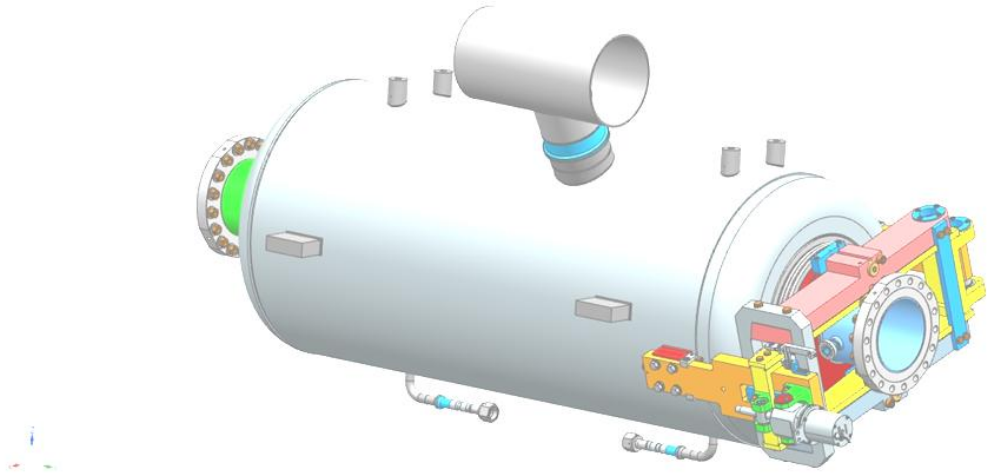
Tuner activities at RRCAT



Vikas Jain, K. K. Singh, A. Puntambekar, P. Shrivastava

SCDD, Proton Accelerator Group

Raja Ramanna Centre for Advanced Technology, Indore, India

650 MHz Tuner FDR

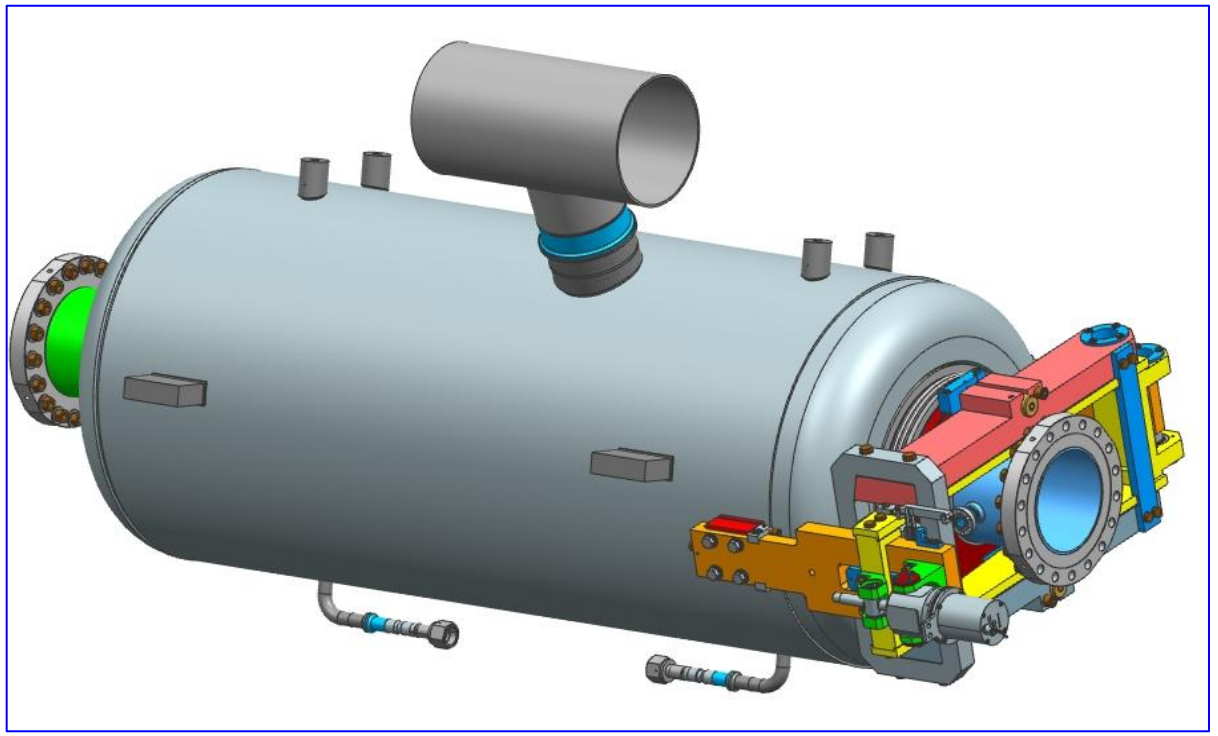
29th July 2020

Outline

- 650 MHz SCRF cavitity Tuner Development at RRCAT
- FRS of HB650 β=0.92 cavity Tuner
- Lever Tuner Development at RRCAT
- Testing of Tuner on Test stand
- Testing of Tuner on Dressed Cavity
  - Slow tuner test
  - Piezo tuner test (DC and Pulsed)
- Transfer Function Measurement
- Pressure & Leak Testing of Dressed Cavity using Safety Bracket
- Summary

650 MHz SCRF cavitity Tuner Development at RRCAT

RRCAT is developing 650 MHz dressed cavities with tuners in collaboration with Femilab (IIFC) and will deliver 4 HB650 dressed cavities with tuner under IIFC during R&D phase. RRCAT is also working for LB650 cavity tuner during R&D phase.



Model of HB650 β=0.92 cavity with IIFC's Lever Tuner

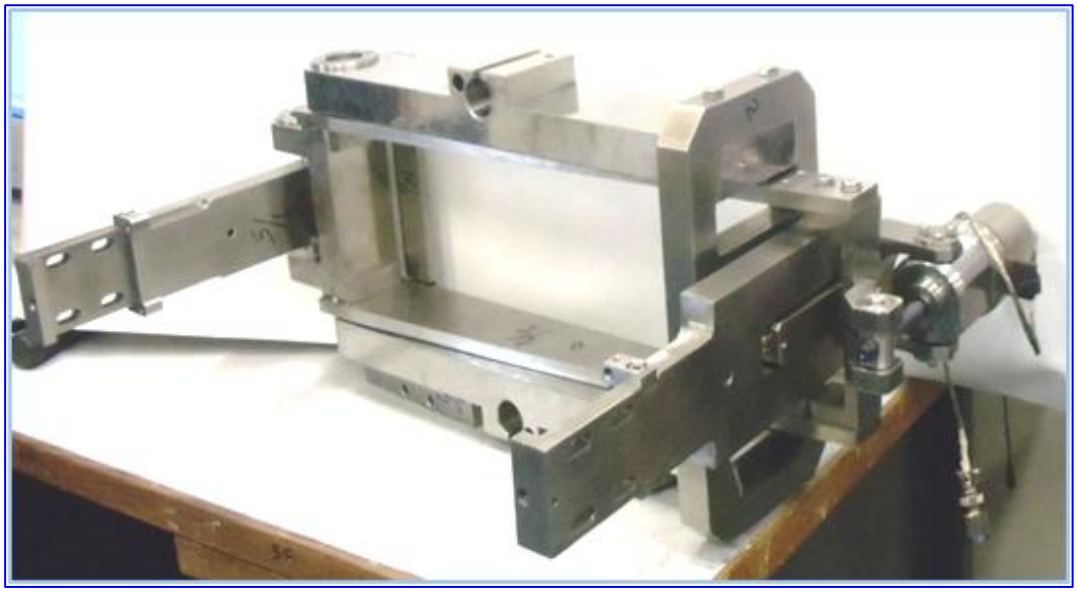
FRS of b=0.92 cavity Tuner, ED0009659

		B0.90	B0.92	B0.61
Cavity	Parameter	Value	Value	Value
	stiffness, N/um	20	5	4
	tuning sensetivity, Hz/um	180	160	240
Mechanical	Parameter	Value	Value	Value
	Tuner-dressed cavity system stiffness, kN/mm	**>40**	**> 40**	**> 40**
	Lowest mechanical resonance of cavity/tuner system, Hz	**>100**	**>100**	**>100**
	Maximum force on the tuner system, kN	11	7	3.5
	Tuner operating temperature (insulating vacuum), K	10-60	10-60	10-60
Slow Tuner	Parameter	Value	Value	Value
	Slow tuner frequency range, kHz	**100**	**200**	**200**
	Stepper motor resolution, Hz/step	**≤ 1**	**≤1**	**≤1**
	Slow tuner hysteresis, Hz	**≤ 100**	**≤ 100**	**≤ 100**
	Slow tuner dimensional range, mm	0.85	1.5	1
	Maximum force on the spindle system, N	550	350	200
	Stepper motor maximum operation current, A	2.5	2.5	2.5
Fast Tuner	Parameter	Value	Value	Value
	Piezo tuner frequency range (at V=120V), Hz	**1200**	**1200**	**1200**
	Piezo tuner frequency resolution, Hz	**<0.5**	**<0.5**	**<0.5**
	Piezo tuner dimensional range, μm	9	9	6
	Maximum operating force (each piezo capsule), kN	6	4.2	2.5
	Piezo actuator maximum operating voltage, V	120	120	120
Lifetime	Parameter	Value	Value	Value
	Tuner operation lifetime, year	**>25**	**>25**	**>25**
	Maximum number of electromechanical actuator spindle rotations	2.00E+03	2.00E+03	2.00E+03
	Maximum number of piezo-electrical actuator control pulses	4.00E+10	4.00E+10	4.00E+10

