Commissioning of the First Three β=0.041 Quarter Wave Resonator Cryomodules in the FRIB Driver Linac - Experience in Microphonics

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Facility for Rare Isotope Beams

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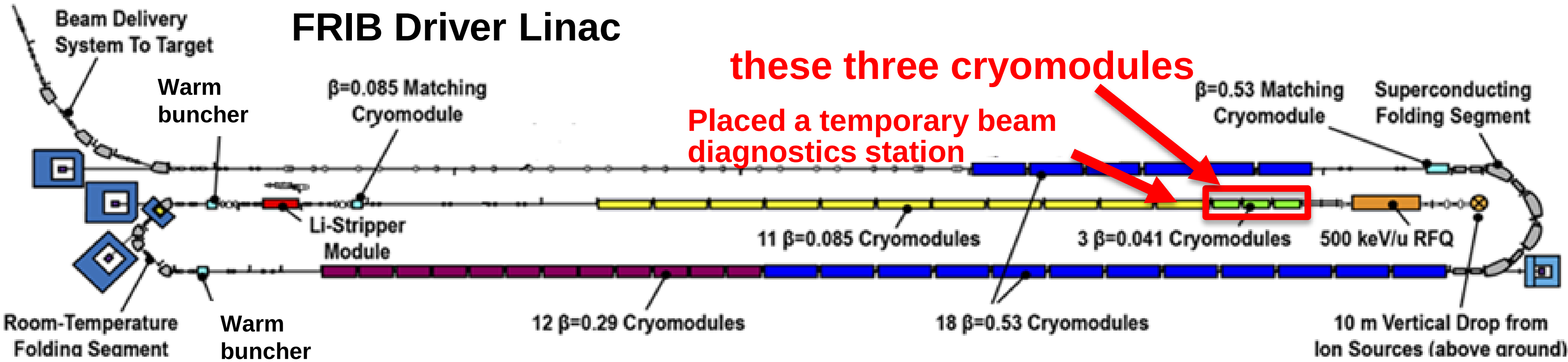
Outline

- Commissioning of β=0.041 Quarter Wave Resonator (QWR) Cryomodules
- Microphonics in the QWR Cryomodules and Mitigation
- Summary

The First Three Cryomodules Have Been Commissioned with Beam in the FRIB Driver Linac



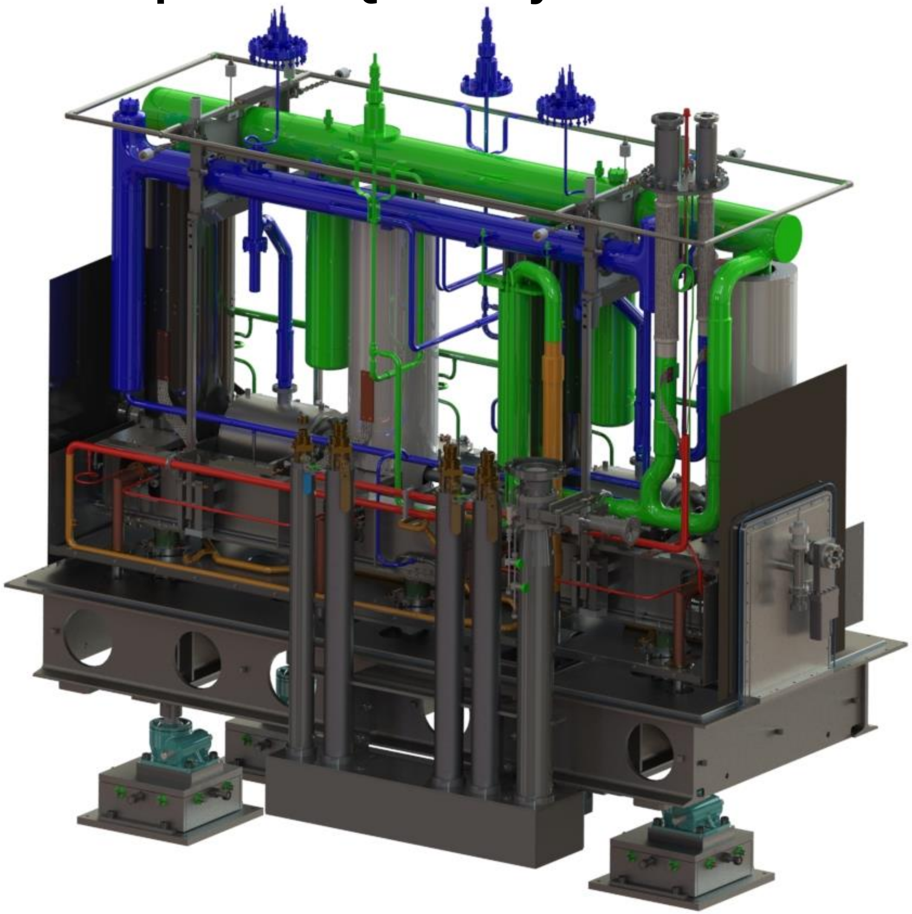
- Accelerated $^{40}Ar^{9+}$ beam up to 2.3 MeV/u
  - Achieved Key Performance Parameter: 1.5 MeV/u $^{40}Ar^{9+}$ and $^{86}Kr^{17+}$ Beam
  - Highest current: I_{peak}=30 μA with 30% duty factor, limited by vacuum in the temporary diagnostics station
- Operated at 4.3 K; Design: 2.0 K
- Completed this commissioning on 8/10/18
- Move forward with the next β=0.085 QWR CMs: 8 out of 12 were cooled down as of 10/22/18

