Pneumatic Tuner Digital Control

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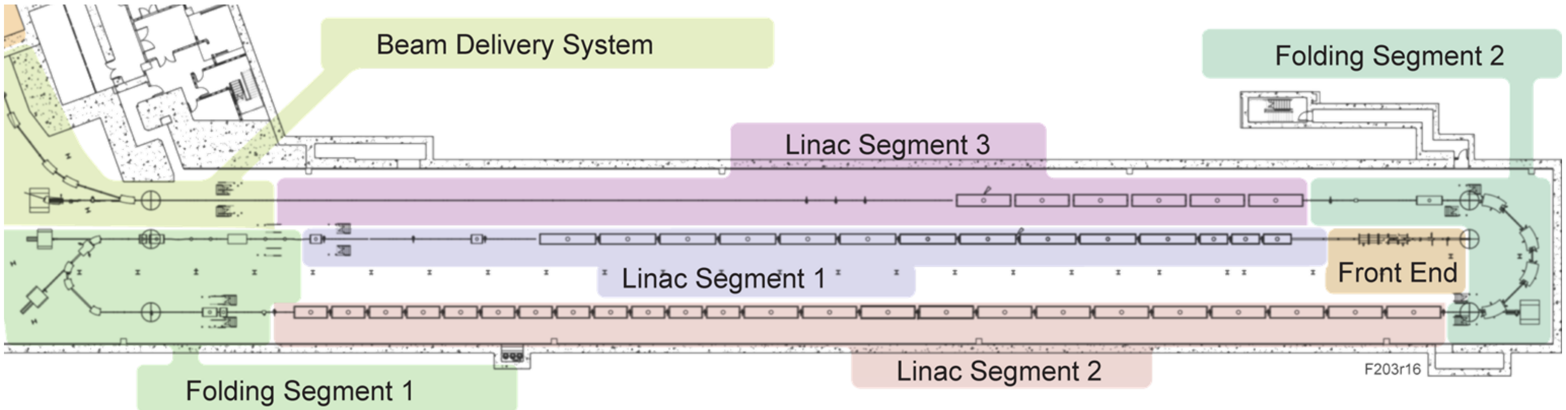
This material is based upon work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661, the State of Michigan and Michigan State University. Michigan State University designs and establishes FRIB as a DOE Office of Science National User Facility in support of the mission of the Office of Nuclear Physics.

Agenda

- Overview
- System diagram
- Analog circuit
- Digital implementation of pneumatic tuner control
- Pressure transducer
- User interface
- Pneumatic valve calibration
- Conclusions & Reference