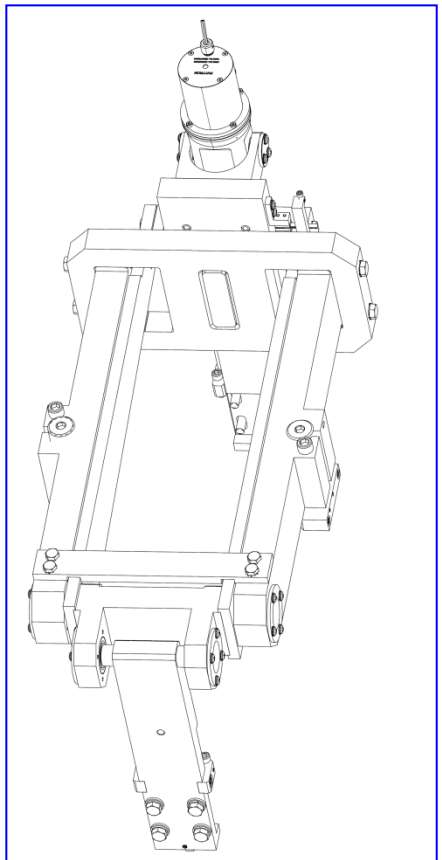
RRCAT/DAE participated in Tuner design activities at Fermilab.

Lever Tuner Development at RRCAT

- FNAL has updated the lever tuner design in April 2018 by shifting piezos to the center of lever. With updated drawings 5 Nos of HB650 tuners have been fabricated.
  - Drawings used ➔ F10088673 (ASSEMBLY, LEVER TUNER 650 CAVITY) and its associated parts
- Tuner components under fabrication for LB650 cavities
- Other component purchased
  - piezos (Make:PI, Model: P-844K075),
  - motors(Make: Phytron, Model: LVA 52-LCLS II-UHVC-X2),

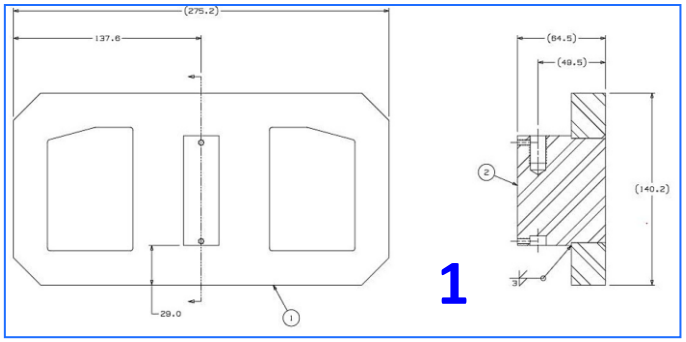


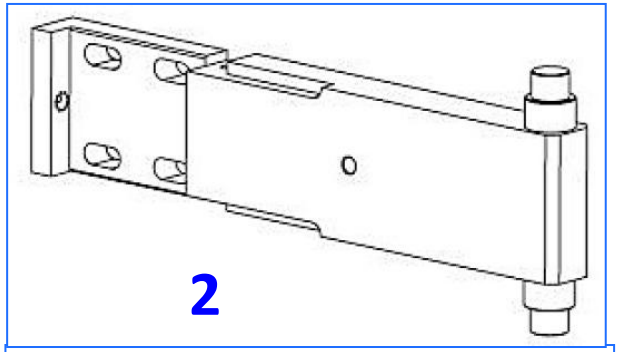
Fabricated Tuner Assembly

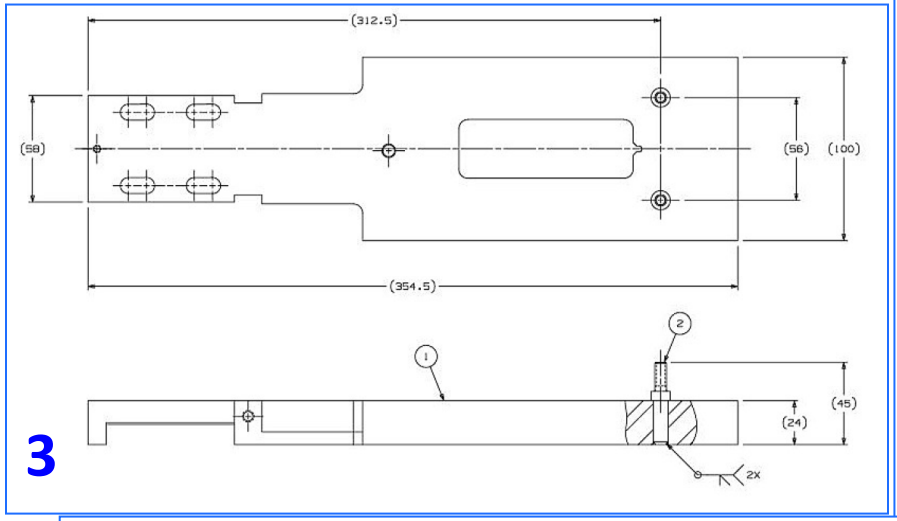


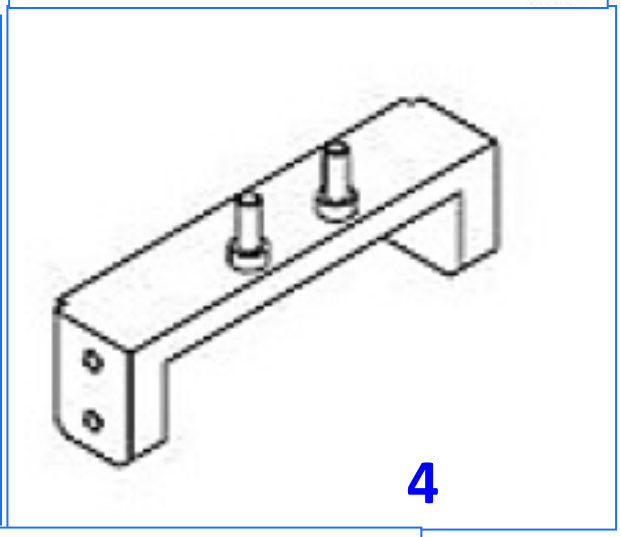
F10088673

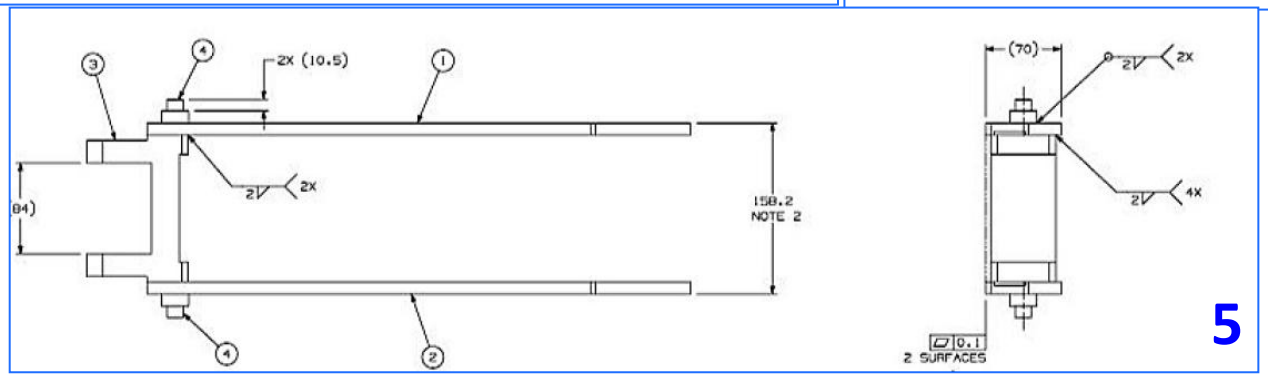
Lever Tuner Development Weldment- subassemblies