β_0	0.041	0.085	0.29	0.53
Type	QWR	QWR	HWR	HWR
f_0 (MHz)	80.5	80.5	322	322
V_{acc} (MV)	0.81	1.8	2.1	3.7
# of CM	3	12	12	18
# of Cavity	12	92	72	148

β=0.041 QWR Cryomodule

β=0.041 QWR

β=0.041 QWR Cryomodule



β=0.041 QWR Design Parameter

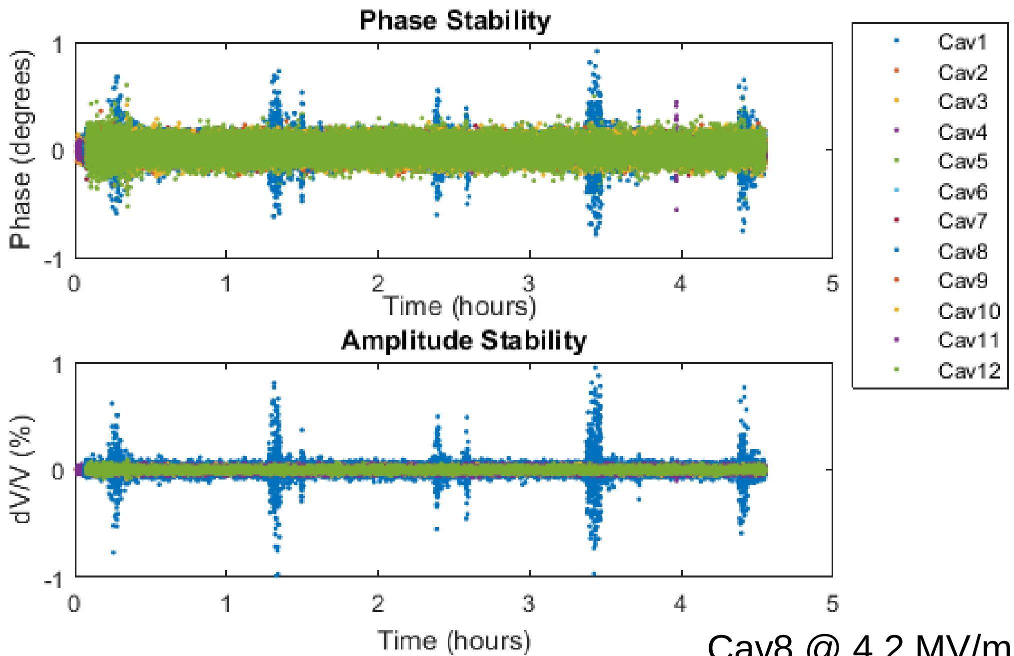
Parameter	Unit	Value
Frequency	MHz	80.5
V_{acc}	MV	0.81
E_{acc}	MV/m	5.1
E_{peak}	MV/m	31
B_{peak}	mT	55
Bandwidth	**Hz**	**40**