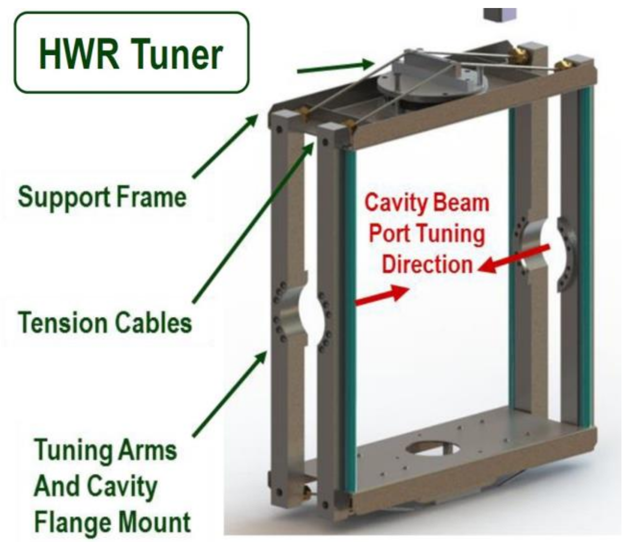
FRIB Linac Overview

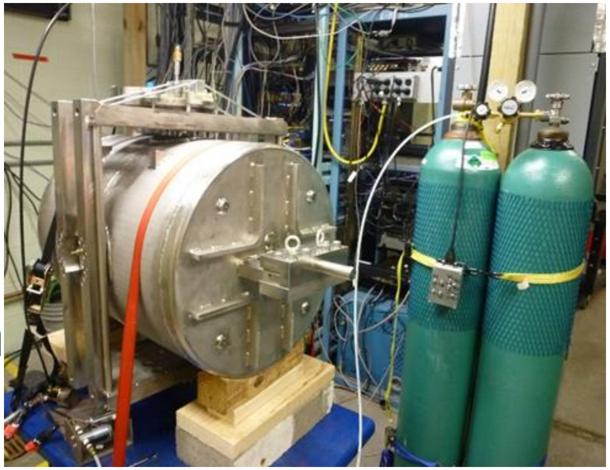


System	Area	Frequency	Cavity Type	Required RF Power	Amplifier Type	Tuner	Qty
Ion Source	FE	14 GHz	ECR	2 kW	Klystron	N/A	1
LEBT Multi-Harmonic Buncher	FE	40.25 MHz - 120.75 MHz	RT	100 W	SS	N/A	3
RFQ Driver	FE	80.5 MHz	RT	8 kW	SS	N/A	1
RFQ Final (Tetrode)	FE	80.5 MHz	RT	100 kW	Tetrode	Servo (water)	1
MEBT Buncher	FE	80.5 MHz	RT	4 kW	SS	2-phase stepper	2
β=0.041 (accelerating)	LS1	80.5 MHz	SC	700 W	SS	2-phase stepper	12
β=0.085 (accelerating and matching)	LS1 - FS1	80.5 MHz	SC	2.5 kW	SS	2-phase stepper	92
IH Multi-Gap Buncher	FS1	161 MHz	RT	18 kW	SS	5-phase stepper	2
β=0.285 (accelerating and matching)	LS2	322 MHz	SC	3.0 kW	SS	Pneumatic	72
β=0.530 (accelerating and matching)	LS2- LS3	322 MHz	SC	5.0 kW	SS	Pneumatic	148

