SRF 2021

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MOPTEV010 RF SYSTEM EXPERIENCE FOR FRIB HALF WAVE RESONATORS

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Introduction

The Facility for Rare Isotope Beams (FRIB) adopts a phased commissioning strategy. Half wave resonators (HWRs) make up two thirds of the FRIB Linac. Compared to the quarter wave resonators (QWRs), the HWRs have a different type of tuner, run at higher power levels and have additional components such as high voltage bias tee for coupler multi-pacting suppression.

ARR Phase	Area with beam	Energy MeV/u	Date
1	Front end	0.5	Jul 2017
2	+ β = 0.041	2	May 2018
3	+ β = 0.085 (LS1)	20	Feb 2019
4	+ β = 0.29, 0.53 (LS2)	200	Mar 2020
5	+ β = 0.53 (LS3)	>200	Apr 2021
6	+ target, beam dump	>200	Sep 2021
Final	integration with NSCL	>200	Jun 2022

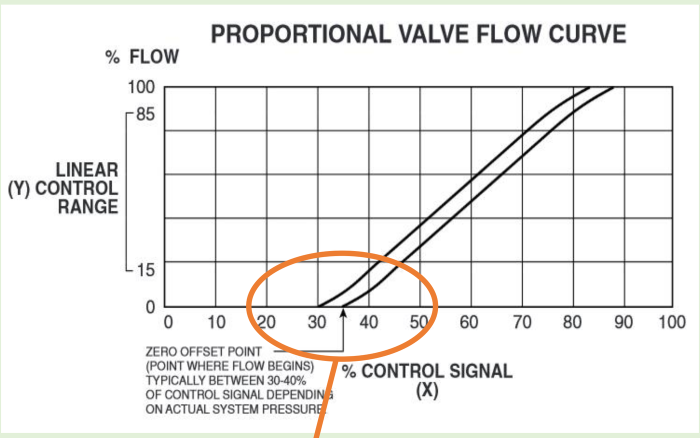
Accelerator Readiness Review (ARR) phases for FRIB.

System	Area	Frequency	Type	Required RF Power	Tuner	Qty
LEBT Multi-Harmonic Buncher (f1, f2, f3)	FE	40.25 MHz - 120.75 MHz	RT	100W	N/A	3
RFQ Driver	FE	80.5 MHz	RT	8 kW	N/A	1
RFQ Final (Tetrode)	FE	80.5 MHz	RT	100 kW	Servo (water)	1
MEBT Buncher	FE	80.5 MHz	RT	4 kW	2-phase stepper	2
β=0.041 (accelerating)	LS1	80.5 MHz	SC	700 W	2-phase stepper	12
β=0.085 (accelerating and matching)	LS1 - FS1	80.5 MHz	SC	2.5 kW	2-phase stepper	92
IH Multi-Gap Buncher	FS1	161 MHz	RT	18 kW	5-phase stepper	2
β=0.285 (accelerating and matching)	LS2	322 MHz	SC	3.0 kW	Pneumatic	72
β=0.530 (accelerating and matching)	LS2- LS3	322 MHz	SC	5.0 kW	Pneumatic	148

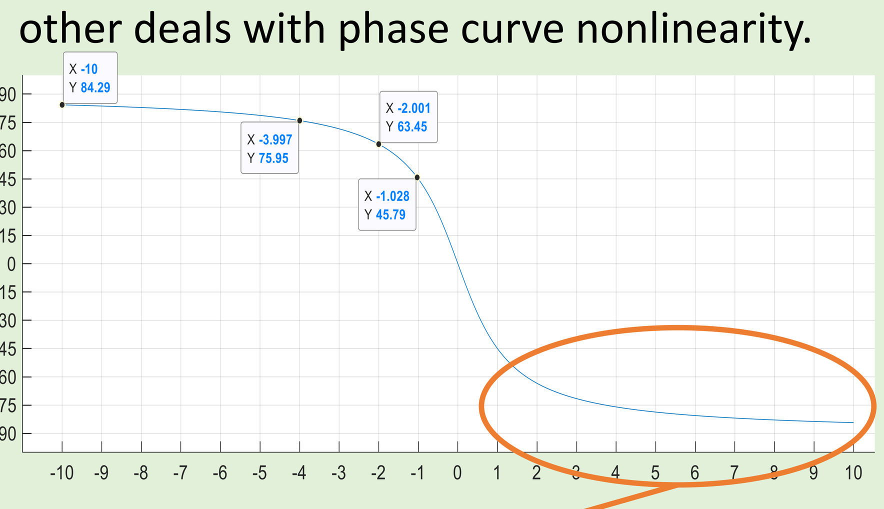
Various FRIB cavity types and related RF system information.