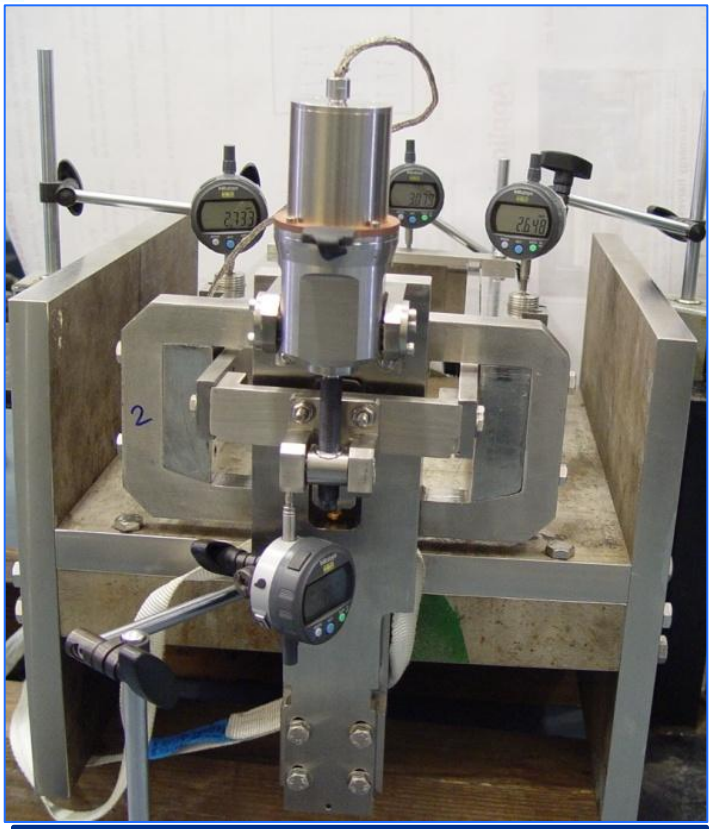




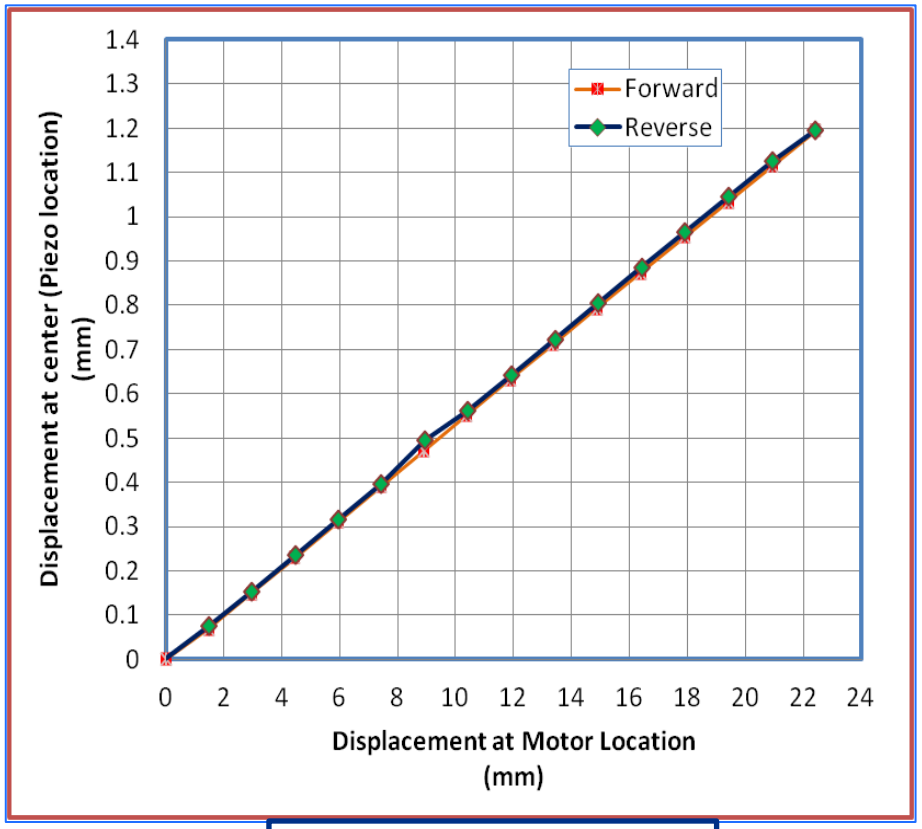




Testing of Tuner on Test stand



Tuner Assembly with Test Stand



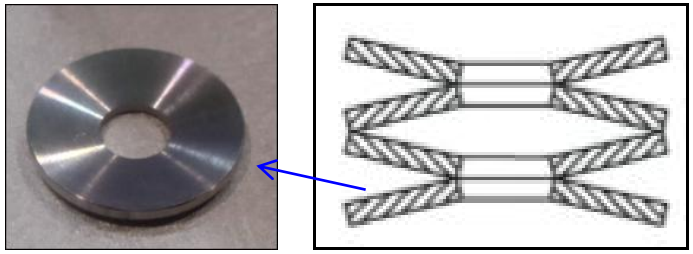
Test result at no load

Spring with very low stiffness for no load test

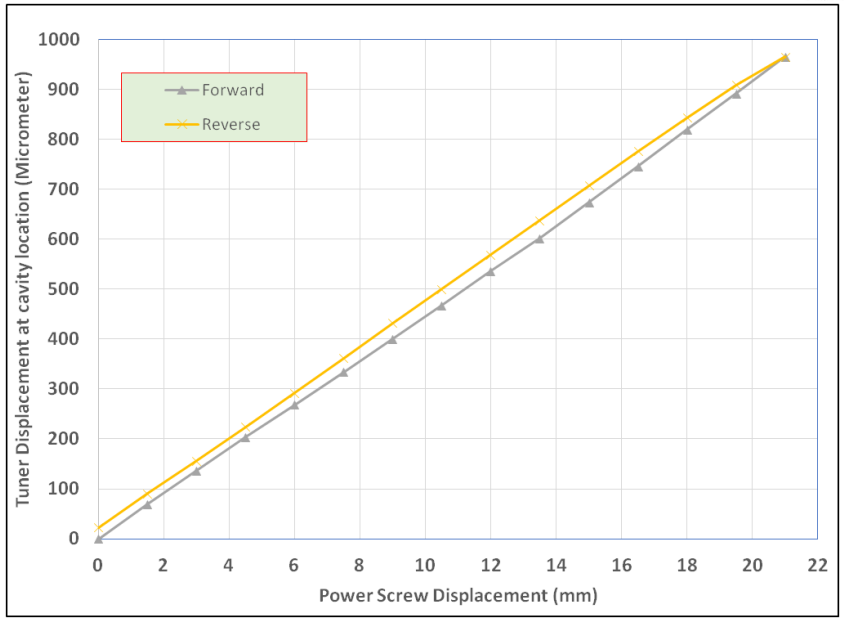
Measured Tuner Mechanism mechanical advantage = 18.98

Testing of Tuner on Test stand …

Testing of Tuner at load



4 – Springs in series for each side



2.8 kN load on each piezo for 1 mm displacement

Stiffness of one Belleville Spring washer : 11.36 kN/mm

Material of Belleville Spring : SS304L

Calculation of Tuner Stiffness

Spring stiffness K_c = 5.68 kN/mm (Total 4 washers each on two tuner arms)

Tuner Mechanism mechanical advantage N_0 = 18.98 @ No Load

Tuner Mechanism mechanical advantage N_L = 21.65 @ 5.6kN Load

Tuner Stiffness $K_T = K_C * (N_L - N_0) / N_0$ ~ 40.3 kN/mm (Using approx. formula)

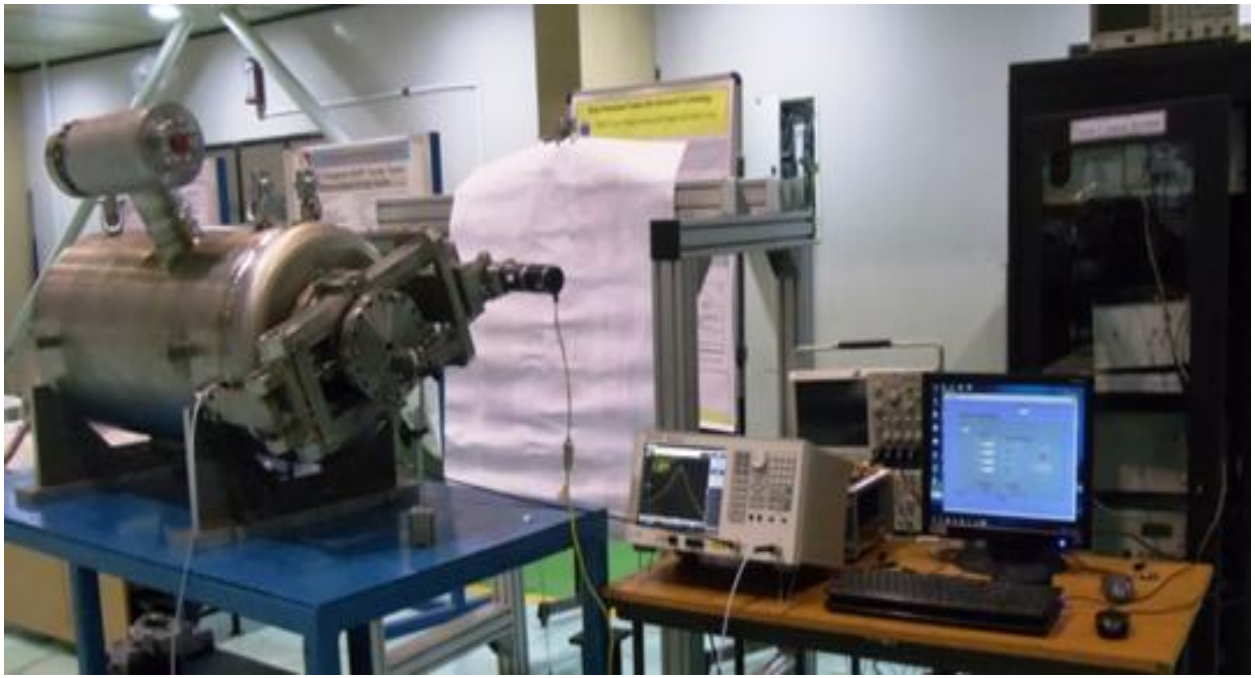
Design value 40 kN/mm (FRS)

Testing of Dressed HB650-501 cavity with Tuner

One HB650 Five-cell SCRF cavity dressing has been completed at RRCAT.

