

# Spallation Neutron Source LLRF Systems

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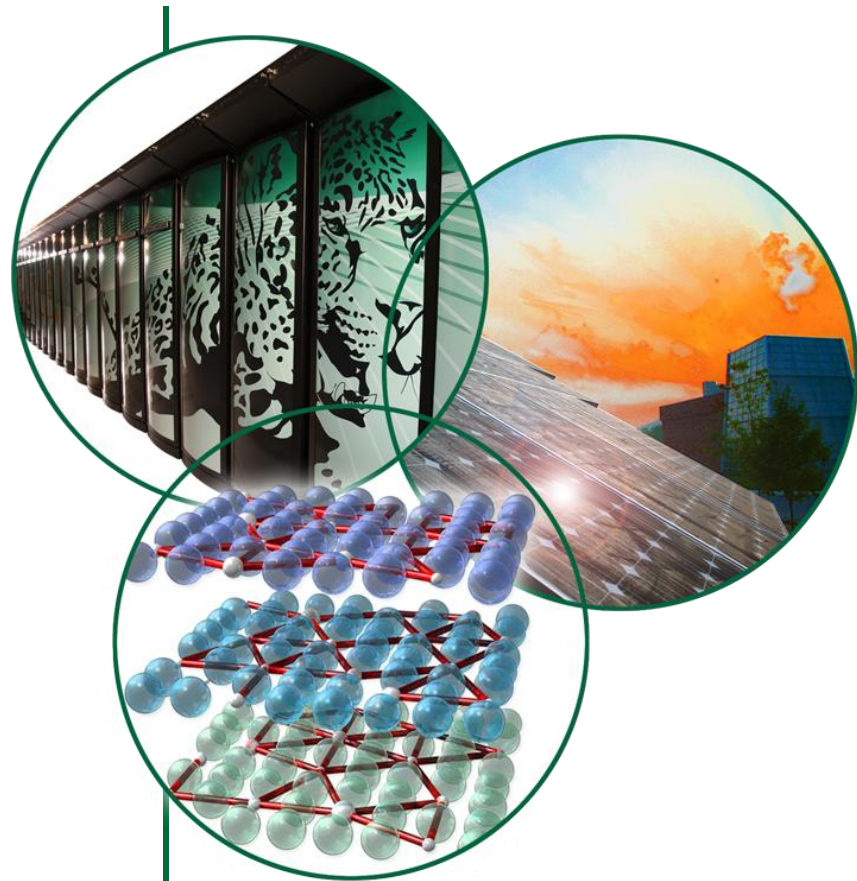
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# LLRF Automation

- The startup of the RF systems is automated with the use of a sequencer
- Systems can be started or stopped using two buttons
- The ramp feature provides the following features:
  - Ramp cavity to a user selectable percentage of goal
  - Verifies vacuum stays below a set value – halts the ramp if exceeds the value, resumes after recovery
  - Tunes cavity prior to closing loop
  - Finishes ramp to operational settings in closed loop

The screenshot displays a control interface for LLRF automation with the following sections:

- Idle / Stopped:** Buttons for 'Idle', 'Ramp', and 'Kill RF'. A 'Stopped' status box with a green indicator is on the right. Navigation arrows point to '...manual...' and '...manual or on errors'.
- Ramp:** Ramp cavity amplitude to 101.0 % of goal, i.e. 0.352. While power is below 700.0 kW, stepping 0.00100 every 1.0 sec. With good vac., accelerate 2.0 time. Check cav. rise after stepping 4 times.
- Tune:** Wait for Res. Err. of 12.0 +- 0.00 kHz for at least 30 sec. Duration: 30 sec.
- Vacuum:** Wait for vacuum 3.2e-07 to get below 5.0e-07.
- Closing...:** Closed Loop 4628.9 min. Regulation Err. 0.03 %. Peak 0.97 %, Limit 12.50 %. A 'Check' button is present.
- Loop Opened:** Limit Fwd Pwr to 550.0 kW for 10 sec 0 sec.