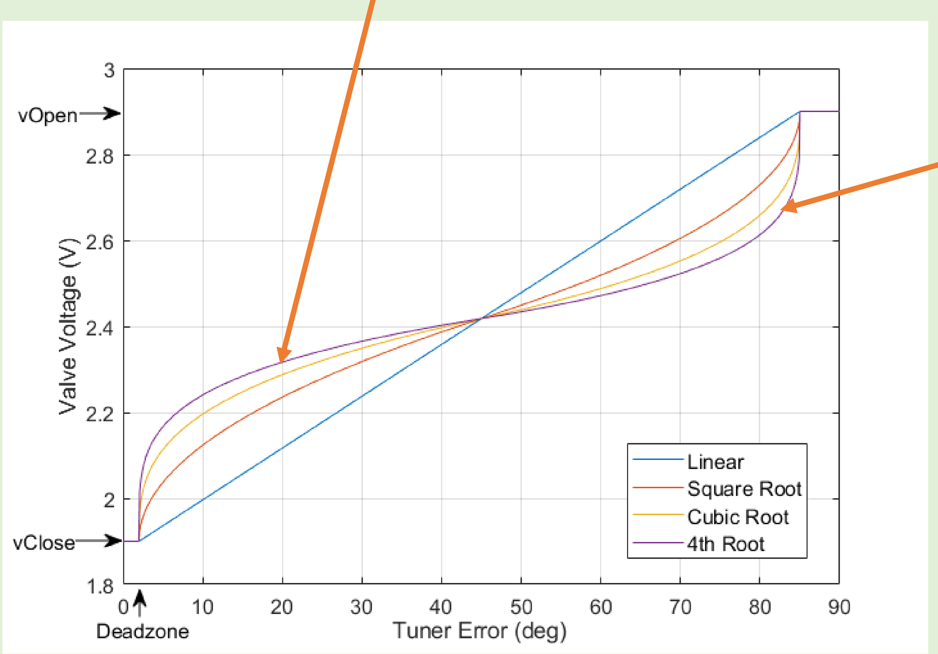
Pneumatic Tuner Control

The HWRs use pneumatic tuners in comparison to the stepper tuner used by the quarter wave resonators (QWRs). The control design for the pneumatic tuner has evolved a lot in the past few years based on new findings. Current implementation contains two nonlinear sections to map the tuner error to the valve control voltage. One is to deal with the valve deadzone; the other deals with phase curve nonlinearity.

