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FRIB

Experience with Resonance Control with Slow Tuners in Low-Beta CW Linac

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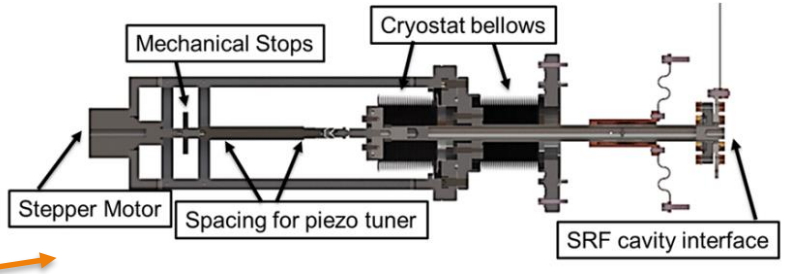
Outline

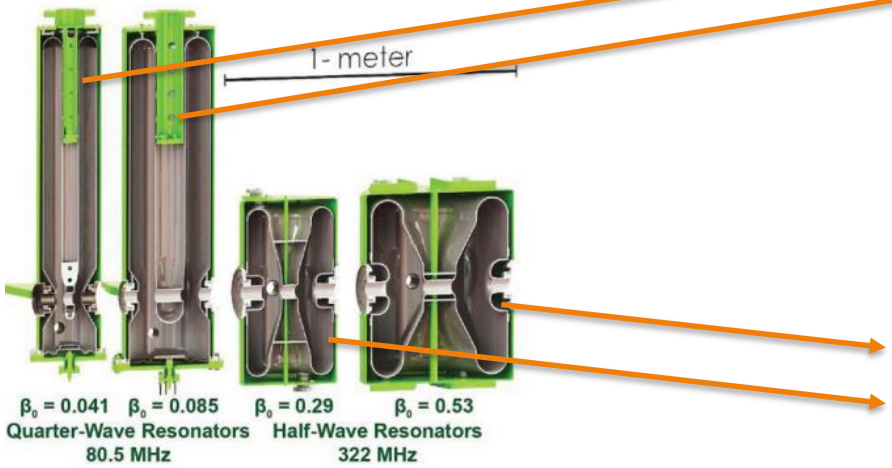
- FRIB SRF cavity overview
- Cavity resonance control, performance and issues
  - QWR stepper motor tuner control method
  - Stepper motor tuner performance
  - Stepper motor slip and mitigation method
  - HWR tuner pneumatic tuner control method
  - Pneumatic tuner performance
- Summary

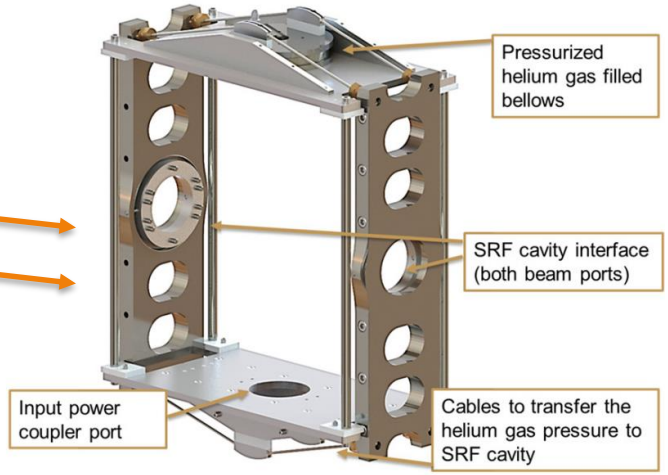
FRIB Linac SRF Cavity and Tuner Overview

- FRIB SC Linac contains 324 SRF cavities in 46 cryomodules.
  - Stepper motor tuner has been used for 104 QWRs
  - Pneumatic tuner has been used for 168 HWRs