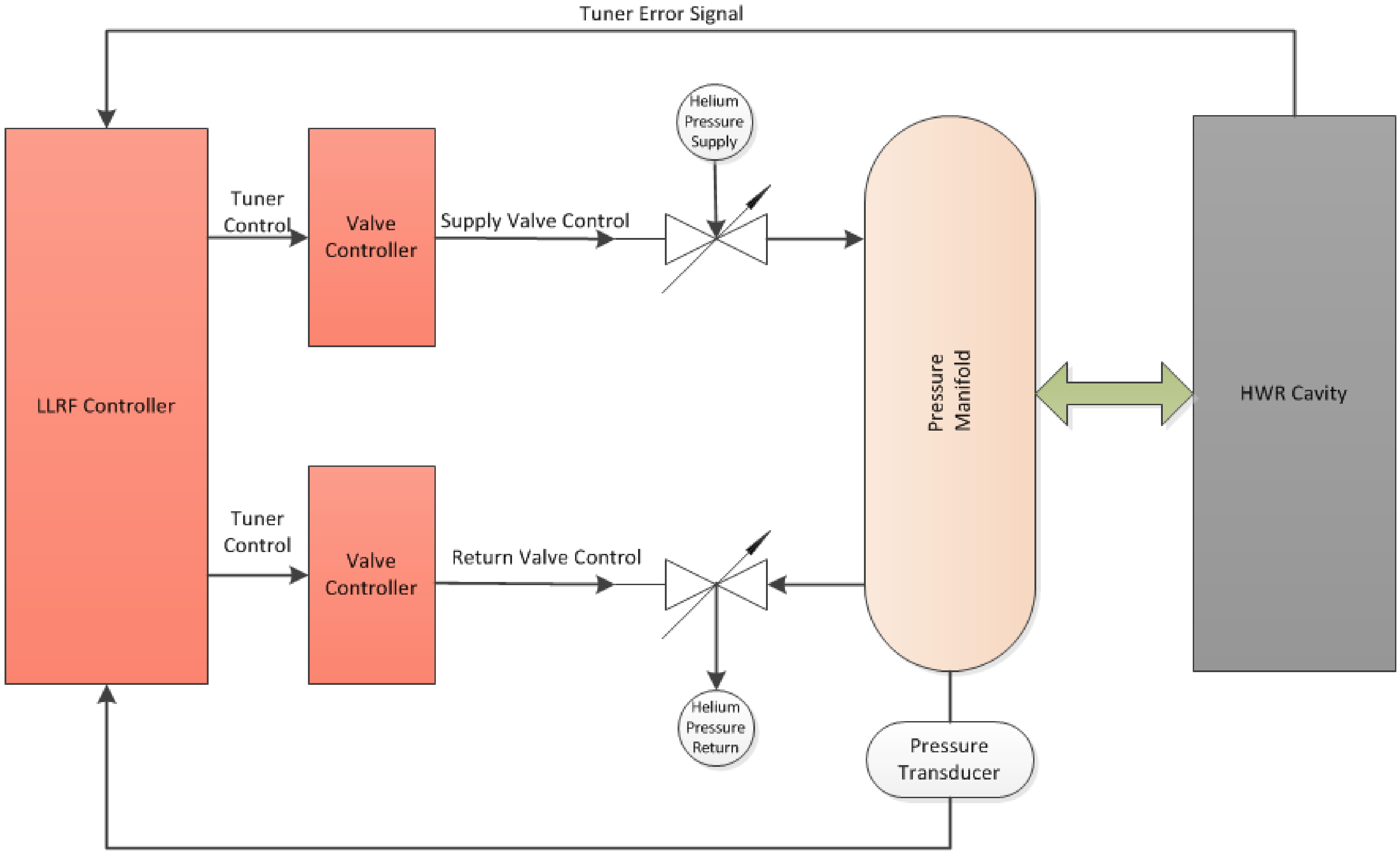
Pneumatic Tuner Overview

- Half Wave Resonator(HWR) cavities use pneumatic tuner to adjust cavity frequency
  - 72 of β = 0.29 and 148 of β = 0.53 cavities in FRIB
- Digital implementation of pneumatic tuner control has been developed based on analog pneumatic tuner control used at ANL [1]
- Helium gas manifold pressure is controlled by opening and closing of pneumatic control valves (supply and return)
- Pneumatic valve calibration technique has been developed
- Improper tuner control voltages and calibration can lead to cavity detuning due to Lorentz force