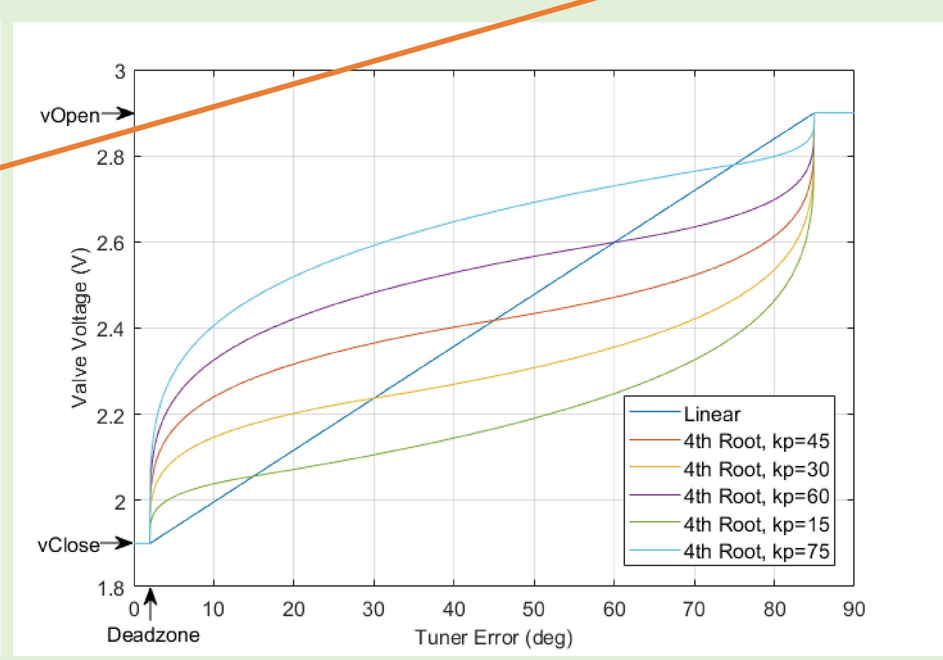


Valve characteristics.





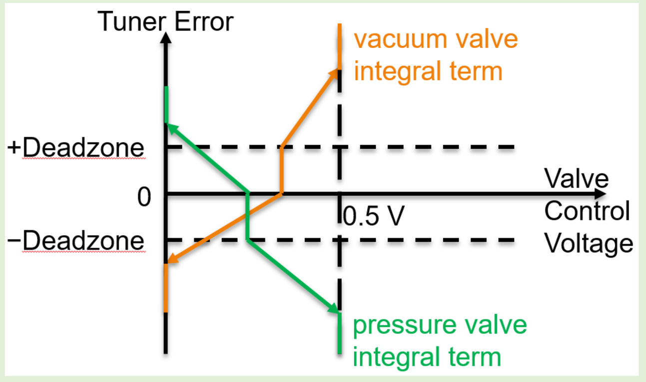
Nonlinear effect



Gain effect

Integration mechanism:

- Tuner error greater than deadzone: Integrate
- Tuner error less than deadzone: Hold
- Tuner error opposite sign: Rewind
- Bounded at 0 V (low limit) and 0.5 V (high limit)



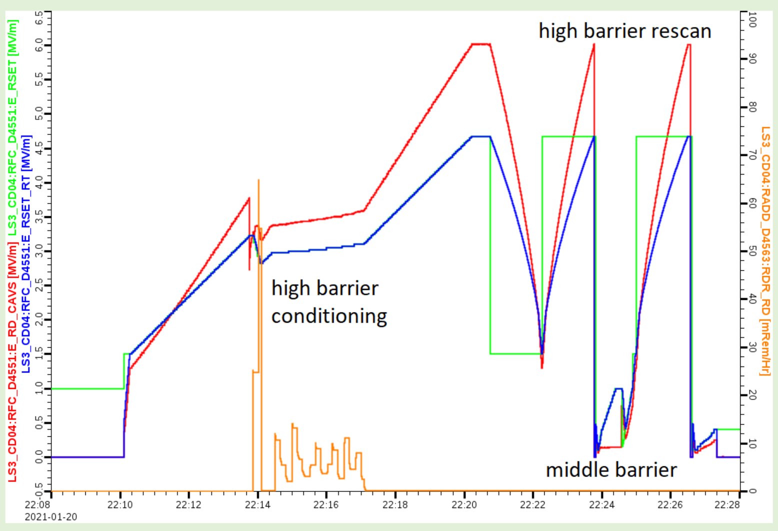
Integration mechanism illustration.

Automatic Multi-pacting Conditioning

The HWRs have multi-pacting (MP) barriers at different field levels. The high barrier occurs at around 3 MV/m. Once the high barrier is excited and conditioned, the middle barrier at around 0.1 MV/m is usually observed. A low barrier less than 0.01 MV/m happens in some cases. But the low barrier can be jumped over relatively easy and usually does not need to be conditioned.