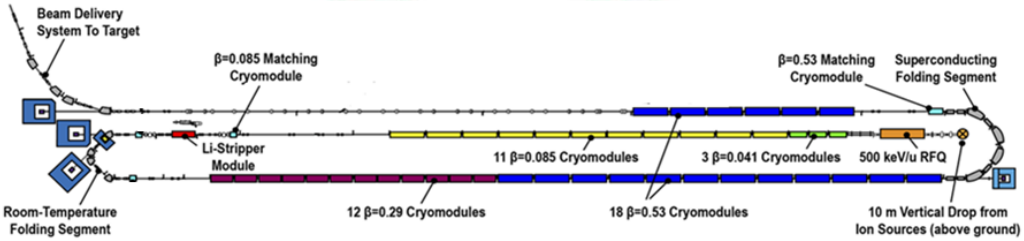


QWR Tuner (rotated 90°)



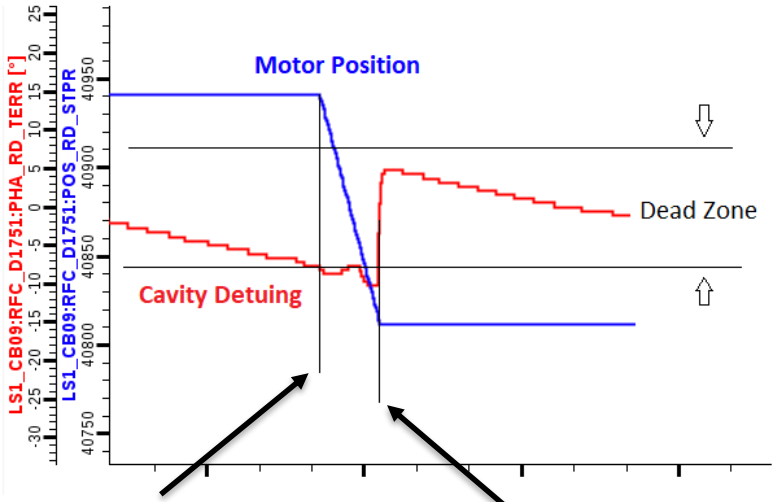


HWR Tuner



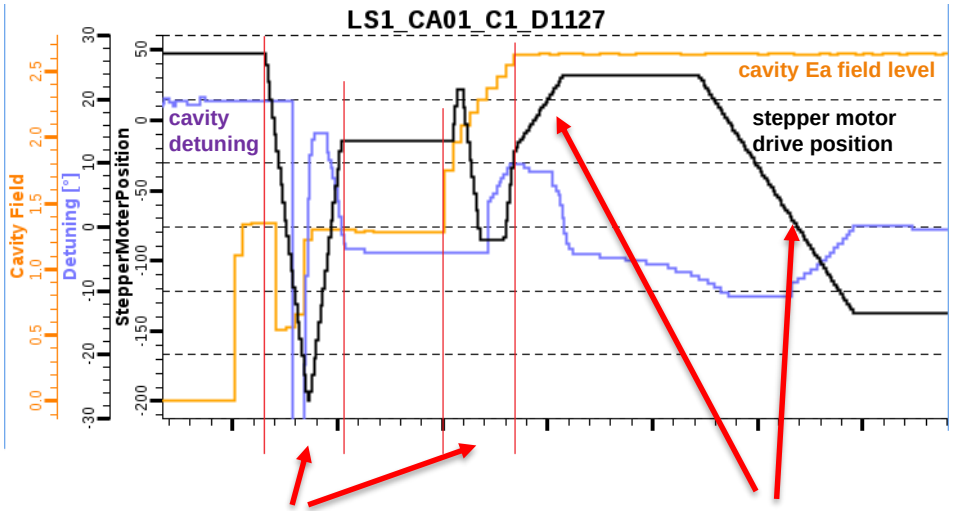
QWR Tuner Control

- Stepper motor with constant speed drive the tuner for all QWRs
  - Tune the cavity to the resonance center when cavity detuning is out of dead zone setting range: ±8º
  - QWR initial turn-on and field ramp up with fast speed, normal operation with slow speed