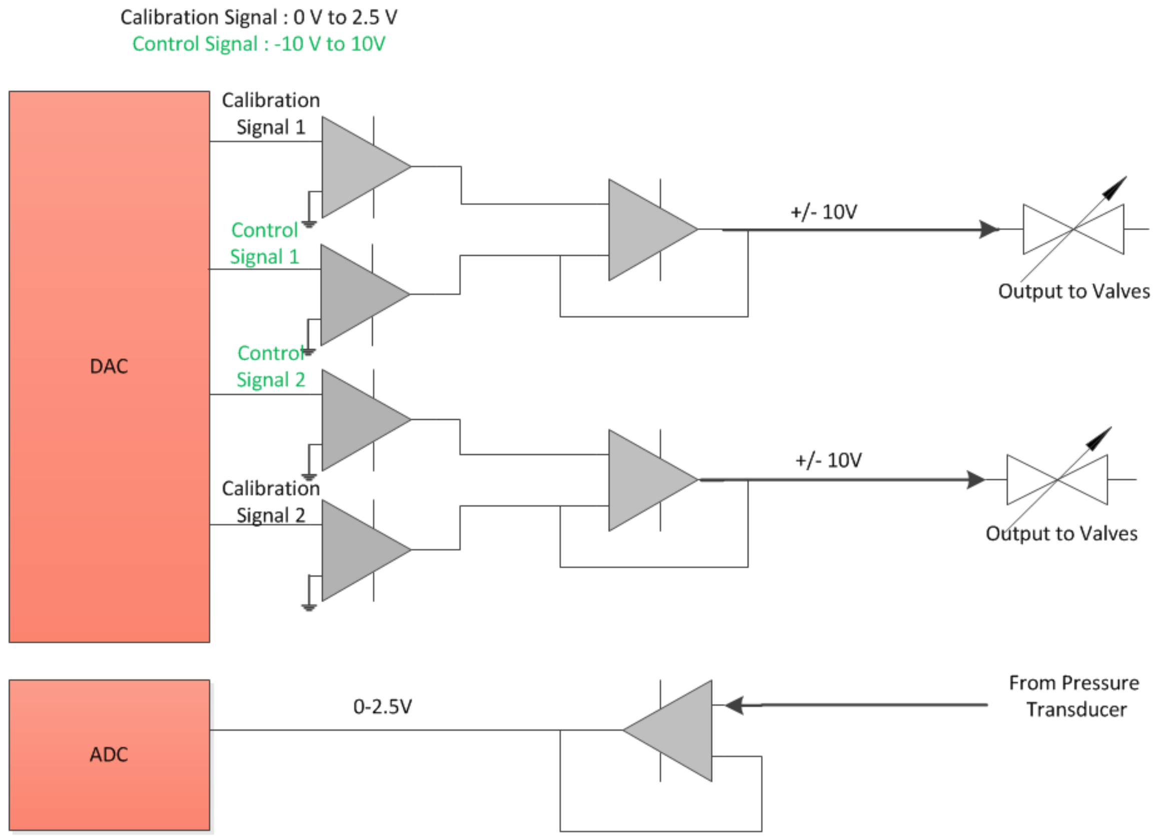


System Diagram



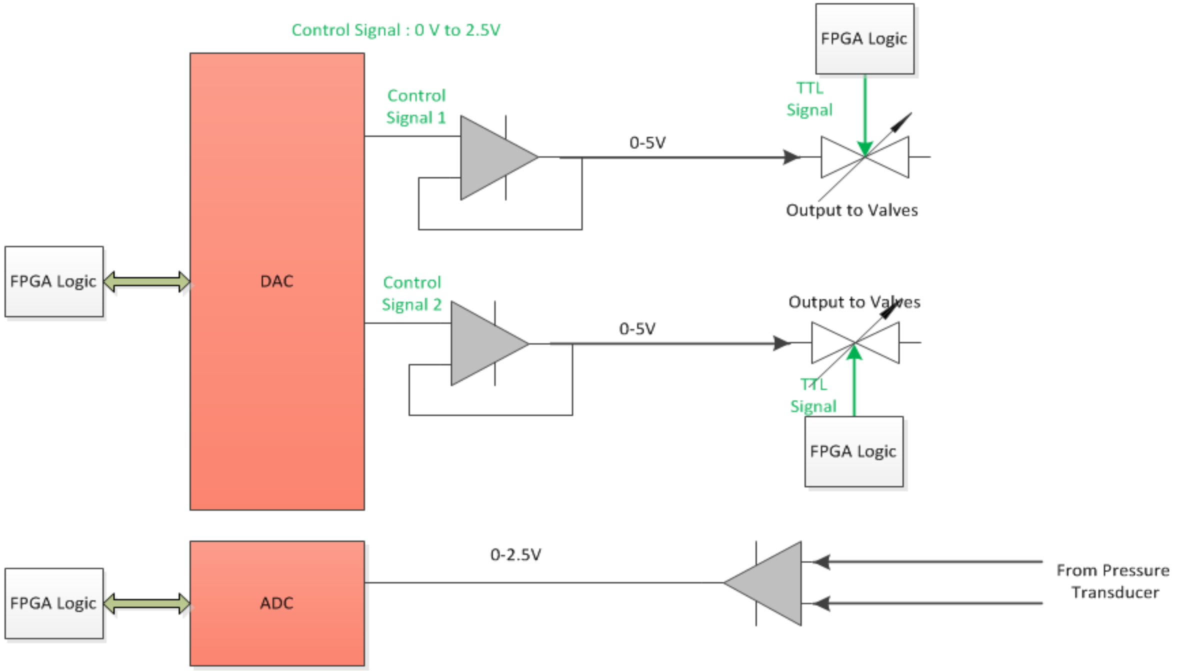
Analog Circuit

- Prototype 1 developed at FRIB, based on ANL design

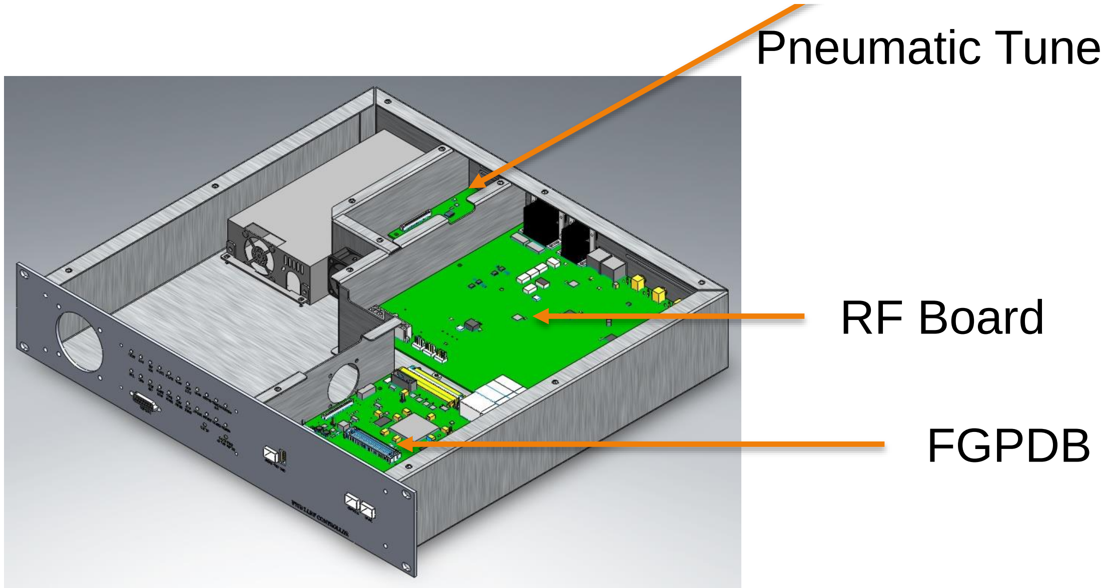


Digital Implementation Circuit

- Simplified circuit
  - Removed calibration signals and related parts, logic implemented in FPGA
  - Added TTL signals to enable / disable valves digitally
  - Pressure transducer differential input for better resolution