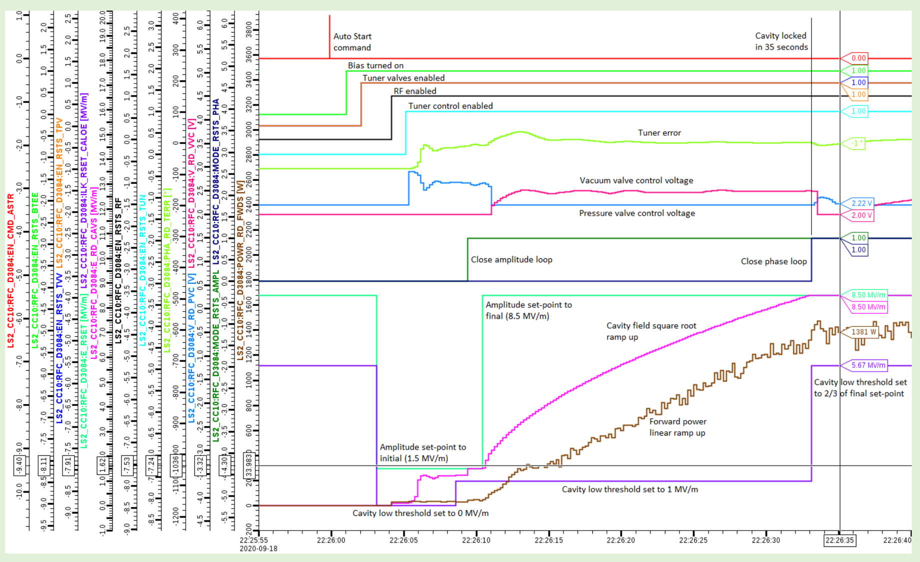
The MP conditioning is time consuming and labor intensive, which motivated us to automate the process. The automation implementation was tested during LS3 SRF commissioning:

- Check for X-ray level while increasing power
- Condition both high barrier and middle barrier
- Rescan to confirm
- Take 20 ~ 50 minutes depending on cavities

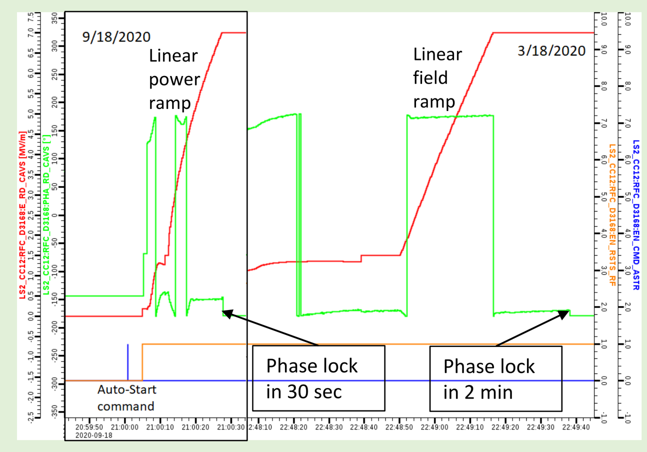


Auto On/Off for HWRs

The auto on feature was developed for all FRIB cavity types. Due to the complexity in the pneumatic tuner control, the HWR auto on was not available until the second beam run of ARR4 in Sep. 2020. During first beam run of ARR4 in Mar. 2020, the HWRs were turned on manually and took about 2 minutes for each cavity in comparison to 30 seconds later in Sep. 2020.