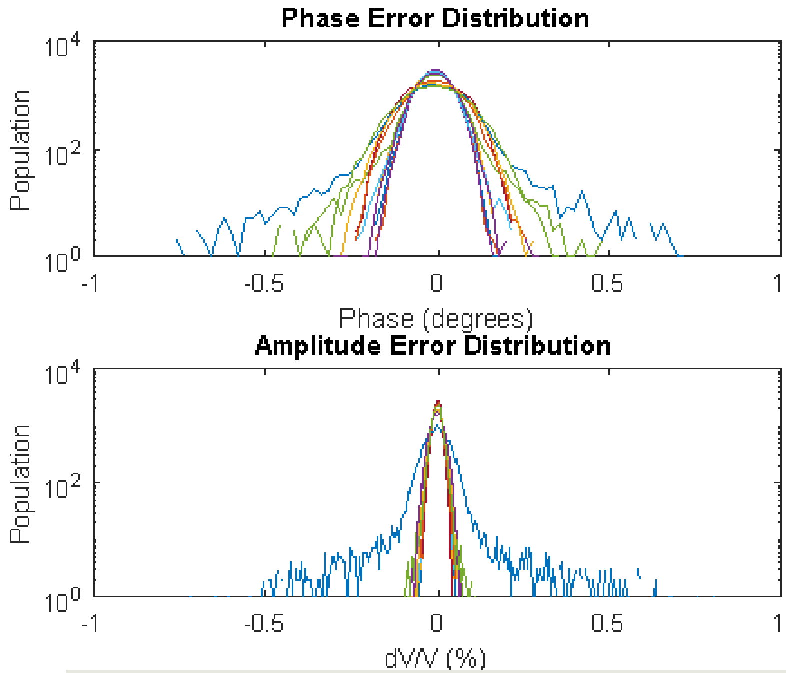
Cavity Performance
155 hours High-power RF run including ~60 hours for beam acceleration

- All 12 cavities reached to E_{acc}=5.6 MV/m (V_{acc}=0.9 MV), 10% higher than the design gradient
- Field Emission (FE)
  - Minor X-rays in one cavity: 0.1 mR/hr @ 5.6 MV/m
  - No degradation after beamline gate valve opening cycles and beam acceleration
- Multipacting (MP) with fixed-coupling RF power couplers
  - High-field MP: easily conditioned
    - » E_{acc}: ~1 MV/m, P_{FWD}: ~10 W
    - » Conditioned in ~10 minutes in a 'matched' condition, never appeared again
  - Low-field MP: 'manageable'
    - » E_a: ~0.01 MV/m, P_{FWD}: ~1 mW
    - » Not conditioned but broken through with fast rising field past the MP region, initial P_{FWD}=~20 W when turning on RF
- No conditioning effects: cold cavity + cold coupler

Phase Lock Stability

- Resonance Control
  - phase and amplitude lock using active disturbance rejection control
  - Slow stepper motor tuner: on-off control with hysteresis bands, 4-8º in each direction
- Meet the phase and amplitude stability specifications, $\pm 1^{o}_{pk\text{-}pk}$ and $\pm 1\%_{pk\text{-}pk}$
- Almost no RF trips per day (8 hour run)
  - Mitigation of microphonics was crucial to achieve this stable operation