  - Added temperature sensor to monitor PCB overheating

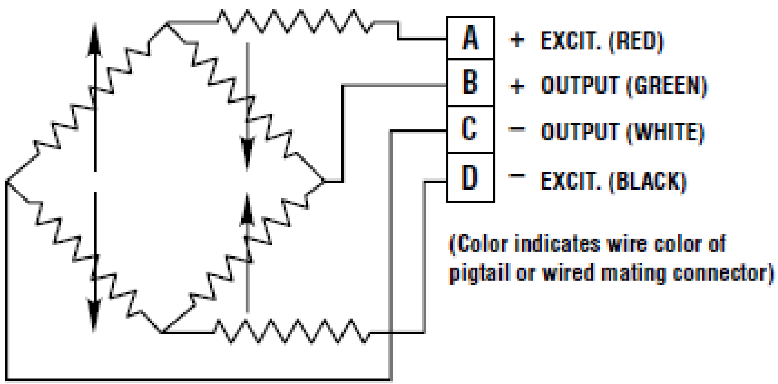


LLRF Hardware



Pressure Transducer

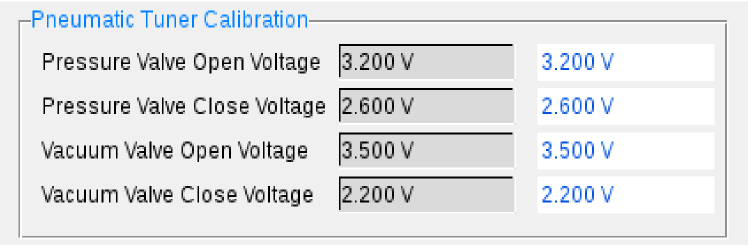
- Installed pressure sensor to monitor accurate manifold pressure
  - Safety features developed i.e. disable supply valve when pressure is too high
- APG PT-L9-C-100
  - Range : 0 to 100 psi
  - Output : 10 mV/V
  - Excitation : 12 VDC
  - Full scale output : 120mV/ 100psi

