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ENHANCED PNEUMATIC TUNER CONTROL FOR FRIB HALF-WAVE RESONATORS*

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Abstract

The superconducting driver linac for the Facility for Rare Isotope Beams (FRIB) includes a total of 46 cryomodules; 31 cryomodules contain half-wave resonators (HWRs) with pneumatic tuners. Pneumatic tuner control is via solenoid valves connecting the tuner to a helium gas supply manifold and a gas return line. For precise compensation of cavity detuning over a small range, the control voltage for the solenoid valves must be calibrated. Some valves have hysteresis in the gas flow rate as a function of control voltage, such that their response may be nonlinear and not repeatable—this makes the control algorithm challenging. To improve the system performance, a new pneumatic tuner control system was developed which regulates the position of one stepper motor instead of the two solenoid valves.

INTRODUCTION

The FRIB half wave resonators (HWRs) use a pneumatic tuner [1], which is linked to HWR beam port cups and actuated by a bellows. The bellows can be expanded or contracted by helium gas pressurization or discharge. The helium gas pressure can thereby shift the HWR frequency. The tuner parameters are shown in Table 1 [2].

Table 1: FRIB HWR Tuner Characteristics

Cavity Type	**HWR**
Deformation	Beam port cups
Actuation	Pneumatic
Force	1000+ lbs
Cavity β	0.29 / 0.53
Range (kHz)	62 / 39

PNEUMATIC TUNER CONTROL

Existing System

As shown in Fig.1, the pneumatic tuner is connected to the helium gas space. There are two solenoid valves, one connected to the gas supply pipe, the other connected to the gas return. The LLRF system controls these valves by roughly setting the voltages or precisely controlling them via a frequency feedback loop. For precise feedback control, the solenoid valves must to be calibrated: measuring the gas flow rate versus valve control voltage; the calibration provides the valve opening voltage and high limit flow rate voltage for each valve. However, for some valves, the opening voltage is not repeatable, the gas flow rate versus control voltage is nonlinear, or the valve has hysteresis (one voltage makes the valve open, but once open, a much lower voltage is required to close the valve again). These behaviours make it difficult to control the frequency. The calibration is repeated frequently to try to mitigate these effects.

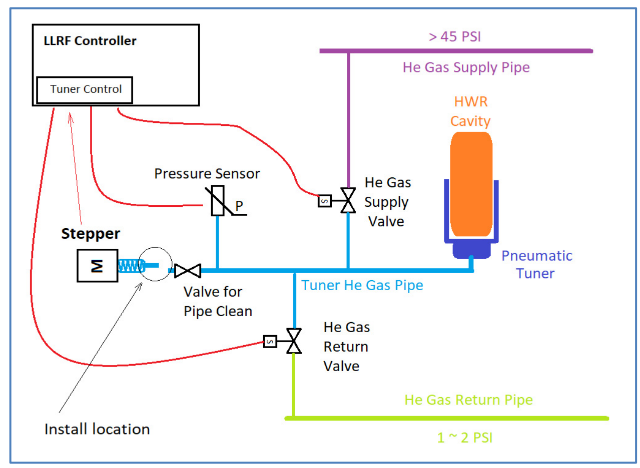

Figure 1: Schematic of pneumatic tuner system. The control valves for the existing control system and the stepper motor with bellows for the new system are shown.

New System

A new enhanced system was developed for improved control without excessive sensitivity to the solenoid valve calibrations. Once the tuner pressure is adjusted to the desired operating range, the supply and return solenoid valves are kept closed all the time during HWR cavity operation. The new method is to adjust the volume of the helium gas space for precise control of the tuner pressure and frequency. To implement this, a stepper motor with a bellows are added to a spare port (used for cleaning the system, as shown in Fig. 1; the location for installation of the new components is circled). Actuation of the stepper motor applies force to the bellows to change the volume of the gas space by a small amount, which produces a small change in the pressure, resulting in a small shift in frequency. Figure 2 provides more detailed information about the new components and the tuner.

The new tuner control system is an update of the existing system. The LLRF controller phase detector provides the cavity phase detune as the error signal for the phase control loop. In the existing tuner control algorithm, the tuner feedback loop shifts the frequency via the supply and return valves [3]. In the new method, the feedback loop controls the stepper motor position with both solenoid valves

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closed. A schematic of the new system is shown in Fig. 3. The new control system allows us to switch between the old and new control methods.