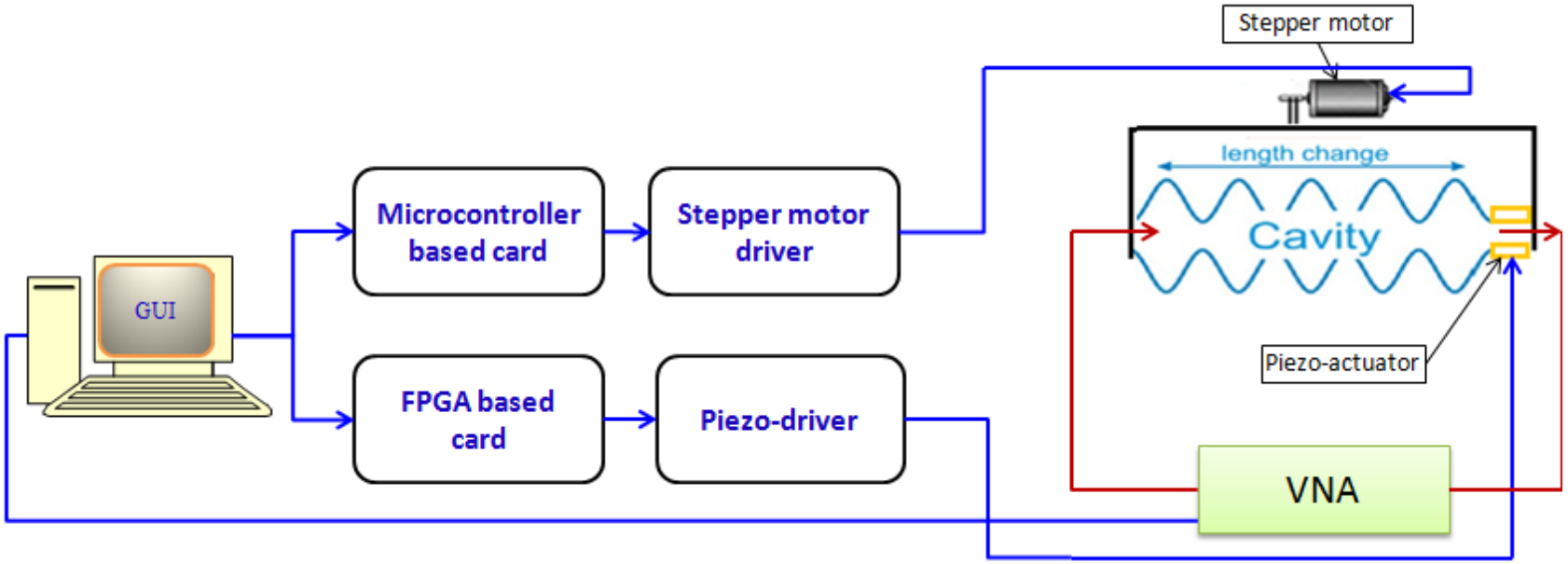
Following tests were carried out on dressed cavity tuner assembly at room temperature

1. Slow tuner test
2. Piezo tuner test
    1. DC excitation
    2. Pulse testing
3. Transfer Function Measurement



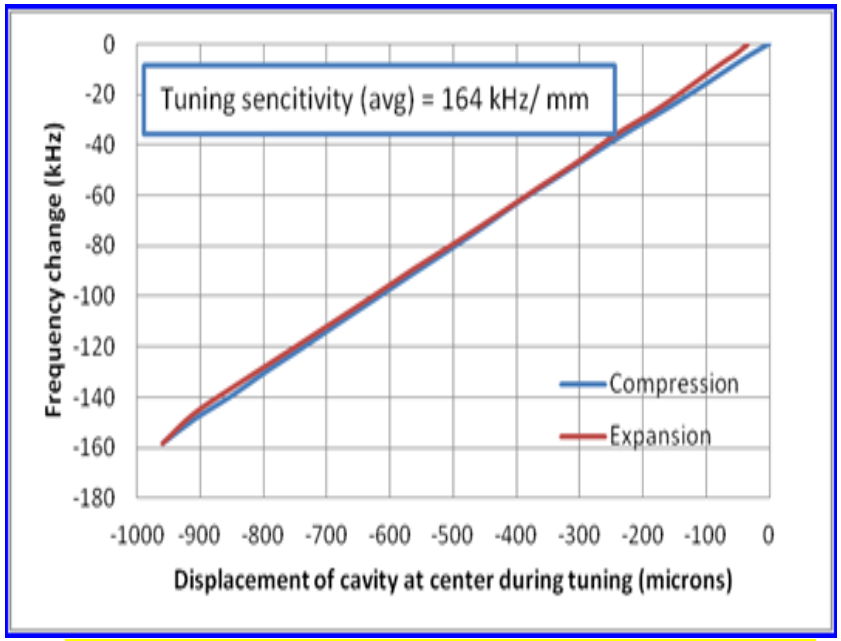
Lever Tuner Test Setup with 5-cell 650 MHz SRF cavity

Tuner control and frequency measurement system

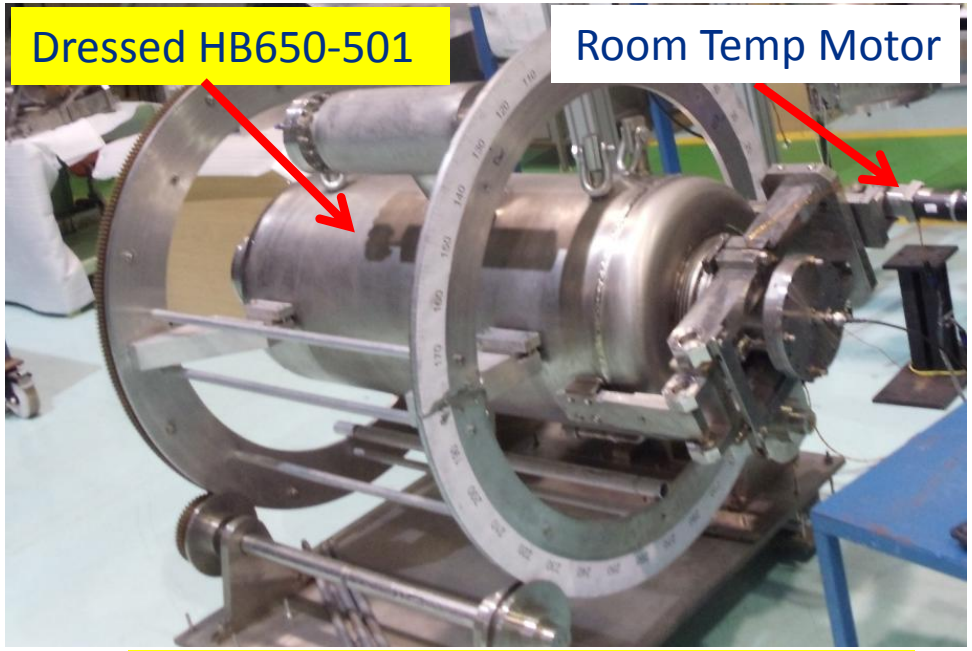


- Motor- controller and driver have been developed to drive the motor upto cryogenic environments.
- Piezo-controller and driver have been developed to excite piezos with half-sinusoidal pulses with pulse width ≥ 1 ms at repetition rate of up to 60 Hz

Tuner Testing for Slow tuning – 300 K



Slow tuner characteristic curve



Tuner Assembly on HB650-501

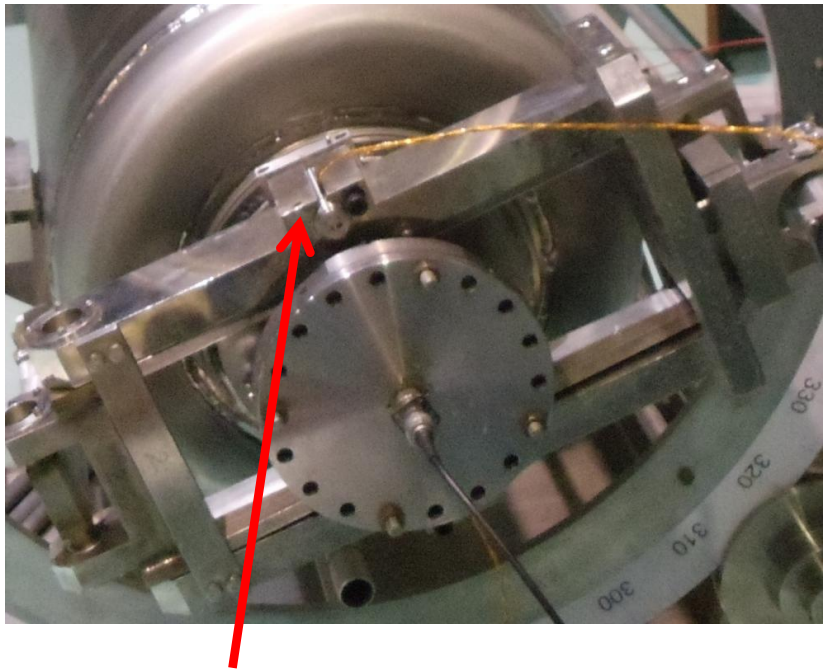
Measured Tuning sensitivity = 164 kHz/mm at 300 K