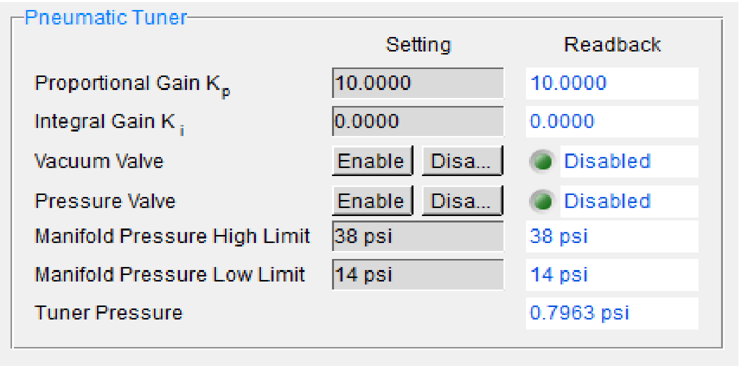


- Wheatstone bridge
  - Tuner driver circuit provides excitation voltages between A and D
  - Differential output from B and C provides 120mV maximum output
  - Tuner circuit has internal gain to amplify this signal before ADC
  - Tested with 100 feet cable (approximate distance between transducer and tuner circuit)

User Interface

- User screens have been developed to let user
  - Calibrate valves (in Volts)
  - Enable / disable valves
  - Change gain
  - Set absolute pressure limits (in psi)