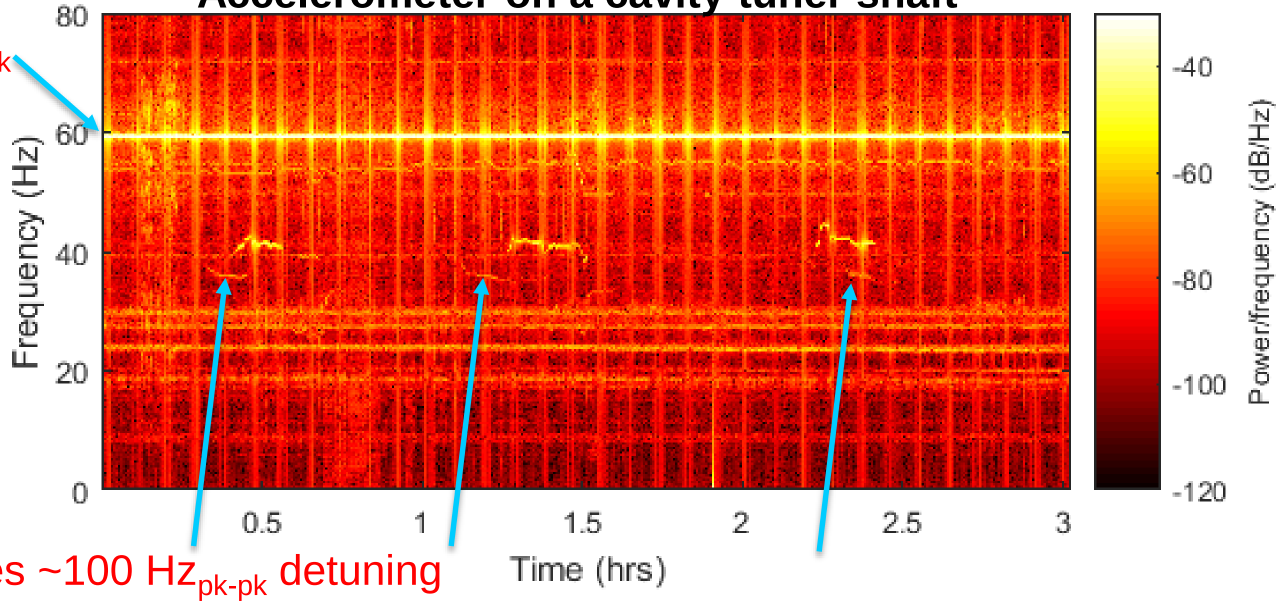
Cav8 @ 4.2 MV/m,
The others @ 5.6 MV/m

Microphonics in β=0.041 QWRs
Resonant excitation

- In these QWRs, cavity detuning is high only if the external vibration is on resonant with the cavity inner-conductor pendulum mode, at ~36 Hz [Z. Conway's yesterday talk]

Vibration Power Spectrogram
Accelerometer on a cavity tuner shaft

Excites ~1 Hz_{pk-pk} detuning



Excites ~100 Hz_{pk-pk} detuning

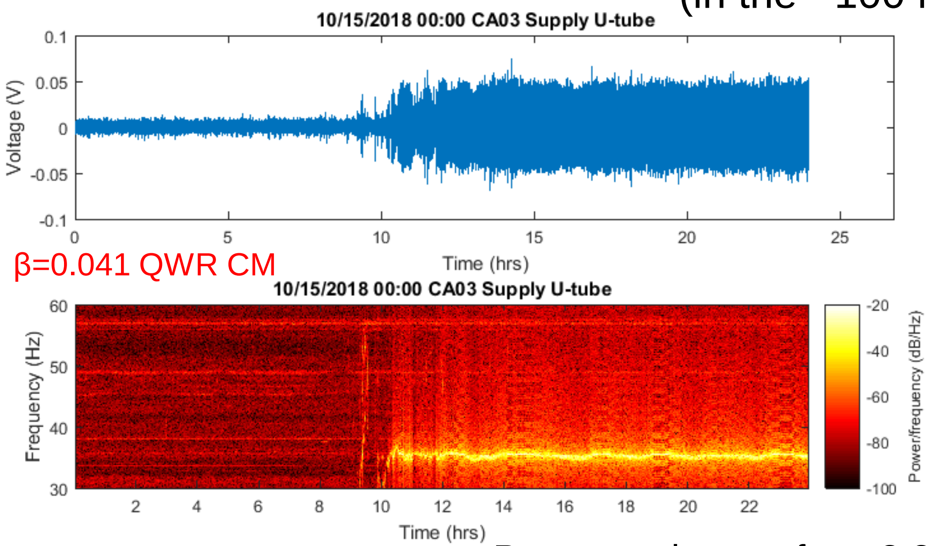
- The 36 Hz mode disappeared as the solenoid lead gas cooling line has flow, thought to be thermal acoustic oscillation when the gas helium column is 'trapped'
- The 60 Hz mode disappeared as a buffer dewar was inserted into the cryogenic supply line; The supply pressure is 1.6 bara