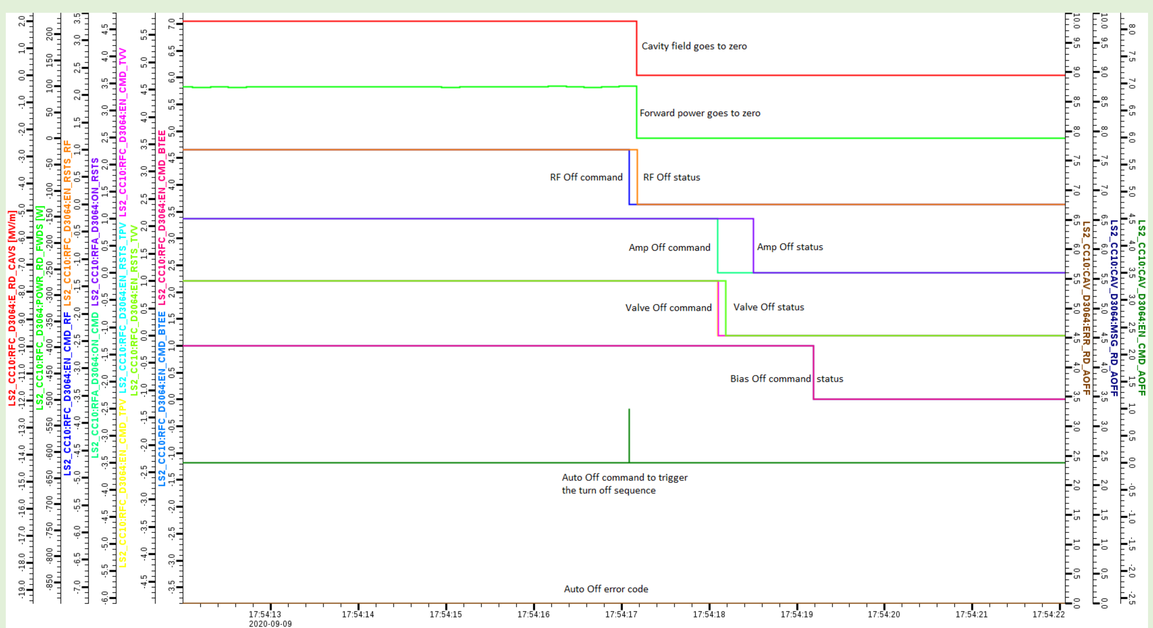


An HWR cavity turned on automatically and locked in 35 seconds.



HWR manual and auto turn on comparison.

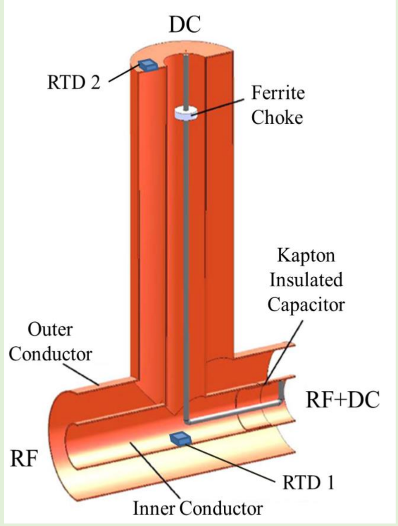
An auto off process is developed for HWR as well, to facilitate turning off related components (e.g. tuner valves, bias tee high voltage, amplifier, etc.) in a predefined order.



An HWR cavity auto off sequence.

Bias Tee and Spark Detector for HWR

The FRIB fundamental power coupler (FPC) for the HWRs was designed to minimize the effect of multi-pacting, but the MP can still occur in certain situations. To reliably suppress the MP in the FPC, a bias tee with high DC bias voltage (- 1kV) was designed in collaboration with an industrial partner.

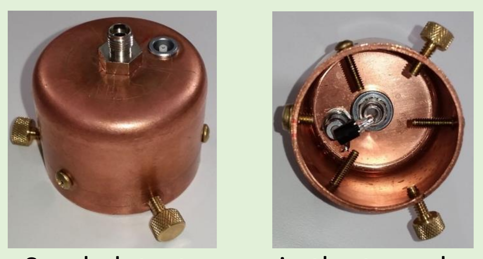


The design was iterated several times to reduce the heating on the inner conductor when operating at high power (5 kW).

5 kW Testing	RTD 1: inner junction	RTD 2: short circuit plate
Prototype	78.56 ºC	39.00 ºC
Rev. A	101.68 ºC	42.23 ºC
Rev. E	49.10 ºC	45.60 ºC

Bias tees installed in the tunnel for HWRs.