motor start run when cavity detuning out of dead zone

motor stop run when cavity detuning reached “0” degree

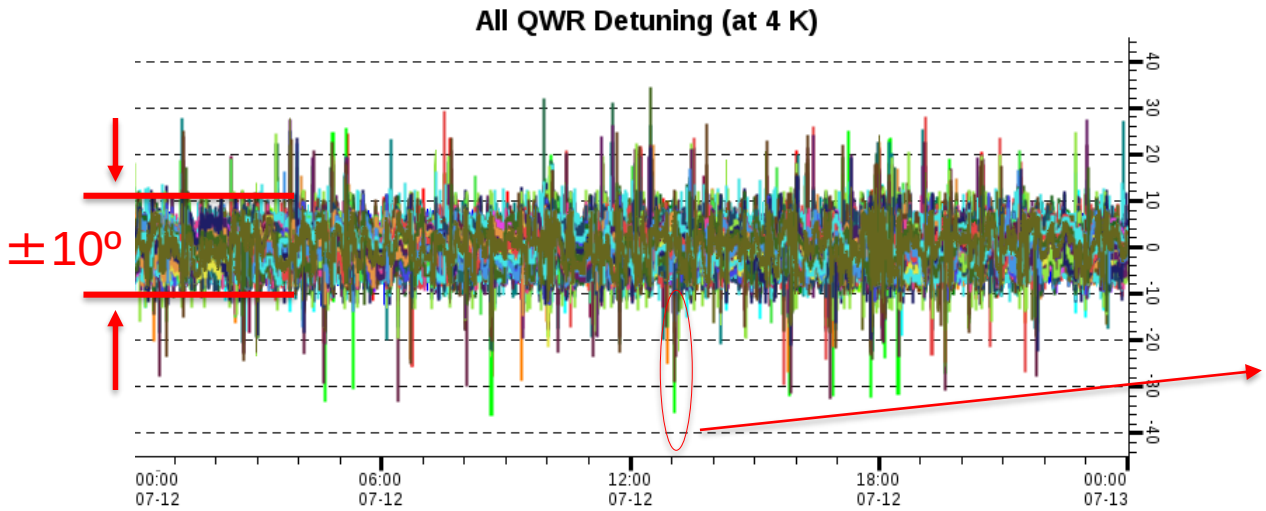


Initial find the resonance center and ramp up field to set-point stepper motor using fast speed

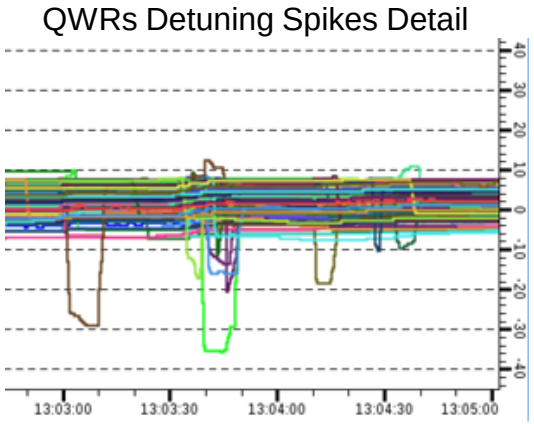
Normal operation using slow speed

QWR Tuner Operation Performance

- All QWRs detuning can be controlled within ±10º for long time operation.
  - The control dead zone is ±8º, the normal hysteresis makes additional 2º
- Some cavities show detuning jump spikes, that is due to the stepper motor slips



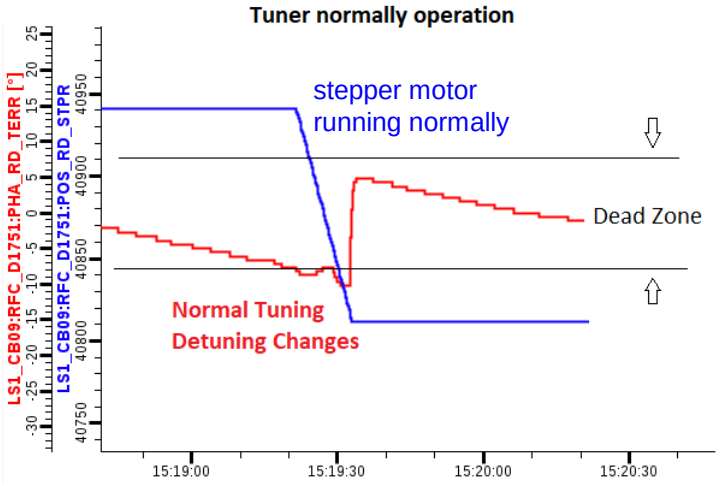
Most cavities within reasonable detuning range for one day operation

