Outline
Beam Related Issues

• Superconducting Linac RF setup
  – Model based RF phase scaling

• Beam Loss in the SCL
  – Magnitude and sensitivities
The SNS Power Ramp-up Experience

- Power increased x 100 in ~ two years
SNS Linac Overview

A warm (copper structure) linac for low energy beam
- 6 DTL tanks from 2.5 to 87 MeV / 6 klystrons
- 4 CCL modules from 87 to 186 MeV / 4 klystrons

A Superconducting Linac for high energy beam (186 to 1000 MeV)
- 33 medium beta ($\beta = 0.61$) cavities / 33 klystrons
- 48 high beta ($\beta = 0.81$) cavities / 48 klystrons
Warm Linac Longitudinal Beam Setup

- Large phase advance (longitudinal) and energy gain per accelerating structure
- Single correct RF phase and amplitude setting

Downstream beam behavior has complicated dependence on RF phase and amplitude – each cavity has a unique signature

Analysis: BPM Phase Difference vs. Cavity Phase

RF phase

Two RF amplitudes

Downstream beam phase difference
SCL Longitudinal Beam Setup

- Small $\delta \beta$ and small longitudinal phase advance per cavity
  - Close to ideal RF gap kick
- No correct setting for each cavity!
  - Set each cavity amplitude for the maximum safe gradient
  - Flexibility in the RF phase setup
SCL Cavity Amplitudes

- Strategy is to run cavities at their maximum safe amplitude limit
- Need to be flexible – SRF capabilities change, not near the design
- Linac output energy is not fixed
Model Scaling to Adjust Cavity Phase for Upstream RF Changes

Step 1: Measure the beam arrival time at each cavity for the nominal setup (set the RF phase with a beam measurement)

Step 2: Change an RF phase and / or amplitude

Step 3: Use a simple model to calculate the change in downstream arrival time (RF phase setpoint) for modifications in the RF setup

- Proton beams for high power applications (< 10 GeV) are not fully relativistic and the velocity is energy dependent
- For SNS if an upstream cavity fails, the arrival time at downstream cavities can be delayed up to 5 nsec
  - This is over 1000 degrees phase setting of an 805 MHz RF cavity
  - Our goal is to set the cavity to within ~ 1 degree
Application of the Cavity Fault Recovery Scheme (II)

- In April 2007 the SCL was lowered from 4.2K to 2 K to facilitate 30 Hz operation.
- About 20 cavity amplitudes changed.
- The fault recovery scheme restored beam to the previous loss state.
SCL Acceptance Measurement
(Y. Zhang)

- Can calculate the longitudinal acceptance space for the SCL linac
- Using scaling techniques one can perform scans across the phase space and measure transmission

Consider this part of the scan
A Closer Look at a Phase Scan
(courtesy Y. Zhang)

- Scan the beam phase for a constant input beam energy
  - Measure the transmitted beam current (core beam)
  - Measure the Beam Loss (halo indicator)
Measured SCL Acceptance

- Create an acceptance measurement from the scans across the...
Beam Loss in the SNS Superconducting Linac

- We measure beam loss and residual activation in the warm sections between SCL cryomodules
  - Location of focusing elements and aperture restriction
- Residual activations range from 10 to 60 mrem/hr at 30 cm, after one day shutdown
- Not an issue for worker dose during maintenance or equipment lifetime

Residual dose rate at 30 cm, 24hrs. after production run
Fractional SCL Beam Loss Characterization: (Y. Zhang)

- Spill an entire (small) single mini-pulse locally in the SCL by purposefully destroying the RF setup: gives nC/Rad calibration
  - Medium $\beta$: 36 nC/Rad $\pm$ factor of 3 variation
  - High $\beta$: 13 nC/Rad $\pm$ factor of 2

- For production conditions we are losing $< 2 \times 10^{-6}$ beam / warm section
  - $< 10^{-4}$ total loss in SCL

- Consistent with the excepted activation for $< 1 \text{W/m}$ beam loss

- Very small fractional beam loss!!!!
SCL Activation Buildup

- Average residual activation of the warm sections saturates after < ~ one month of running
- Ring residual activation shows slower rate of saturation - also higher value
SCL Beam Loss Sensitivities

- Sensitive to upstream warm linac RF set-up
- Insensitive to input SCL matching quads
- Insensitive to longitudinal RF tune (constant phase, constant focusing phase law)
- Insensitive to flattened trajectory (+ 3 mm)
- Can reduce SCL loss by ~ 1/3 by reducing the quadrupole focusing strength (10-20 %)
- Can increase the loss by creating local trajectory bumps
Create a local bump (~ 5 mm) and observe loss downstream

- H- magnetic stripping – not likely, fields are lower than transport line
- Off axis RF fields – happens in dummy sections with no cryomodules
- “Shaking’ off-energy beam ???
- Strong sextupole component in dipole windings ???
Summary

- The SNS Superconducting Linac is operating at over 500 kW
- We are not running cavities at expected design voltages
  - The SCL is flexible to many different operating set-ups
- Model based phase scaling works to reset downstream cavities
  - Can be used to work around failed cavities and facilitate beam studies
- We see a low level of beam loss, albeit higher than expected
  - Source is not understood
Backup
**SCL Activation decay**

- Decays close to starting value
Residual Activation Decay Across the Machine

Beam loss normalized to the initial reading

- The SCL warm sections decay faster than the rest of the machine
  - Except SCL2_3 is intermediate
Residual Activation Decay (Zhukov, Assadi, Popova)

- SCL decays quite fast – model comparisons are underway

Real time measurement of residual activation after shutdown
Application of the Cavity Fault Recovery Scheme

- In the spring 2006, 11 cavities had to be either turned off or have their amplitudes reduced for safe operation, 1 cavity was returned to operation.

- The fault recovery scheme was applied “all at once”.

- Phase scan spot checks indicate the scaling was within 4 degrees.

- No detectable change in beam loss.
## SNS Linac Beam Parameters

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Best Ever (Not Simultaneous)</th>
<th>Highest Power Run (Simultaneous)</th>
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<tr>
<td>Pulse Length (μSec)</td>
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<td>Beam Energy (MeV)</td>
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<td>Peak Accelerated Current (mA)</td>
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<td>Average Accelerated Current (mA)</td>
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<td>Repetition Rate (Hz)</td>
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<tr>
<td>Beam Power (kW)</td>
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<td>540</td>
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