On the FPC a window is available for the purpose of detecting sparks. Due to potential radiation damage, the spark detector circuitry is placed in the rack room rather than in the tunnel. A thick core (ϕ1.8 mm) fiber is used to transmit the light from the tunnel to the rack room. The light emitting diode (LED) in the spark detector cup is used to perform a roll call test to ensure that the fiber is not clouded or broken and the spark detector circuitry functions normally. If a spark is detected while the cavity is running, the cavity will be interlocked off by the low level radio frequency (LLRF) controller.



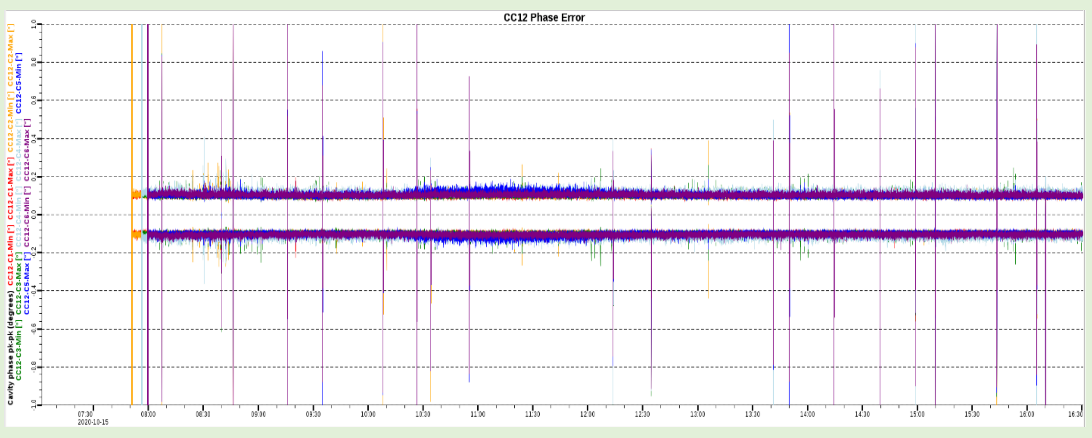
Spark detector cup in the tunnel.

Spark detector chassis in the rack room.

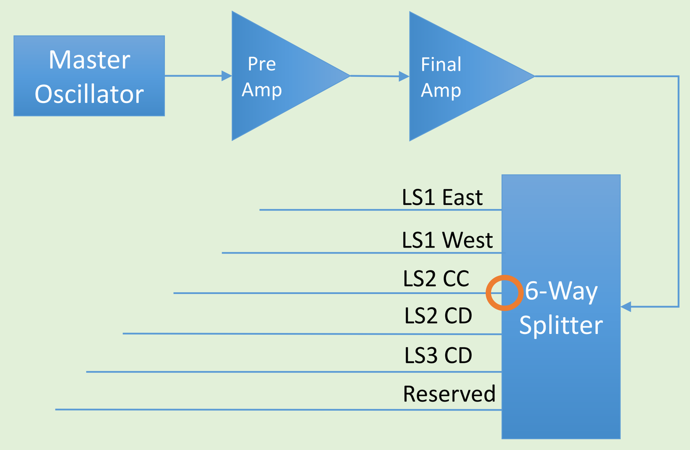
Phase Jump Issue On All LS2 β=0.29 HWRs

During the ARR4 second beam commissioning in October 2020, it was noticed that some of the β=0.29 HWRs tripped the fast protection system (FPS) at the same time due to phase error exceeding +/- 1 degree.

Later it was confirmed that all β=0.29 HWRs (LS2 CC) had phase jumps at the same time, while other parts (β=0.53 HWRs and QWRs) of the linac were not affected.



Correlated phase jumps in the last β=0.29 cryomodule.



FRIB reference clock distribution diagram.

After extensive data collection, cross checking and debugging, the issue was finally resolved in December 2020. The culprit turns out to be a bad connection at the six-way splitter for the reference clock distribution.

FRIB

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