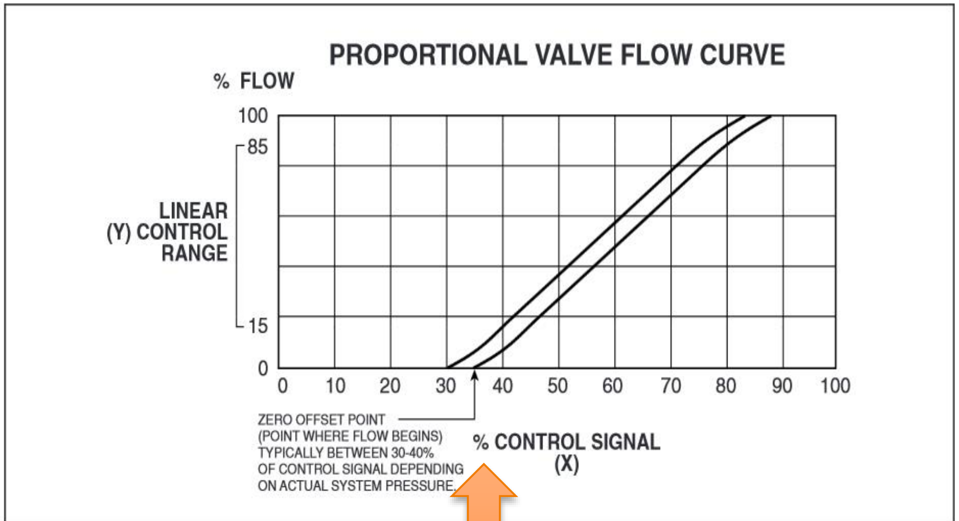


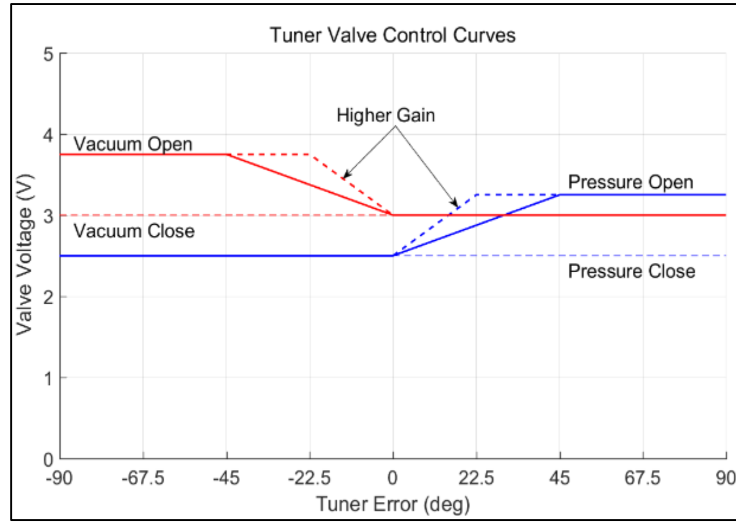


- Firmware development
  - Four different signals to control opening and closing of supply and return valves
    - » Range : 0-5V
    - » Pressure Close : PC, Vacuum Close : VC
    - » Pressure Open : PO, Vacuum Open : VO
  - Safety features : Closes supply valve if pressure reaches high limit

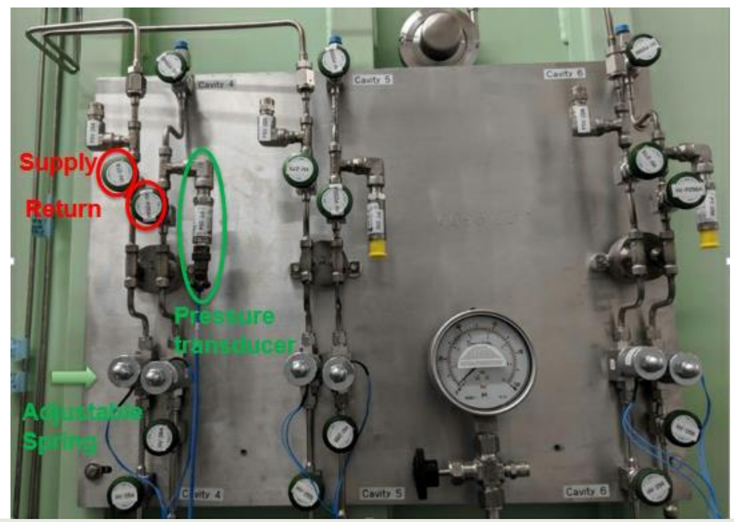
- Formula used for conversion from voltage to psi
  - Full scale pressure / Sensor sensitivity * Excitation voltage * Differential amplifier gain

Valve Calibration (1)



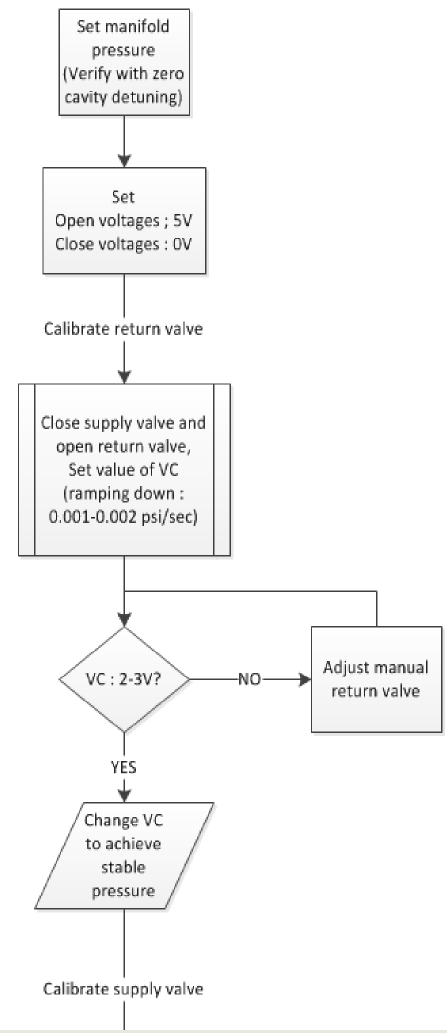


Adjust spring screw and valve control voltages to keep control signal at zero offset point