FRS value = 160 kHz/mm

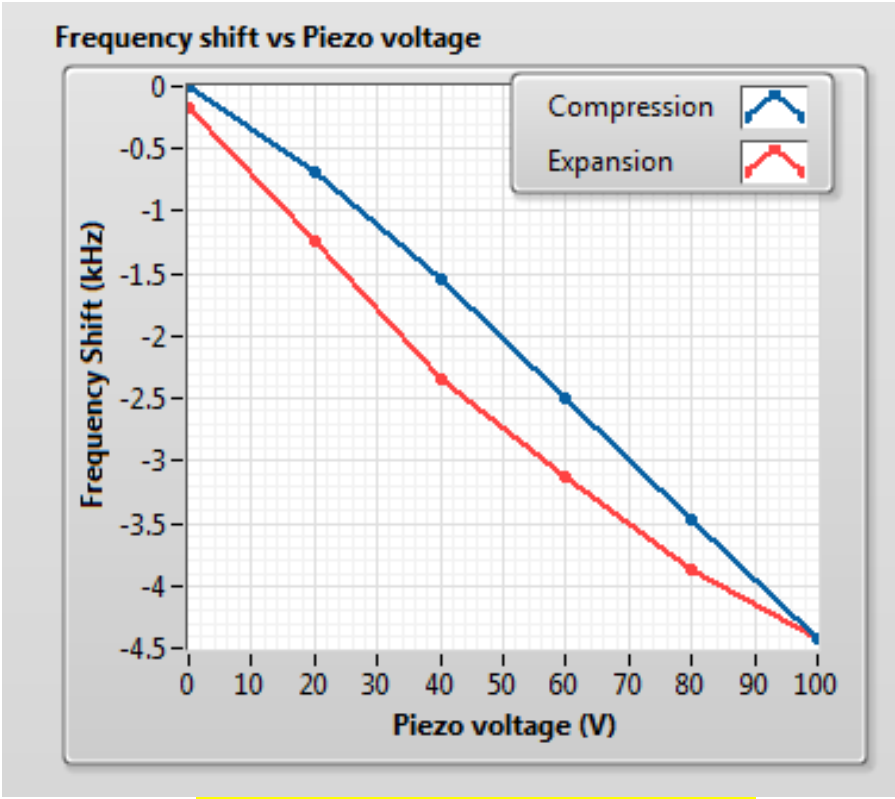
Estimated value (FEM analysis) = 164.34 kHz/mm)

Slow tuning resolution is calculated from the measurement done over the entire range as **0.76 Hz/step as against FRS ≤ 2 Hz/step.**

Tuner Testing for Piezo tuner DC Excitation – 300 K



Piezo Actuator



Piezo DC excitation Curve

- Piezo voltage is increased in the steps of 20 V.
- A total of 4.4 kHz frequency was changed for 100V at 300 K.

Tuner Testing : Piezo actuator pulse Excitation for fast Tuning- 300 K

Phase measurement by VNA during piezo excitation

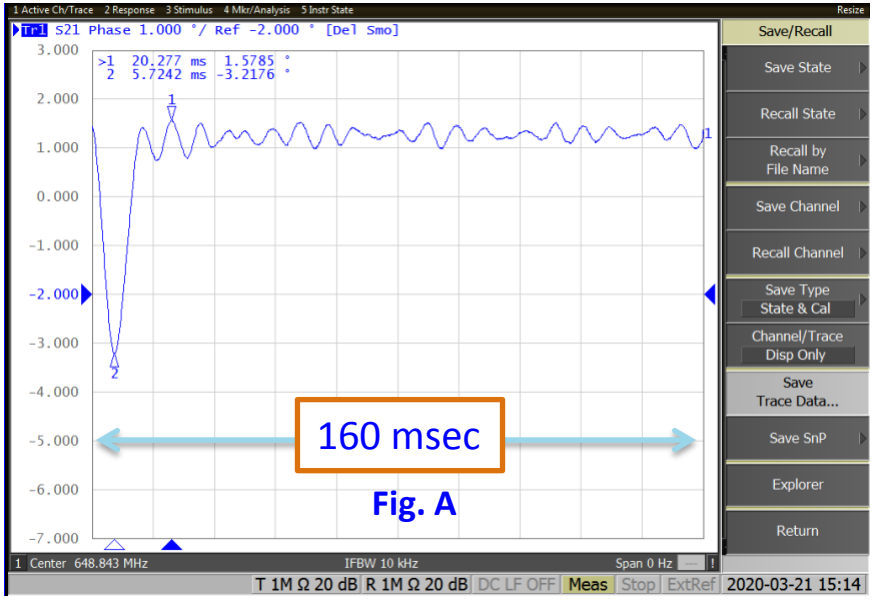


Fig. A

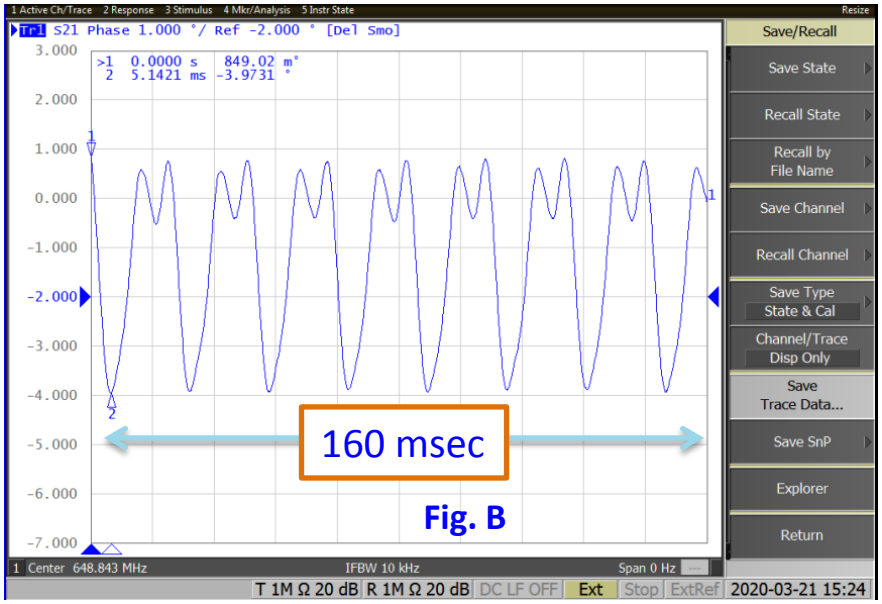


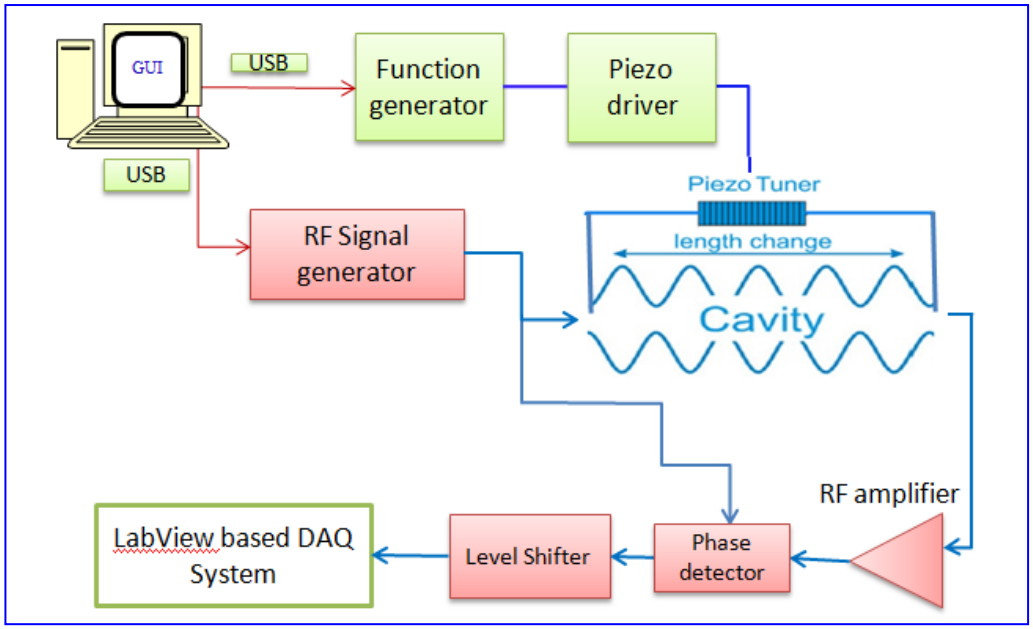
Fig. B

Piezo pulse: 10 msec,
rep rate: 1 Hz
Peak to peal voltage: 60V

Piezo pulse: 10 msec,
rep rate: 50 Hz
Peak to peal voltage: 60V

For 60V pulse Half sine wave Maximum of 4.7^{o} Phase shift was observed, which corresponds to 2.8 kHz Frequency change. The effect of previous pulse is also observed as shown in Fig. B.