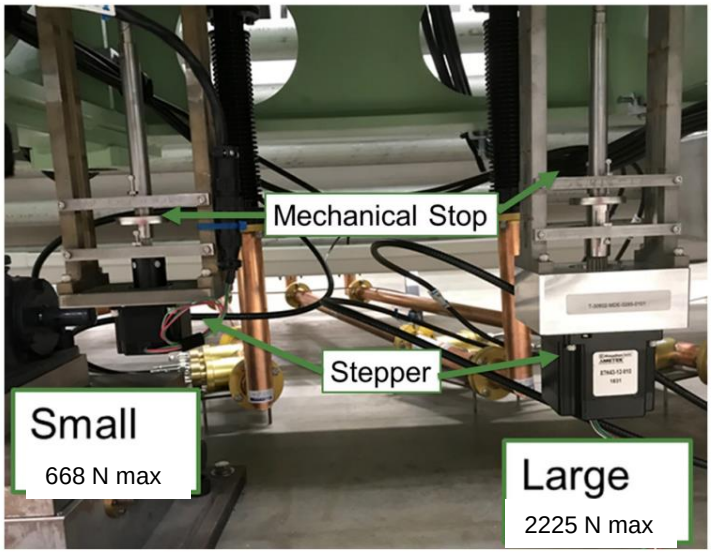


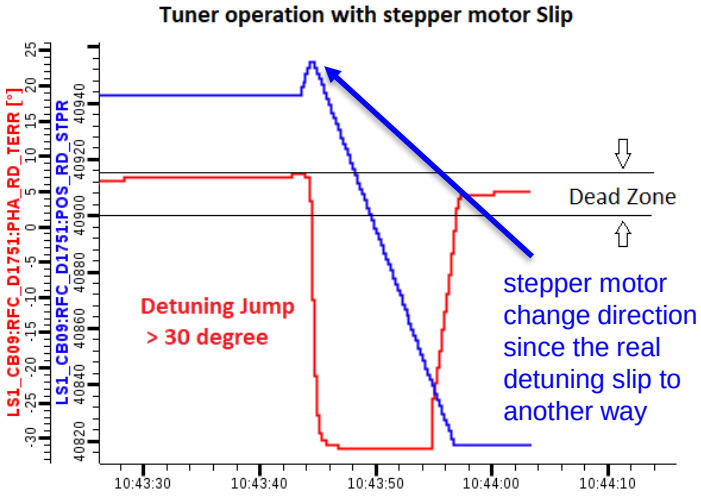
Some cavities show detuning spike when tuner change the tuning direction

Stepper Motor Tuner Slip Issue

- Cavity detuning sudden jump during the operation
  - Previous solution is replaced small motor with a big motor(higher torque). Issue fixed right after replacement, but it shows up again after long time running and will get worse
  - To avoid trip due to large detuning, the motor need to be replaced after one or two years

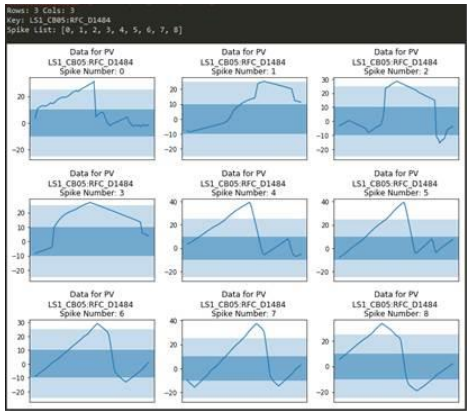






QWR Tuner Maintenance and Improvement

- Monitoring stepper motor performance and perform the replacement in time during the Linac maintenance period.
  - Tracking the life time for the current stepper
  - Find a method to estimate the replacement time
- Test new type stepper motor (with gear, be able to hold the tuner position without supply holding current) on a worst tuner.
  - No large jump on cavity detuning during the operation since it installed (07/07/2022)