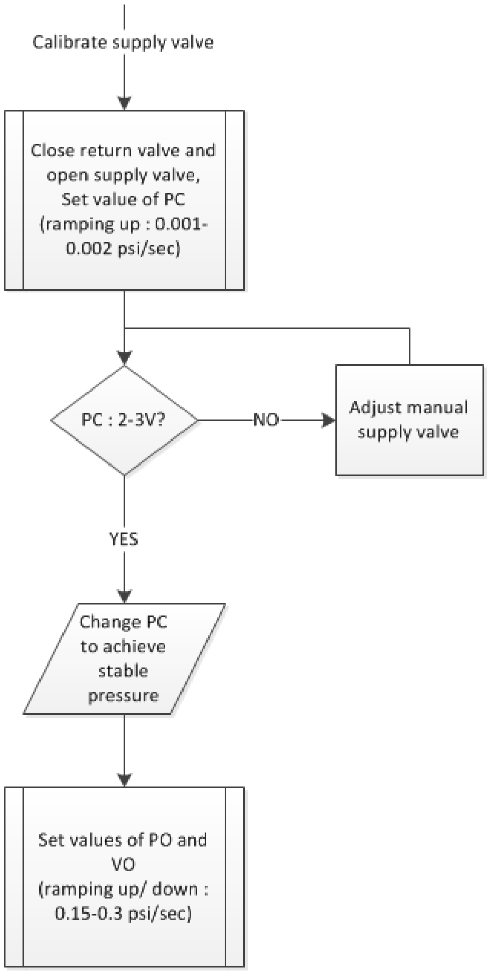
Valve calibration (2)

- Set manifold pressure needed for 322 MHz
  - Verify pressure with zero cavity detuning
    - » In Self-Excited Loop (SEL) mode
    - » Or in open loop mode and tuner ON
- Set open and close values for pneumatic valves
- Calibrate return valve
  - Close supply manual valve and open return manual valve
  - Set value of VC so manifold pressure starts ramping down at 0.001-0.002 psi/sec rate
  - Typically value of VC should be in range of 2-3V to avoid hysteresis on valves
    - » If not, adjust spring screw on manual return valve
  - Change VC so pressure gets stable and note that value, set VC to 0 volts after that to calibrate supply valve



Valve calibration (3)

- Calibrate supply valve
  - Close return manual valve and open supply manual valve
  - Set value of PC so manifold pressure starts ramping up
  - Typically value of PC should be in range of 2-3V to avoid hysteresis on valves
    - » If not, adjust spring screw on manual supply valve
  - Change PC so pressure gets stable and note that value
- Set VC and PC values from noted calibration values, open both manual valves
- Set PO and VO values so pressure increase/ decrease at rate of 0.15-0.3 psi/ sec
  - Typical open voltage values 3-3.5 volts



Conclusions

- Resonance control with the developed digital pneumatic tuner has been verified multiple times during cryo-module tests at FRIB
  - Cavities can be stably locked at designed field
- Valve calibration technique has been proved efficient to achieve stable pressure level for smooth operation
- Tuner tracks changes in bath pressure and compensates for Lorentz force detuning
- Pressure transducer differential feedback (in mV) and differential amplifier gain provides correct pressure level inside manifold
- TTL signals allow users to enable / disable valves from CS-Studio screens
- Safety features developed in firmware
  - Avoid excessive manifold pressure and damage to cavities by disabling supply valve when pressure is too high

Path Forward

- Develop scripts to run automatic valve calibration for FRIB Linac
- Manifold pressure keeps changing with change in cryo parameters (i.e. bath pressure), which changes operating point
  - Might need to re-calibrate all valves when installed in FRIB Linac

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- Acknowledgement
  - Special thanks to Gary Zinkann (ANL), Sergey Sharamentov (ANL)
  - Argonne National Laboratory, Argonne, IL 60439, USA

- Reference

  - [1] G. Zinkann, E. Clifft, S.I. Sharamentov, An Improved Pneumatic Frequency Control for Superconducting Cavities, Proc. of PAC-2005, p.4090.