Transfer Function measurement

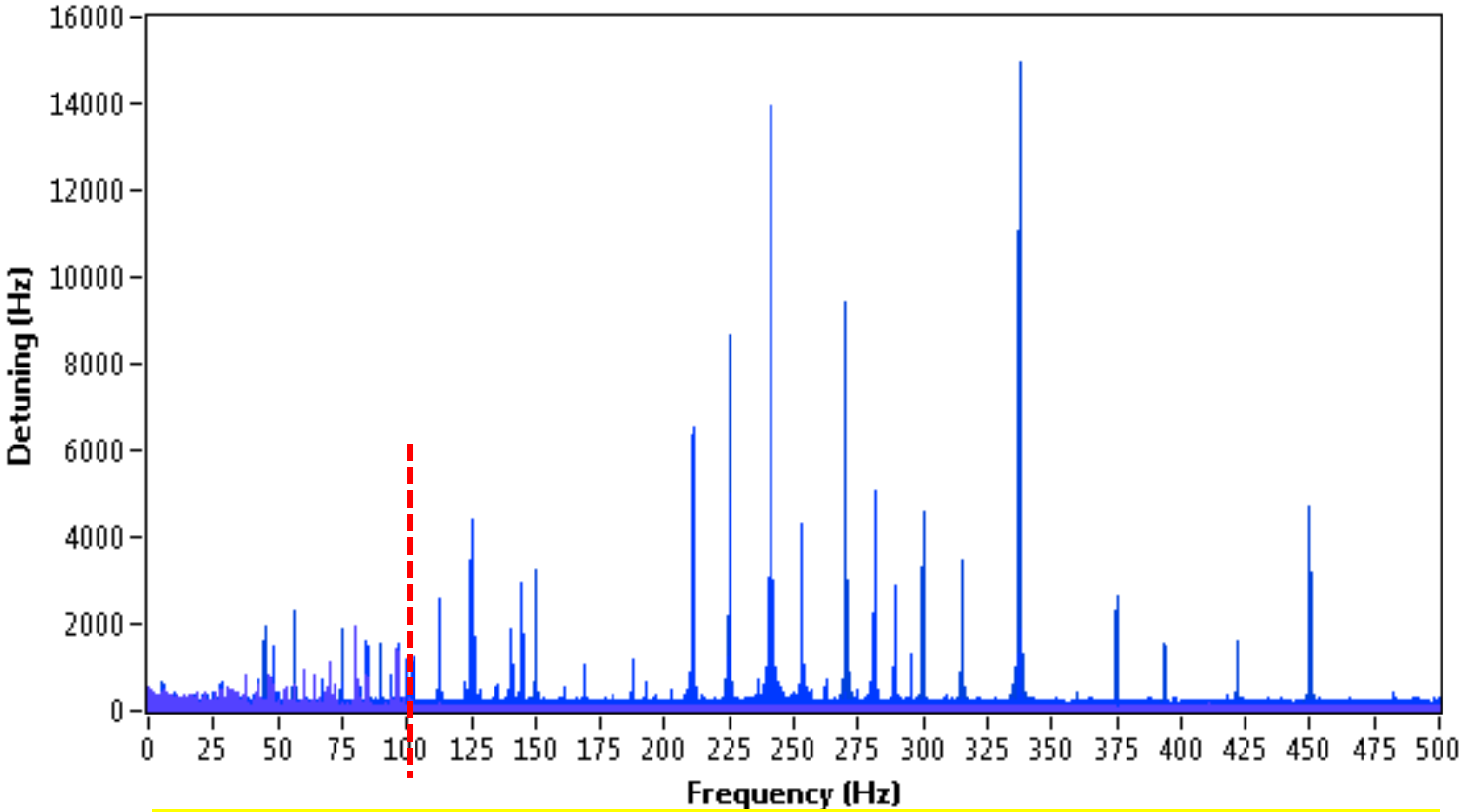


Layout

- Setup consists of RF signal generator, Function generator, splitter, phase detector, LabView DAQ system and Piezo- amplifier
- The output signal of the phase detector is proportional to the phase shift between Incident and transmitted power was digitized using LabView based DAQ system

Transfer Function measurement

- Piezos are excited with Sinusoidal waves and frequency Swept from 1 Hz to 500 Hz
- Cavity response measured ➔ Plotted FFT



Transfer function of HB650-501 Cavity Mounted on rotating Fixture.
This will be measured again HTS assembly at 300K.

B0.92 tuner warm test results and simulation :Summary

			RRCAT	
			Warm test	
	TC documents which has Tuner requirements	B0.92	**B0.92**	B0.61
Cavity	**Parameter**	Value		Value
	stiffness, N/um	5		4
	tuning sensetivity, Hz/um	150	**164**	240
Mechanical	**Parameter**	Value		Value
	Tuner-dressed cavity system stiffness, kN/mm	**> 40**	**40.3**	**> 40**
	Maximum force on the tuner system, kN	7	**7.5**	3.5
	Tuner operating temperature (insulating vacuum), K	10-60		10-60
	Lowest mechanical resonance of cavity/tuner system, Hz	**>100**		**>100**
Slow Tuner	Parameter	Value		Value
	Slow tuner frequency range, kHz	**200**	**150** [1]	**200**
	Stepper motor resolution, Hz/step	**≤1**	**0.76** [3]	**≤1**
	Slow tuner hysteresis, Hz	**≤ 100**		**≤ 100**
	Slow tuner dimensional range, mm	1.5	**0.95**	1
	Maximum force on the spindle system, N	350		200
	Stepper motor maximum operation current, A	2.5		2.5
Fast Tuner	Parameter	Value		Value
	Piezo tuner frequency range (at V=120V), Hz	**1200**	**4400** [2]	**1200**
	Piezo tuner frequency resolution, Hz	**<1**		**<1**
	Piezo tuner dimensional range, μm	9	**27**	6
	Maximum operating force (each piezo capsule), kN	4.2	**3.75**	2.5
	Piezo actuator maximum operating voltage, V	120	**100**	120
Lifetime	Parameter	Value		Value
	Tuner operation lifetime, year	**>25**		**>25**
	Maximum number of electromechanical actuator spindle	2.00E+03		2.00E+03
	Maximum number of piezo-electrical actuator control pulses	4.00E+10		4.00E+10
	Maximum allowable radiation dose, Rad	5.00E+08		5.00E+08
	[1] **Warm tuner range limited by cavity max. allowable compression**			
	[2] **Stroke of the warm piezo large than cold.**			

Pressure test of dressed cavity with Safety Bracket

As per the design requirement of MAWP (Maximum Allowable Working Pressure) at room temperature the cavity was tested (Pneumatic, 1.15 x MAWP) upto 34.5 psig using ultrapure nitrogen gas.

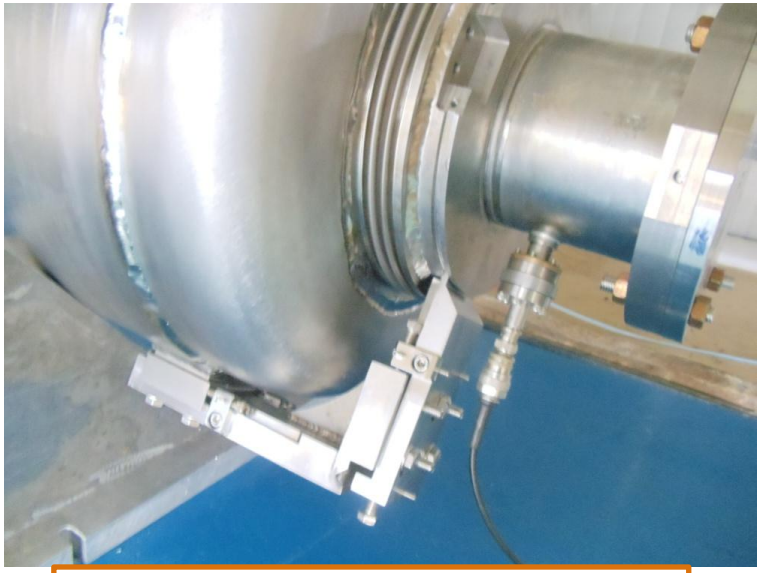
•Having proper pressure relief valves and properly installed safety bracket are crucial to ensure protection of cavity and bellow from over pressure.

•The pressure in the helium jacket was gradually increased with pre-defined hold time at each pressure.

•Change in cavity frequency is recorded with pressure variation and plotted with time is shown in fig..

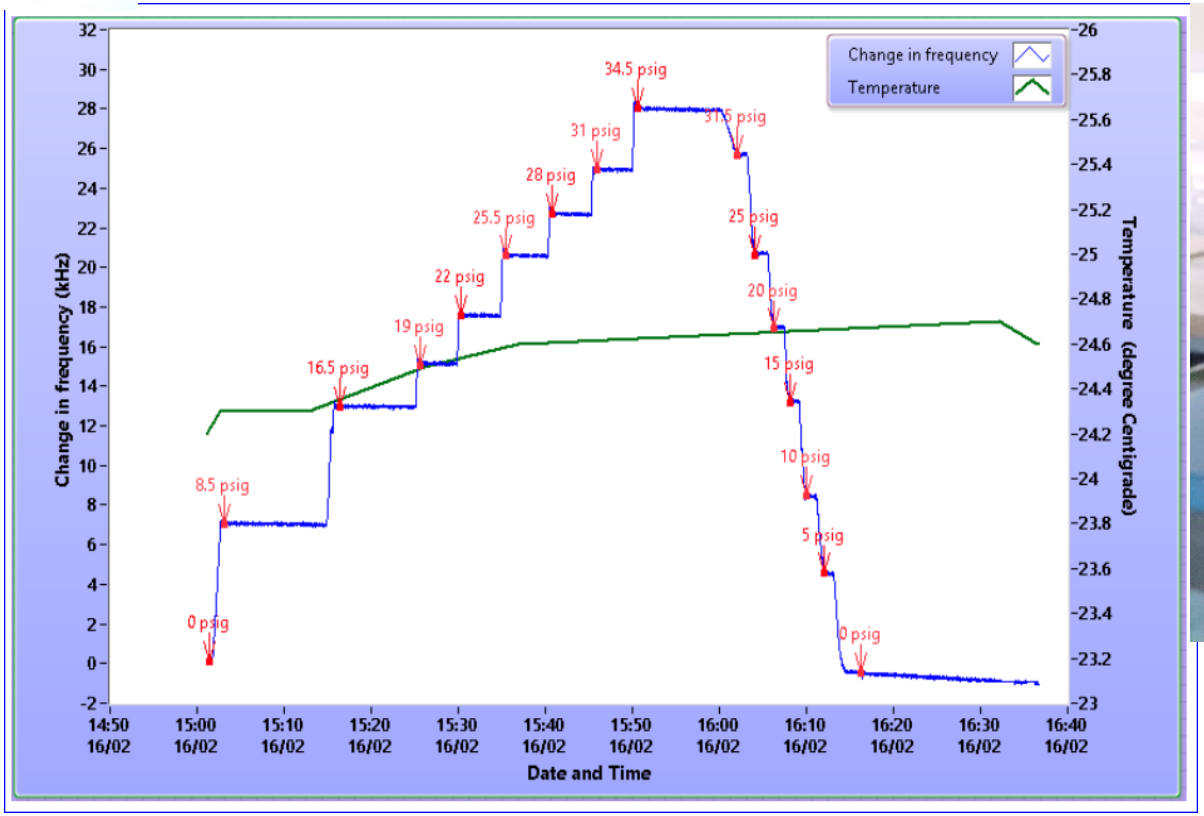
•Maximum frequency change of 28 kHz (transient) has been observed at 34.5 psig and no reduction in the pressure was observed at different stages during pressure testing.