Detuning jump plot analysis for replacement time estimate

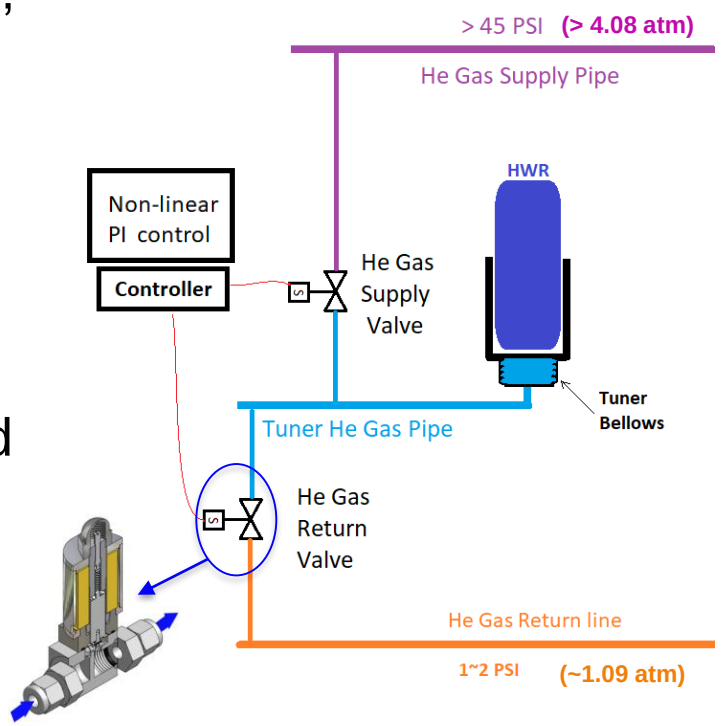
Big Motor replacement record (big to big)

	Initial install	1st replacement	1st delta days
CA01-C1	8/7/2020	2/4/2022	546
CB03-C1	11/5/2019		
CB03-C3	5/28/2019	12/17/2021	934
CB05-C1	5/28/2019	2/4/2022	983
CB05-C7	2/23/2021	8/11/2022	534
CB06-C4	7/22/2020	6/7/2022	685
CB06-C5	7/22/2020	5/20/2022	667
CB07-C7	10/7/2019	8/11/2022	1039
CB08-C2	2/5/2020	5/20/2022	835
CB09-C2	5/28/2019	12/17/2021	934
CB09-C4	6/30/2020	5/20/2022	689
CB10-C6	2/13/2020	2/4/2022	722
CB10-C8	5/28/2019	2/4/2022	983
CH01-C1	before 5/28/2019	8/11/2022	>1171
CH01-C2	before 5/28/2019	9/28/2022	>1219