# LLRF additions to address Superconducting Cavity issues

- **Quench detection**
  - Quench detection was included in the original LLRF package but didn't function properly
  - We now have two functional quench detection schemes
    - Hardware quench detection implemented in HPM module for detection during beam
    - Software based detects the onset of a quench and shuts off RF preventing the quench over full pulse
- **Heater control**
  - Heaters are provided to keep the thermal load on the cryogenic system constant
    - LLRF enables these heaters when RF power is disabled
- **Monitor electron probe current**
  - Cold Cathode vacuum gauges go to sleep and can leave us unprotected
  - We installed pico-ammeters to monitor electron current in the couplers
  - Provided electron current display and interlock
- **Chatter Fault Protection**
  - Inhibit RF after preselected number of successive faults
  - Require manual reset

# LLRF additions to address RFQ Issues

- **As we increased the pulse length toward full beam power operation we began experiencing RFQ tuning issues**
  - **With the RFQ operation stable something would disturb the operation and require much effort and time to recover**
    - **Observed that excessive Ion Source gas flow reduces structure Q over time**
      - **Now monitor gas flow**
    - **Structure cooling seemed marginal**
      - **The RFQ is cooled by a pair of chillers**
      - **The chillers operate at a fixed temperature set point**
        - » **One chiller cools the vanes**
        - » **A second chiller cools the body and MEBT cavities**
        - » **Replaced the water manifolds**
      - **Replaced chillers**
  - **We observed that a minor adjustment of RF pulse length prior to losing control would correct the problem**
    - **We added a slow pulse-length adjusting feedback loop to the LLRF control software**
    - **We also added slow control loops for the chiller temperature**

# RFQ Software Control Loops

- Issues discovered with high duty, long pulse operation of RFQ
- Software loops added to enable up to 1 mS pulse operation
- Adjust pulse width for fine adjustment
- Adjust chiller temperatures to center pulse width

The screenshot shows a software window titled "Tuning" with a sub-header "Res.Error Adjustments, RFQ 1". It contains four main sections for parameter adjustment:

- Resonance Error:** A table of parameters with input fields.

Parameter	Value
Goal (center)	12.00 kHz
Chill. Adj. High	18.00 kHz
PW Adj. High	17.00 kHz
PW Deadband	5.00 kHz
Chill. Deadband	120 %
Current Res.Err.	11.55 kHz
PW Adj. Low	7.00 kHz
Chill. Adj. Low	6.00 kHz
- Pulse Width Adjustment:** Includes a "State" dropdown set to "Enable" and a "Resonance error within deadband" slider. Below is a table of parameters.

Current PW	Adjust. Step	Min. PW	Max. PW	Wait Time
871.5 uS	4 us	860 us	920 us	40 s
- Chiller 1 Adjustment:** Includes a "State" dropdown set to "Enable" and a "Resonance error within deadband" slider. Below is a table of parameters.

Current Temp.	Adjust. Step	Min. Temp	Max. Temp	Wait Time
19.8 C	0.10 C	19.00 C	22.00 C	150 s
- Chiller 2 Adjustment:** Includes a "State" dropdown set to "Disable" and a "Disabled" slider. Below is a table of parameters.

Current Temp.	Adjust. Step	Min. Temp	Max. Temp	Wait Time
23.6 C	-0.10 C	22.00 C	25.00 C	150 s

# Beam Blanking

- **Downstream RF must be disabled during beam tuning**
- **Initially the LLRF was shifted in time to simplify tuning process**
  - Time shift is limited by HV Pulse Width
  - More time consuming to perform
- **Beam blanking allows for turning RF off during beam pulse**
  - All RF stations remain on
    - Those not yet in use are not gated on during beam pulse
    - Allows physics team ability to turn on entire Linac and step through each cavity in sequence
    - No need to stop tuning process to turn on the next cavity