•At the end of pressure only marginal frequency shift of -0.5 kHz was recorded.



Dressed cavity with Safety Bracket

Date and Time: 16 March 2020, 15:00



Change in cavity frequency is recorded with pressure variation and plotted with time is shown in figure below. Maximum frequency change of 28 kHz has been observed at 34.5 psig.

Leak testing of dressed cavity with Safety Bracket

Pressure test steps – 650 MHz beta=0.92 Dressed Cavity

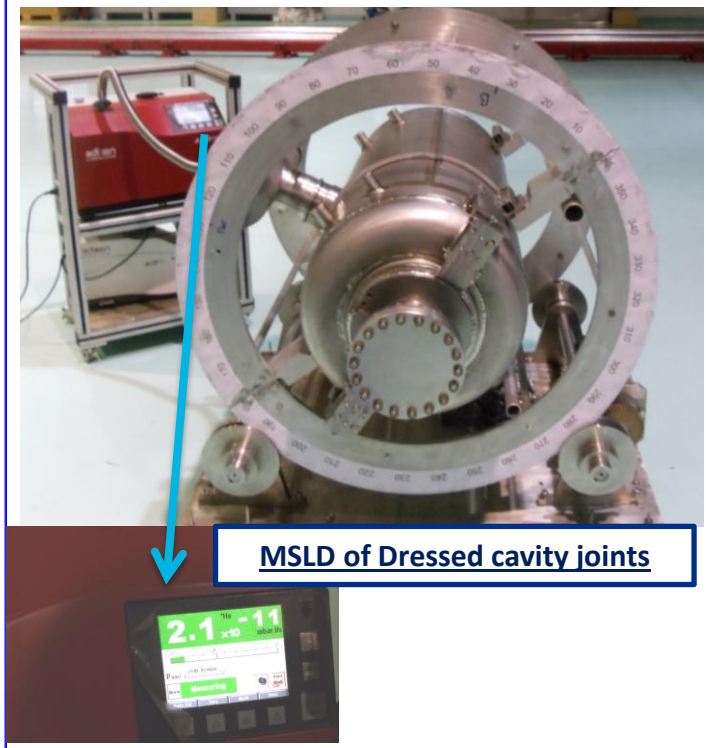
RF representative: Kuldeep Kumar Singh

Starting frequency: 648·933 MHz Temp = 24·2°C

Pressure (psig)	Hold time (minutes)	Activity at pressure	Frequency change [kHz]	Maximum frequency change [kHz]	Temp (°C)
0	As needed	RF Check	0	0	24·2
8	10 min	RF Check, Visual leak check	7·0	17	24·3
16.5	10 min	RF Check	13·0	35	24·4
~~19.5~~ 19·0	5 min	RF Check	15·1	42	24·4
~~22.5~~ 22·0	5 min	RF Check	17·6	48	24·5
25.5	5 min	RF Check	20·6	55	24·5
~~28.5~~ 28·0	5 min	RF Check	22·7	61	24·6
~~31.5~~ 31·0	5 min	RF Check	24·3	68	24·6
34.5	10 min	RF Check	28·0	74	24·6
31.5	As needed	RF Check, Visual leak check	25·7	69	24·6
25	As needed	RF Check	20·7	57	24·6
20	As needed	RF Check	16·9	49	24·6
15	As needed	RF Check	13·2	40	24·6
10	As needed	RF Check	8·4	31	24·6
5	As needed	RF Check	4·5	23	24·6
0	As needed	RF Check	−0·5	14	24·5

Comments:

Kuldeep 16/5/20



MSLD of Dressed cavity joints

MSLD setup is attached at one of the port of T.
➔ Leak rate of 2.1×10^{-11} mbar-lt/sec

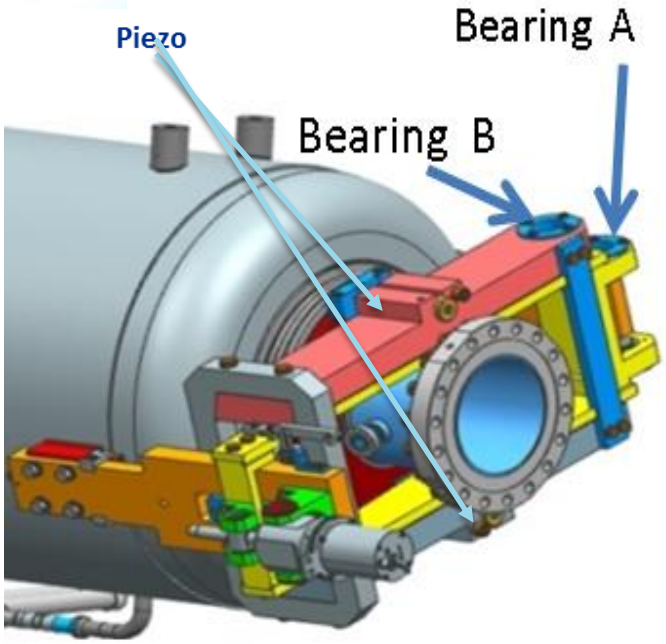
Summary

- Design and analysis of HB650 Lever Tuner has been completed.
- Five numbers of Lever tuner for HB650 Cavity are fabricated at RRCAT. (Two sets Tuner for LB650 cavity are also under fabrication.)
- RRCAT has developed stepper motor driver controller and piezo driver controller.
- HB650 tuner and controller is tested for slow and fast tuning at 300 K.
- Tuner test at cold
  - Planned on AES-010 (beta=0.9) dressed cavity (Incoming from FNAL).
  - Planned on HB650-501 (beta =0.92) dressed cavity.
- Pressure testing using **safety bracket** of HB650-501 was carried out successfully

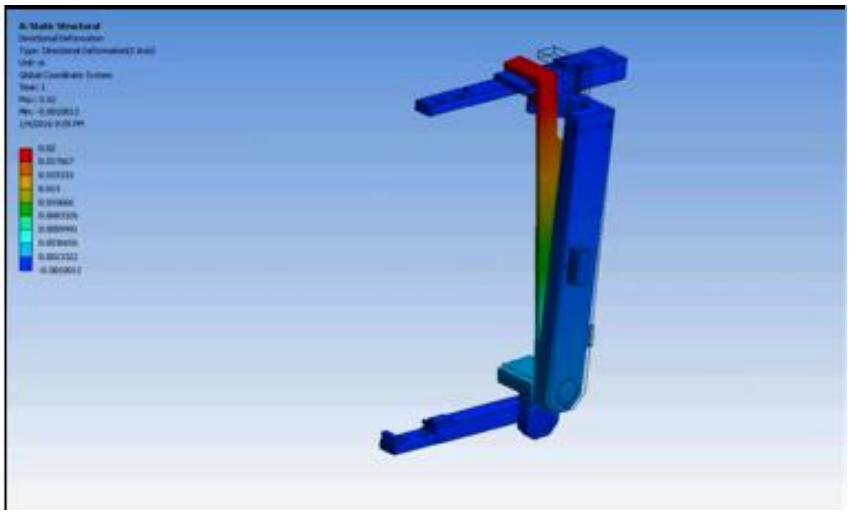

Thanks For Your Kind Attention!