Stepper motor life time tracker

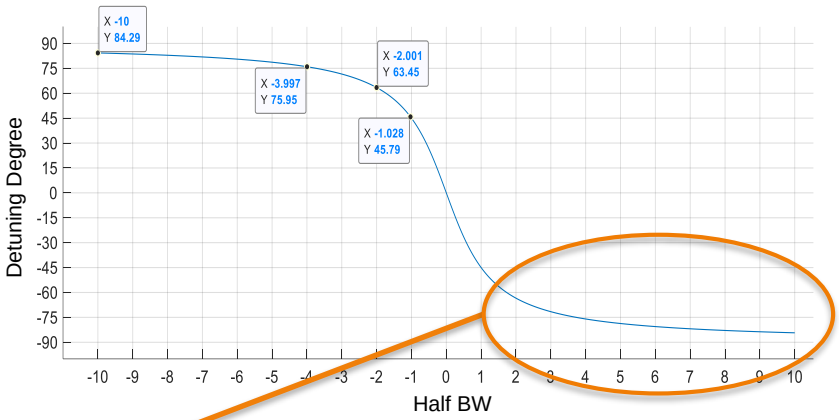
HWR Pneumatic Tuner Control

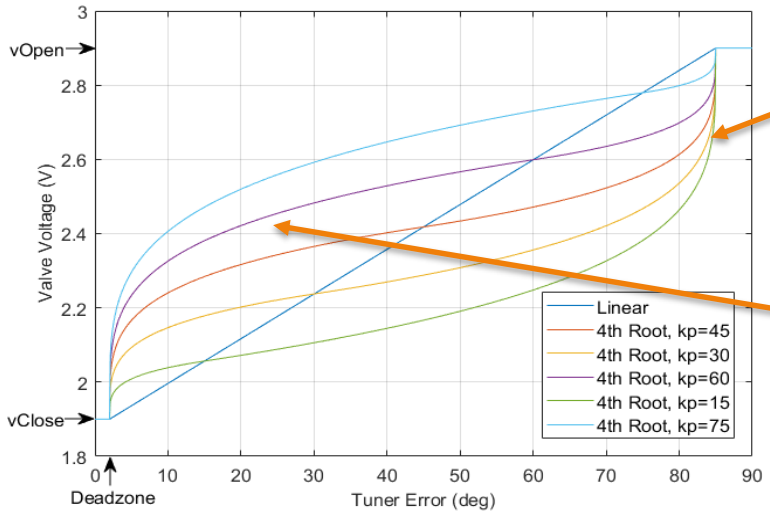
- Pneumatic tuner is controlled by two solenoid valves (Supply Valve and Return Valve) to charge or release the helium gas pressure in the pneumatic tuner bellows
  - Each valve is calibrated with two voltage: ‘close’ (the valve just close at this voltage) and ‘open’ (related to the reasonable maximum gas flow rate)
  - The valve voltage is between ‘close’ and ‘open’ to control the gas flow so control the bellows pressure during the operation
  - Cavity frequency change by tuner pressure is ~2.0 KHz/PSI (~290 Hz/kPa) for HWR029 and ~1.2 KHz/PSI (~174 Hz/kPa) for HWR053, detuning is sensitive to the small gas flow
  - Non-linear Proportional-integral control method is implemented for the valve



Pneumatic Tuner Control Method

- Two nonlinear sections to map tuner error to valve control voltage
  - Phase curve nonlinearity
  - Valve dead-zone
  - Flat in mid-range
- Proportional-integral control
  - Proportional gain moves curve up/down
  - Adjustable integration limit