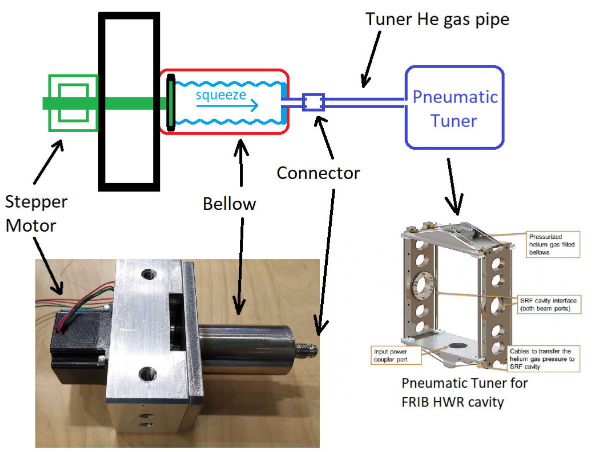

Figure 2: New components for the pneumatic tuner: stepper motor with bellows connecting to the tuner gas space.

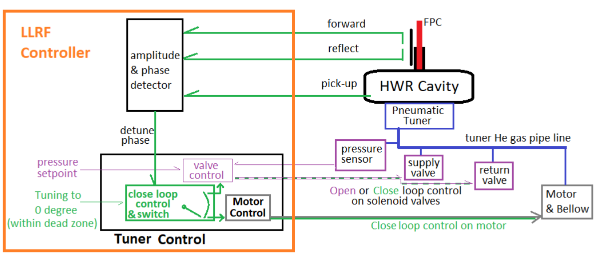

Figure 3: Schematic of the new tuner control system.

TESTING

The stepper motor and bellows were installed on a β = 0.53 HWR tuner for evaluation during a cryomodule certification test ("bunker test" of SCM518).

Tuning Range and Resolution

The new method can provide 0.2 psi tuning range, as shown in Fig. 4. The blue curve unit "V" is actually "psia"; the green curve is the stepper position. The tuning extrema are listed in Table 2.

The cavity's frequency sensitivity to manifold pressure is approximately 1 kHz/psi. The total tuning range is about 260 Hz. With the new method, the frequency shift produced with the stepper motor is 6.5e-4 Hz/step (based on 1.5e+6 steps/psi, per Table 2). Hence the new method can easily achieve 0.1 Hz tuning resolution, which is almost impossible controlling the valves with the old method.

Ramping

We checked the new tuner control loop during ramp-up to 7.4 MV/m (the accelerating gradient goal), as shown in Fig. 5. The red curve is cavity detuning, which can be controlled within ± 5 degrees during ramp up with the new tuning method.

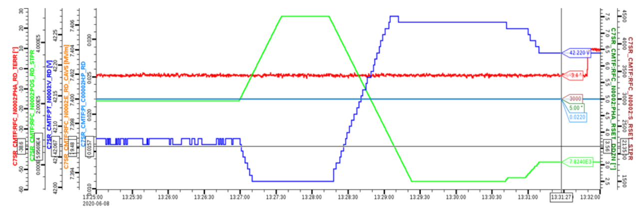

Figure 4: Tuning range measurement with the new method.

Table 2: Tuning Range with the Stepper Motor

Tuning Range	Pressure (psia)	Stepper Position (step count)
High Limit	42.27	0.85E+5
Low Limit	42.01	4.86E+5

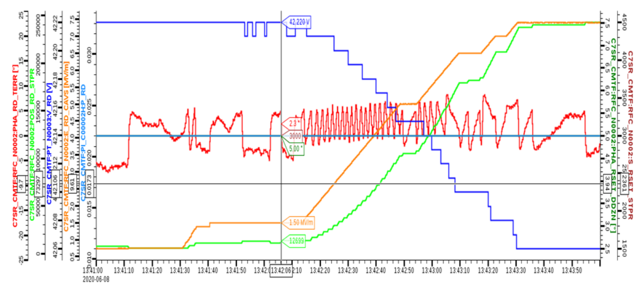

Figure 5: Tuner control during cavity field ramp-up.

Locking

Amplitude and phase stability test results with the new method are shown in Fig. 6. We locked the cavity for one hour. The cavity detuning (red curve in Fig. 6) is within ± 5 degrees. The amplitude and phase stability are comparable to results obtained using the original method with valve control.

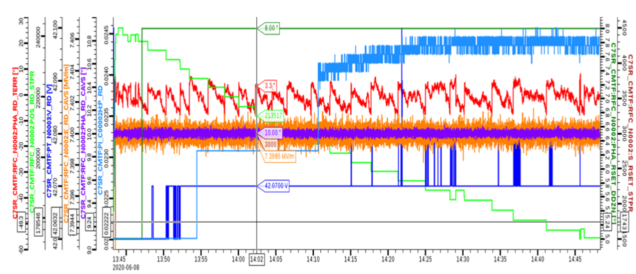

Figure 6: Amplitude and phase locking with the new method.

SUMMARY

A new pneumatic tuner control has been developed with the goal of improved tuning precision and avoidance of vulnerability to imperfect solenoid valve behavior. Testing of the new method on a β = 0.53 half-wave resonator in a cryomodule showed that it works as expected for stable cavity operation; cavity detuning was within ± 5 degrees. The new method, using stepper motor control instead of valve control, is simpler and does not require frequent valve recalibration.

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