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The Spallation Neutron Source Accumulator Ring RF System

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Overview

- General SNS Machine Background
- Accumulator Ring RF System Details
- Present Status
- Some current operational results
- Conclusions
SNS Facility – Artists View
Overall Site Layout

- Power supplies for all Ring Magnets
- RF System supplies and LLRF
- FRONT END BUILDING
- LINAC TUNNEL
- KLYSTRON GALLERY
- CRYOGENICS BUILDING
- HEBT TUNNEL
- RTBT TUNNEL
- Target
Layout of Linac RF Modules

- SRF, $\beta=0.81$ (48 cavities, all powered)
- SRF, $\beta=0.61$ (33 cavities)
- RFQ
- DTL
- CCL

- 402.5 MHz, 2.5 MW klystron
- 805 MHz, 5 MW klystron
- 805 MHz, 0.55 MW klystron

- 3 Transmitter 3 Modulators
- 4 Transmitter 4 Modulators
- 16 Transmitter 8 Modulators

- 2.5 MeV
- 86.8 MeV
- 1000 MeV

- 186 MeV
- 379 MeV

- 1000 MeV HEBT

- 805 MHz, 0.55 MW klystron
- 805 MHz, 5 MW klystron
- 402.5 MHz, 2.5 MW klystron

- 1 Transmitter 1 Modulator
- 3 Transmitter 3 Modulators
- 4 Transmitter 4 Modulators

- HFIR
- SNS

Neutron Sciences
Spallation Neutron Source

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY
Accumulator Ring Parameters

- Circum 248 m
- Energy 1 GeV
- frev 1 MHz
- Accum turns 1060
- Final Intensity 1.5x10^{14}
- Peak Current 52 A
- RF Volts (h=1) 40 kV
  (h=2) 20 kV
- Injected Pulse 645 ns
- Injected Gap 300 ns
- Extracted Pulse 695 ns
- Extracted Gap 250 ns
RF System Parameters

- 4 Cavities – Two Gaps per Cavity
- 3 Fundamental Revolution Frequency Cavities – 7 kV per Gap
- 1 Second Harmonic Cavity – 10 kV per Gap
- Each Cavity has one Final Amplifier
- The System must handle 52 amperes peak beam current
- Beam Loading Compensation – Cavity Tuning, Feed Forward
- Single Turn Delay RF Feedback is possible but will take some development.

Diagram:

- RF-21, H=2
- RF-13, H=1
- RF-12, H=1
- RF-11, H=1
Beam Loading Is A Major Issue

Here are some options we have considered.

- **I&Q Feedback**
  - Basic feedback that samples cavity field and corrects for deviations from a programmed function.

- **Cavity Dynamic Tuning**
  - Cavity bias is dynamically adjusted to compensate for the apparent cavity detuning resulting from beam current (180 Hz Sinusoidal function is used).

- **Programmed Feed Forward**
  - Provide rf drive to the amplifier chain based on predicted beam loading effects.
  - The system can learn from previous beam cycles.

- **Beam Derived Feed Forward**
  - Sample beam current and feed an inverted beam current signal into the amplifier chain.

- **One Turn Delayed RF Feedback**
  - We placed the driver amplifiers as close to the final stage as reasonably possible to allow this approach if needed.

- **Direct RF Feedback**
  - Sample the cavity voltage and feed the inverted signal directly to the final amplifier.
  - We have not planned to use this method.
Present Operational Status

- The system is installed and fully operational
- We have stored over $8 \times 10^{13}$ Protons
- The original I&Q feedback system to control Amplitude and Phase performed well at $8 \times 10^{13}$ protons.
- We have demonstrated Cavity Dynamic Tuning
- A Beam Derived Feed-Forward system included in the original design is still under development but we have completed a preliminary test demonstrating feasibility.
- Operated the 2nd harmonic cavity to help clear the beam gap.
Amplifiers and Cavities installed in Ring

RF21
RF13
RF12
RF11

2005/09/20
Station RF21 in Ring Service Building

- Filament Supply
- Anode Power Supply Rack
- Anode Capacitor Bank
- Cavity Tuning Supply

2005/09/20
RF System performance with 9e13 Protons

- Upper trace is cavity voltage for station RF-12
- Beam is injected at T1
- Feedback corrects for beam loading.
- Voltage excursion is about 500 volts.
- No real effort went into adjusting the feedback parameters.
- Beam is extracted at T2
- Transient at extraction can be removed by gating RF drive off at extraction
- Lower trace shows phase with respect to the beam
RF System performance with 9e13 Protons
Cavity Dynamic Tuning Example
-- Phase detector looking at the phase between Grid and Anode

T1 = RF Voltage is at full programmed voltage and waiting for beam.
  - Lower trace shows cavity being pulled by bias function.

T2 = Beam injection starts
  - Upper trace shows beam pulling cavity.

T3 = Injection ends. Beam is stored briefly
  - Lower trace shows bias pulling cavity during store time.

T4 = Beam is extracted
  - Lower trace shows cavity way off resonance with no beam loading.
Operation with 2\textsuperscript{nd} Harmonic

- The 2\textsuperscript{nd} harmonic feature was intended to flatten the longitudinal beam distribution avoiding high peak currents.
- With our present intensity level we have not utilized the 2\textsuperscript{nd} harmonic cavity.
- During our last run cycle we experienced problems with our Low Energy Beam Transport (LEBT) beam Chopper.
- To keep the accelerator operational we chose to limit the chopper rise time which resulted in leaking small amounts of beam into the extraction gap.
- We found that by adding more fundamental RF power and applying second harmonic component we could clear the gap sufficiently to continue operation.
Display of the beam current with 2\textsuperscript{nd} Harmonic component
Ring LLRF development - Current Status – Hardware

• First prototype for testing uses 1 MHz -> 10MHz up-conversion scheme for minimizing coding work (straight I/Q scheme as in linac system)

• Firmware/software modification completed.

• Preliminary Bench-test for checking control functions – done

• Site test will follow soon.

• Signal I/O:
  • Input vectors: Cavity gap V, Grid V, Beam I,
  • Output vector: RF
  • Monitors: regulation error, output power, and gap-grid phase.
  • Misc.: cavity tuning, rf gate, cycle reset, clocks etc.
Concluding Comments

- The Amplifiers can supply enough power to control beam loading well beyond the 1.5e14 Protons per Pulse.
- Existing LLRF system performs well but leaves us with some maintenance and operational concerns.
- We are pursuing a LLRF approach that will utilize much of our existing control system features and allow us to work on the system with existing tools.
- I hope to be able to show performance data at full design intensity (1.5e14 Protons Per Pulse) at PAC09.