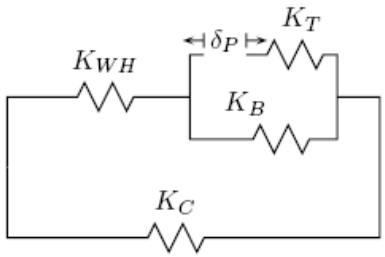
Back-up Slides

Lever Tuner design



Motor & power screw location





Equivalent spring model

Lever tuner Description

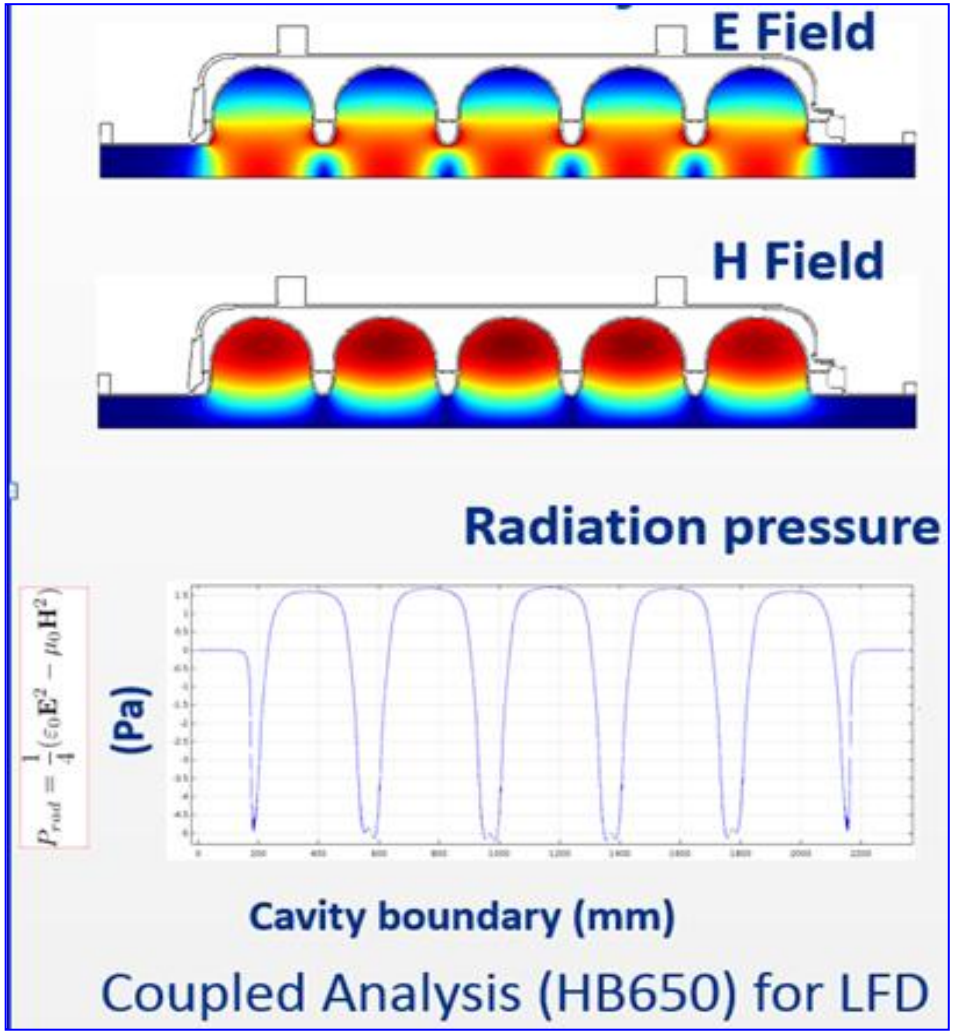
This mechanism consists of double lever arrangement, with ~ 20:1 mechanical advantage ratio.

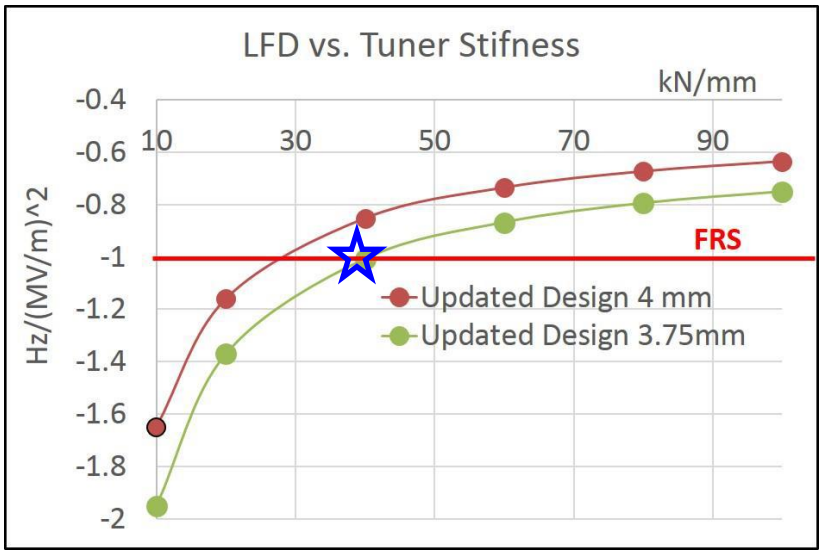
Slow tuning: Geared stepper motor guides the thin lever (yellow) which turn around bearing A and move bearing B in order to move thick lever (Red). Thick lever is in connection with transition ring connected to the cavity. So, stepper motor transmits force through thick liver to the cavity through piezo elements.

Fast tuning: Two piezo actuators, assembled at the centre between transition ring and red lever, transmit force directly to the cavity . In order to operate the tuner in fast tuning mode piezo actuators are excited.

Lever Tuner design …..

LFD analysis for Tuner *





Tuner Stiffness required = 40 kN/mm

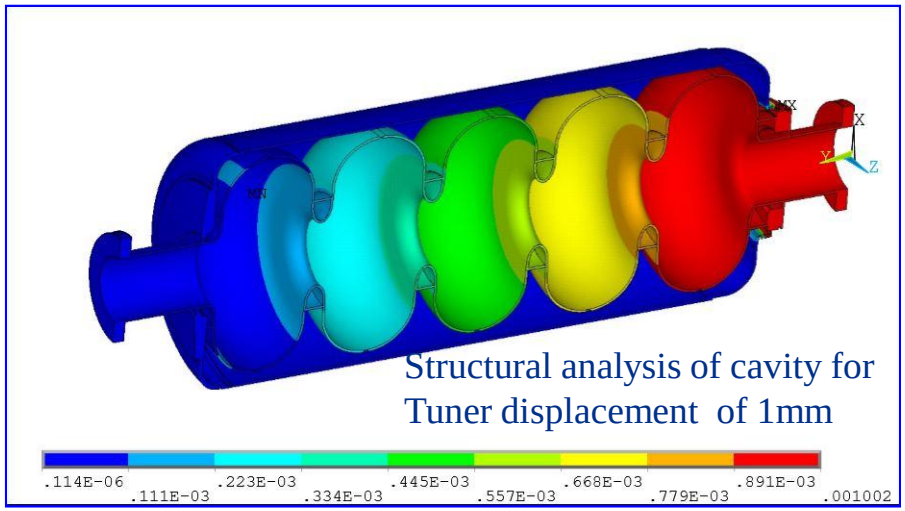
LFD, *df/dp* and 1st longitudinal mechanical mode with respect to tuner stiffness for HB650. **

Tuner Stiff-ness (kN/mm)	df/dp (Hz/mbar)	LFD Hz/(MV/m)^2	1st L. Mode (Hz)
0	14.5	-5.7	48.1
20	11.5	-1.152	98.2
40	11.1	-0.831	101.7
60	10.9	-0.713	102.8
80	10.8	-0.684	103.6

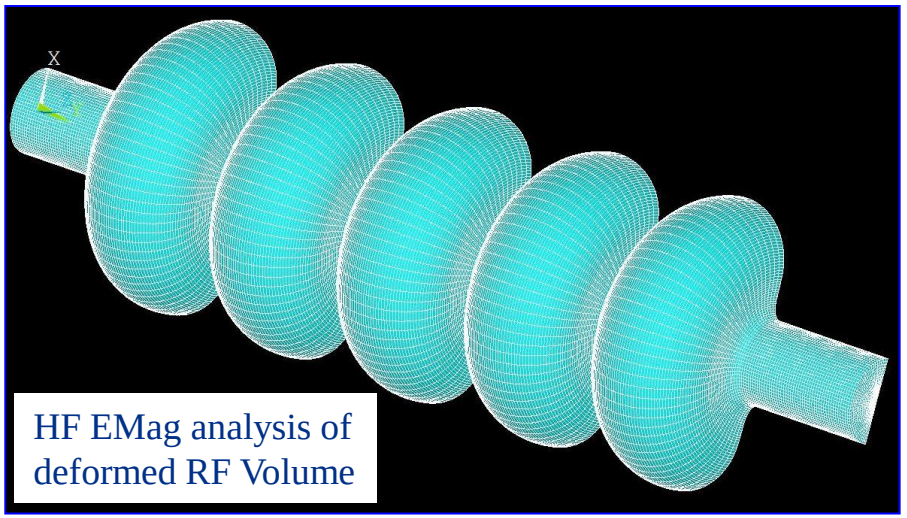
*T.N. Khabiboulline, et al "Mechanical Optimization of High Beta 650 MHz Cavity for Pulse and CW Op-eration of PIP-II Project", SRF2015,Whistler, BC

**V. Jain, I. Gonin, C. Grimm. Y. Pischalnikov, et. al., "650 MHz ELLIPTICAL SUPERCONDUCTING RF CAVITIES FOR PIP-II PROJECT ", NAPAC-2016, Chicago

Cavity Analysis for Tuner Sensitivity



Structural analysis of cavity for Tuner displacement of 1mm



HF EMag analysis of deformed RF Volume

Tuner test analysis using Coupled structural- HF Emag: To find out the tuner sensitivity (df/dl)

Result of Coupled analysis

Mode	Undeform Freq	Deform Freq	Freq. Shift (Hz)
(1/5)-π-TM010	641865454	641689694	-175760
(2/5)-π-TM010	643961109	643790826	-170283
(3/5)-π-TM010	646593664	646430024	-163640
(4/5)-π-TM010	648758444	648600128	-158316
π-TM010	649592828	649428451	**-164377**

Coupled analysis summary for π-TM010 mode

- Displacement of tuner at cavity contact

  = 1 mm

- Tuner sensitivity

  = 164.377 kHz/mm (For π mode)