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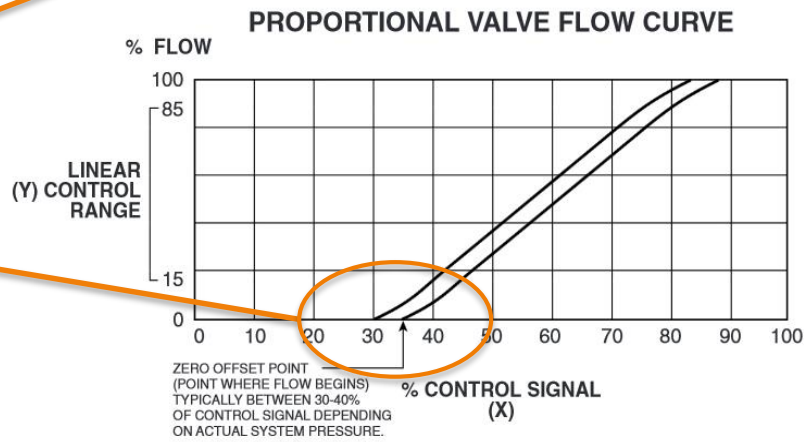
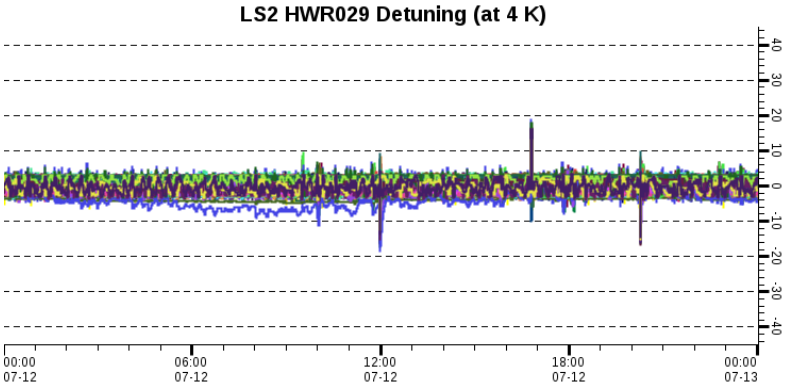
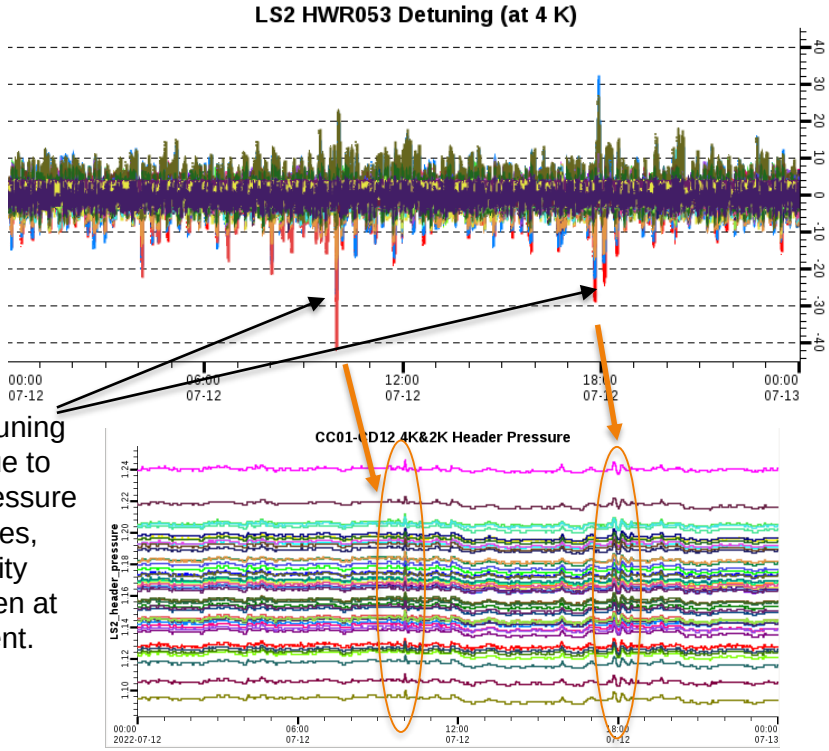


HWR Tuner Control and Performance

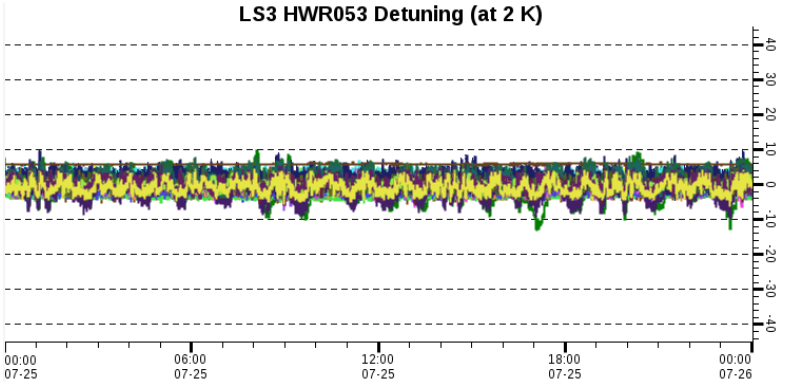
- All HWRs tuner control works fine, cavity detuning be controlled within reasonable range for long time operation



HWR029 cavity run at 4 K, some detuning spike due to header pressure fast changes, no trips happen at that moment



These detuning spike is due to header pressure fast changes, but no cavity trips happen at that moment.

