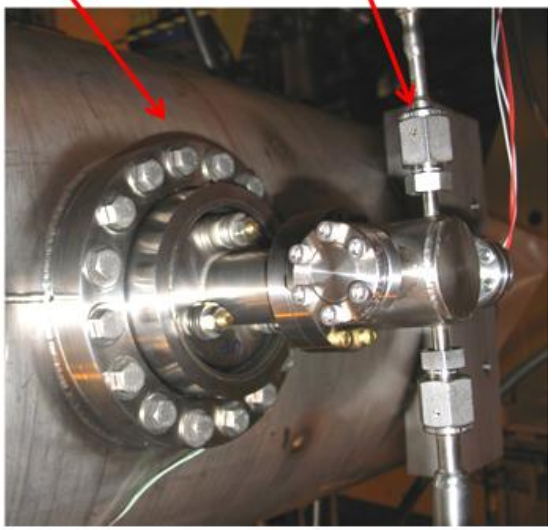
ANL Fast Tuning System for Atlas Intensity Upgrade Cryomodule

<u>The piezo transducer presses on a small niobium button electron-beam welded directly to the cavity wall</u> and reacts against a 3 inch diameter niobium ring also welded to the cavity wall. In this way the cavity helium vessel is essentially removed from the tuner mechanical system.

The 80 K piezoelectric stacks are directly cooled by liquid nitrogen and separated from the 4 K niobium by G-10 thermal breaks.



Fast Tuner Cross Section
Nb Ring and Button Welded To Cavity



Fast Tuner On HWR Cavity

Kelly et al, LINAC2010, THP057

<u>There is no link between slow and fast tuner… piezo preload (360lb) is provided by Belleville washers.</u>

Special design efforts (choice materials with know ΔL/ΔT) have been made to keep tuner operational (control of preload and ΔL) after cool-down.

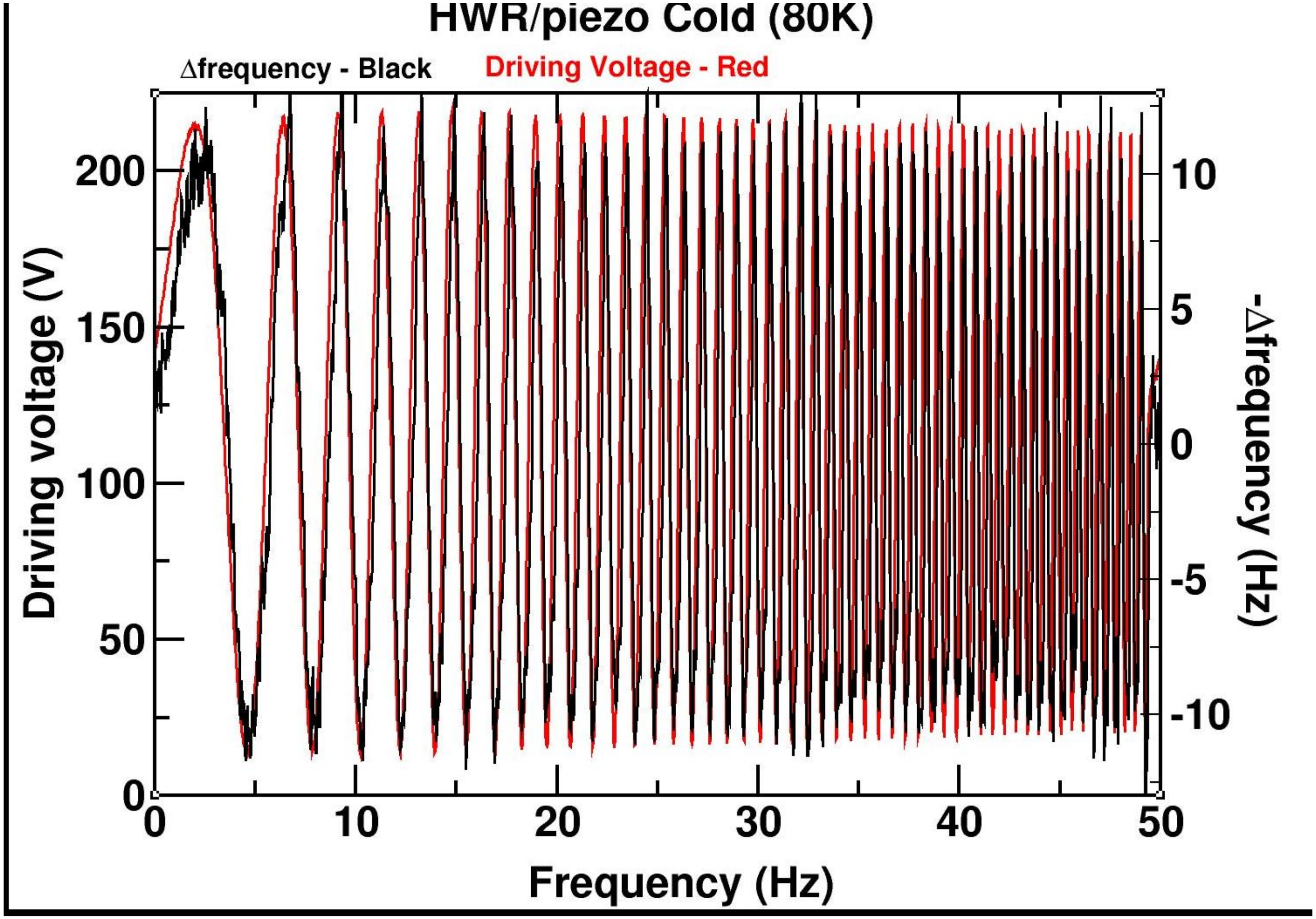


Figure 4: First measurement at 4 Kelvin of cavity frequency response to a piezoelectric tuner driving voltage.