Accelerator Physics – Progress and Challenges

J. Galambos
SNS AAC Meeting
Jan. 22-24, 2008

On behalf of the AP Team
Accelerator Physics Group Activities

- Reduce Beam Loss
- Perform beam studies
  - Same team that commissioned the machine
  - Devise measurements to understand and correct causes of beam loss
- Request new modified beamline equipment
- Develop and maintain the high level software
- Perform simulations and beam modeling
  - ORBIT code for Ring
  - Parmila, IMPACT models for linac
- Keep an eye on the future
  - high intensity effects
  - laser stripping
SNS Time Structure Nomenclature

**Macro-pulse** Structure
(made by the High power RF)

- 16.7ms (1/60 Hz)
- 15.7ms
- 1ms

**Mini-pulse** Structure
(made by the choppers)

- 945 ns (1/1.059 MHz)
- 645 ns
- 300 ns

**Micro-pulse** structure
(made by the RFQ)

- 2.4845 ns (1/402.5 MHz)
- 260 micro-pulses
Accelerator Physics Beam Study Rhythm

### Run Schedule for FY 2008

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**Red** – extended outage

**Yellow** = AP

**Green** = neutron Production

- Post extended maintenance: linac setup, beam RF, diagnostic studies, equipment shakedown
Layout of Linac RF with Warm and SCL Modules

- **SRF, β=0.61, 33 cavities**
  - 186 MeV
  - 402.5 MHz, 2.5 MW klystron
  - 805 MHz, 5 MW klystron
  - 805 MHz, 0.55 MW klystron

**Warm Linac**
- 2.5 MeV
- SRF, β=0.81, 48 cavities
- 1000 MeV (81 total powered)

**SCL Linac**
- from CCL

- **Warm linac has 10 independently powered RF structures**
  - Typically each structure has 50-100 gaps
  - β change is substantial
  - One correct amplitude and phase setting
Normal Conducting LINAC Tuneup Procedures

- Warm Linac RF Amplitude and phase setpoints determined with a phase scan method
  - Accurate to ~ 1%, 2 degrees
- Use design quadrupole strengths and RF settings
- First machine to routinely use this method

- Scan RF phase for multiple amplitude settings
- Solve for input beam energy, RF amplitude calibration, RF phase offset

![Graph showing BPM Phase Difference vs. RF Phase](image_url)
SCL Cavity Tuneup

- Use highest available SCL gradients – far from design
- Set the SCL cavity phases using phase scan technique
- Scale design quadrupoles with beam energy
SCL Cavity Amplitudes

- Strategy is to run cavities at their maximum safe amplitude limit (S. Kim’s talk)
- Need to be flexible – SRF capabilities change, not near the design
- Linac output energy is a moving target
SCL Setup Times are Decreasing

- The procedures used to setup the superconducting linac have matured, and the setup time is now minimal.
- Still exists a need for fast recovery from changes in the SCL setup.
1 GeV is not ultra-relativistic – change in upstream cavity has a large impact on downstream cavity phase settings.

Use a model to predict change in measured downstream arrival times from a change in an upstream cavity.

In April 2007 the SCL was lowered from 4.2K to 2 K to facilitate 30 Hz operation, 20 cavity amplitudes changed.

The fault recovery scheme restored beam to the previous loss state.
Linac RMS Beam Size *(Nov. 2007)*

Lines are model predictions with design Twiss parameters, and dots are wire profile measurements.

- Warm linac beam size is in good agreement with design values.
Linac Beam Profiles

- Profiles at the start of the HEBT 12/10/2007
- Beam profiles are close to Gaussian at the end of the linac than previously observed
  - Ignore startup portion of the beam
  - Quadrupole settings are closer to design values
  - Source dependent
**Linac concern: Chopper Quality**

*(S. Aleksandrov’s Talk)*

- The chopper system provides clean gaps between mini-pulses to provide a gap to fire the extraction kicker in the Ring
- It is a 2 stage system designed to clear the gap to 1 part in $10^4$
  - LEBT chopper at 65 keV
  - MEBT chopper at 2.5 MeV
- The MEBT chopper has never been used during neutron production
- Sometimes have leading/trailing satellites
- Protection measures introduced in the LEBT system have slowed the rise / fall times
- Improperly centered beam through the LEBT can cause mini-pulse to mini-pulse position jitter - effectively increasing the beam size.

March 6, 2007
Beam Loss / Residual Activation

- SNS is designed to be a hands-on maintainable accelerator
- 100 mRem/hr at 1 foot is considered the limit for relatively easy hands on maintenance
  - Corresponds to ~ 1 W/m beam loss
- BLMs give a measure of beam loss
  - (~ 400 BLMs throughout the machine)
- Residual activation measured after every production run
- Use the relationship between BLM readings/ measured activation to predict activation during production setups and prioritize areas for beam study
CCL Residual Activation

1/7/2008 Measurements

- Hot spots: 10-30 mRem/hr
- Scaled to 1.4MW: 90-250 mRem/hr
- Context: similar residual activation as Dec. 2006 at ~ 30 kW
  - Better trajectory control (S. Aleksandrov’s talk)
  - Additional BLMs
- Keys to further improvement:
  - Longitudinal RF setup refinement
  - Transverse matching
  - MEBT chopping
SCL Residual Activation Status

1/7/2008 Measurements

- Average warm section residual levels are 10-20 mrem/hr.
- Context:
  - These activation levels correspond to 1-2 x 10^{-4} fractional beam loss.
- Scaled to 1.4 MW: 90-250 mRem/hr.
Believe the SCL losses are longitudinal (Aleksandrov's talk)