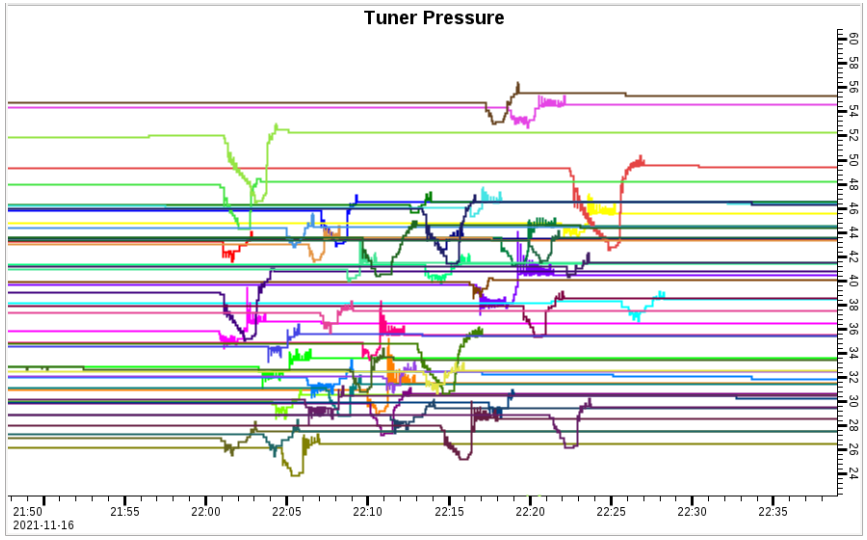


LS3 HWR053 cavity at 2 K
All cavity running stable with no detuning spikes

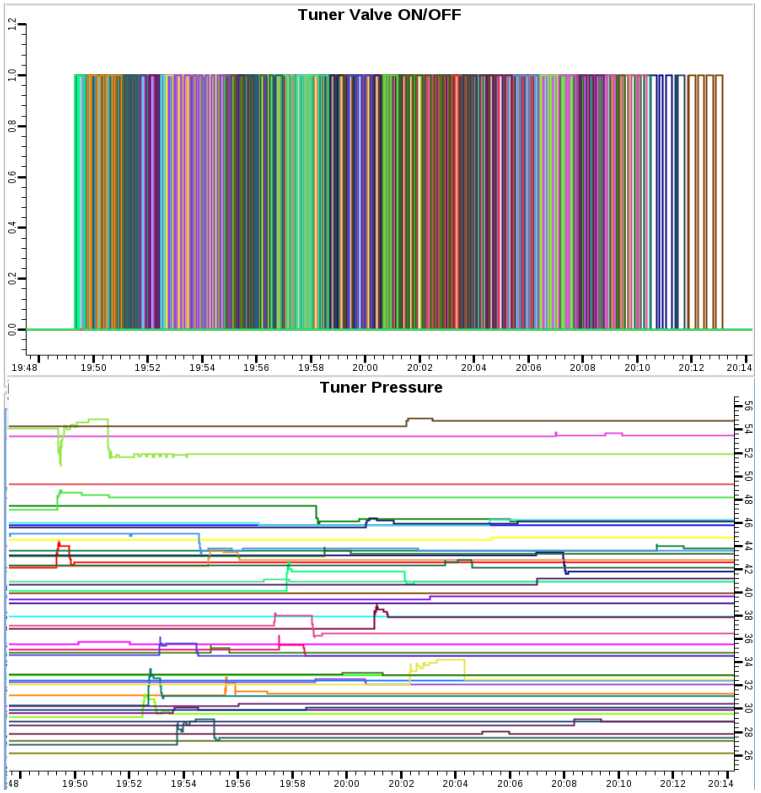
Snapshots for 1 day operation

Pneumatic Tuner Valve Automatic Calibration

- Automation method implemented for tuner valve calibrations, significantly reduces the time cost
  - Manual calibration of 440 valves takes 3 person-days of SRF expert effort; reduced to 2 hours of machine effort



‘Open’ voltage calibration for all valves: 1 hour



‘Close’ voltage calibration for all valves: 1 hour

Summary

- FRIB SC Linac 324 SRF cavities' slow tuner resonance control is successfully operated, long time stability is also verified
- The current QWR tuner stepper motor has 1~2 years life time, maintenance need to be planed. The mitigation plan: new stepper motor long time stability operation test is in progress.
- The HWR pneumatic tuner operation performance is reached the design goal.