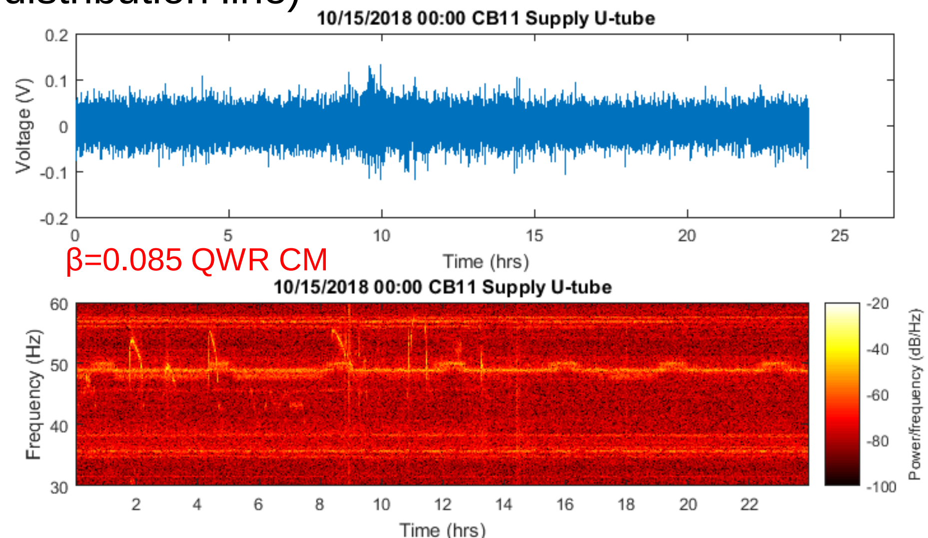
Microphonics in β=0.041 QWRs: Effects of the Cryogenics Supply Pressure

- At 3.2 bar strong ~35 Hz was observed on the supply U-tubes as well as cryomodules but it disappeared as the pressure was reduced to 1.6 bar

~70 m away from each other
(in the ~100 m distribution line)

Supply side





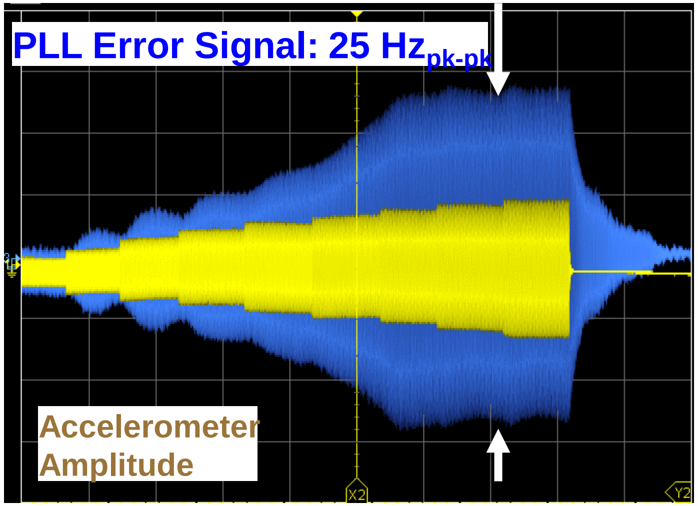
Pressure change: from 3.2 bar to 1.6 bar @ 10 am

- Commissioned the first three β=0.041 QWR cryomodules at 1.6 bar
  - β=0.085 QWR cryomodules are also OK at this pressure based on low-level tests
  - Cryogenics is capable of operating at this pressure

Lesson Learned

- Murphy's law: If there is a potential vibration source, the frequency of which is close to the cavity mechanical mode, it would be safe to assume the worst case, "the source will hit the cavity mechanical resonance in the real machine/site"
- Mechanical damper in the inner conductor of the QWR: damping performance, in terms of cavity detuning, is different cavity by cavity
  - A conservative approach: test damper performance for all cavities; this can be tested even at room temperature using, e.g., real-time spectrum analyzer
- Early test in the real site was helpful for us
  - Observing multiple cryomodules is helpful to better understand microphonics behavior related to cryogenics

A β=0.085 QWR: cavity detuning with respect to external vibration strength



Horizontal: 10 sec/div

Summary

- The first three β=0.041 QWR cryomodules have been commissioned in the FRIB Driver Linac
- Mitigation of microphonics was necessary for stable operation. There are a couple of potential sources which could be harmful for resonance control unless otherwise mitigated