- Loss magnitude is not sensitive to matching quadrupole settings
- Loss magnitude and distribution is very sensitive to linac RF phase setpoints
- Developing methods for measuring and increasing the SCL longitudinal acceptance

Measured SCL acceptance (courtesy Zhang)

Simulated SCL acceptance
HEBT Transport Line

- Not much beam loss / activation
- Upstream transverse + momentum collimation has been tested but is not used
  - Causes more beam loss in the arc than halo reduction benefit
• **Primary functions:**
  - Injection
  - Fast Extraction
  - Collimation
  - RF
Ring Setup Recovery / Repeatability is Good

- ~ 1 shift to recover a Ring / Transport line setup after an extended maintenance period
- Magnet cycling application for hysteresis effects
  - Determine which magnets require cycling and the minimal cycling periods
- Sophisticated save/compare/restore application
Ring Injection Area (M. Plum’s talk)

- “As delivered” Ring could not transport beam to the injection dump and circulate beam in the Ring (M. Plum’s talk)
  - Inconsistency in chicane values for Ring and dumpline designs
  - Did not fully appreciate the influence of 3-D magnetic effects

- Remedial actions
  - Moved chicane
  - Use oversize injection foil (reduce fractional beam to the Injection dump)
  - Added additional diagnostics and magnet to the dumpline to understand waste beam transport
  - Further upgrades are planned
**Injection Dump-line Beam Loss**

- One hot spot from secondary foil scattering
- Rest of the Injection dump line ~ 10 mRem/hr residual activation

**Future upgrades:**
- New, larger aperture septum to be installed in Feb. 08 outage
- Additional quadrupole in the injection line
Ring Extraction / Collimation beam loss

- Extraction area is sensitive to beam in gap
- Collimation works close to expectations (*J. Holmes talk*)
  - Presently we are using short pulse beams (small beam size) and to not employ collimation
Ring RF

- Use 2 fundamental cavities, 1 2nd harmonic cavity
  - Purpose of the dual harmonic is to reduce the bunch factor to minimize space charge
  - 2nd harmonic useful for gap cleaning
  - Can further clean the gap with RF manipulations, but time scale is long (100’s of turns) – injection losses increase.
Ring Beam Loss Progress

- In general we are making progress
- Ring injection is the toughest area in the accelerator
- Most of the Ring is loss free
Ring Injection Straight Prediction – Residual activation from foil scattering

- 5000 hrs operation @ 1.4 MW, 3 hrs after shutdown
- > 1000 mRem/hr downstream from the foil – we are on track
- Keys to improvement is reducing foil traversals with:
  - better injection painting
  - Reduced linac beam tails
  - Smaller / thinner foil
Beam Size Control On Target

- Use wire profiles and harp to predict the beam size and beam density on the Target (*T. McManamy’s talk*)
- Difficulties understanding transport in the RTBT (*M. Plum’s talk*)
  - Swapped plane in harp, coupled H/V beam in the RTBT
- Reluctance to vary RTBT quads from values used with view-screen during commissioning
- With the power density on Target at the upper limit
  - Painting a larger beam in the Ring is the only option, but this causes excessive beam loss at the end of the RTBT
RTBT Radiation

- Hot spot from extraction loss – reduced with improved chopping
- End of RTBT losses reduced with updated lattice to keep the beam small there.

Beam in gap induced hot spot (38 mRem/hr)

Large beam at the end of the RTBT, 10-40 mRem/hr spots
Equipment Requirements for 1.4 MW Capability

- Ion source current, pulse length and repetition rate requirements to meet the power ramp-up
  - These requirements assume a 1 GeV beam
- Presently at 60 Hz we are limited to:
  - ~850 MeV beam energy
  - ~880 μs flattop pulse length
  - ~30 mA current at ~700 μs
Equipment Concerns for Power Ramp Up

- Ion source needs to provide 38mA at 1 mS/60 Hz.
  - *M Stockli’s talk*

- SCL needs to provide ~20% more accelerating gradient with an additional installed cryomodule + enhanced high beta cavity gradients through cavity reworking and surface processing.
  - *S. Kim’s + J. Mammosser’s talks*

- Starting the SCL RF fill during the HVCM ramp-up will provide ~70 μS longer flattop.
  - *S. Kim’s talk*

- Increase the (medium $\beta$ / high $\beta$) HVCM operating voltages from the present (69/71) kV settings to 73/75 kV to provide an additional 50 μs flattop capability, support the increased cavity gradients, and support beam loading associated with 38 mA.
  - *D. Anderson’s and T. Hardek’s talks*
AP Concerns

- **Linac**
  - Quality of beam chopping (*A. Aleksandrov’s talk*)
  - Understanding and controlling the source of beam loss in the SCL (*A. Aleksandrov’s talk*)
  - Controlling the transverse beam size and halo delivered to the foil

- **Ring**
  - Injection area
  - Clean transport of waste beams to the Injection Dump (*M. Plum’s talk*)
  - Good understanding and control of the beam distribution delivered to the Target (*M. Plum’s talk*)
  - Foil scattering losses
  - Foil survivability (*M. Plum’s talk*)
  - High intensity effects (*V. Danilov’s talk*)
Summary

- We have increased beam powers from a few kW to > 200 kW.
  - Large reductions in normalized beam loss through the ramp-up
- Have been equipment issues, but none are show-stoppers.
- Now we are dealing with low loss fractions, and are continuing to develop strategies to understand them and further reduce them.