RF System Performance

Mark Champion, Group Leader
AAC Meeting, 7-9 May, 2013
High Level View: Most of the original equipment is still in use after 7 years of operation

- 100 RF systems are installed and operational
  - Supported Ring and Target beam commissioning
  - Ready to support routine operations
- RF Group is fully staffed
  - 8 engineers, 9 technicians, secretary and group leader

June 2006
Increased Solid-State Amplifier Utilization

MEBT Rebuncher RF System was upgraded in September 2010 and has performed flawlessly

- 4+1 systems, 25 kW each, 402.5 MHz

Also replaced tube-based drive amplifiers in Ring RF system with solid-state amplifiers (not pictured here, but same vendor)

2 MHz, 120 kW amplifier is presently being tested on the ion source test stand

- Ability to survive ion source sparking has been demonstrated
- Presently working to improve load mismatch capability
## High Power Amplifier Inventory

<table>
<thead>
<tr>
<th>Type</th>
<th>Application</th>
<th>Frequency</th>
<th>Peak Power</th>
<th>Vendor</th>
<th>Installed</th>
<th>Spare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid-State</td>
<td>MEBT Rebunchers</td>
<td>402.5 MHz</td>
<td>25 kW</td>
<td>Tomco</td>
<td>4+1*</td>
<td>a few modules</td>
</tr>
<tr>
<td>Klystron</td>
<td>RFQ, DTL</td>
<td>402.5 MHz</td>
<td>2.5 MW</td>
<td>E2V &amp; Thales</td>
<td>7+2**</td>
<td>5</td>
</tr>
<tr>
<td>Klystron</td>
<td>CCL</td>
<td>805 MHz</td>
<td>5 MW</td>
<td>Thales</td>
<td>4+1**</td>
<td>6</td>
</tr>
<tr>
<td>Klystron</td>
<td>SCL</td>
<td>805 MHz</td>
<td>550-700 kW</td>
<td>CPI &amp; Thales</td>
<td>81</td>
<td>51</td>
</tr>
<tr>
<td>Tetrode</td>
<td>Accumulator Ring</td>
<td>1 &amp; 2 MHz</td>
<td>500 kW</td>
<td>Thales &amp; CPI</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes:
- E2V discontinued their production and support of the 2.5 MW klystrons; Thales developed a plug-compatible replacement (3 delivered).
- Thales is presently finishing up production of two 5 MW klystrons.
- CPI has not constructed any SCL klystrons since ~2008.

Key:
- * hot spare
- ** test stand
Klystron Lifetime and Vendor Engagement

• The majority of the klystrons presently used in the Linac have about 50,000 hours of run time.

• Cathode loading is relatively low and ranges from 0.5 to 1.25 A/cm$^2$.
  – lifetimes approaching 100,000 hours are likely, but uncertain
  – zero cathode-based failures to date

• Cathode emission data being collected to assist in monitoring and predicting lifetimes.

• E2V provided original 402.5 MHz klystrons; Thales has produced plug-compatible replacements.
  – Thales has produced every flavor of klystron or tube presently utilized at SNS.

• CPI produced the vast majority of the SC Linac klystrons but has not built any klystrons for us since 2008
  – We would like to procure additional SC Linac spare klystrons to increase spares quantity and maintain vendor engagement, but budgets have been inadequate.
**Klystron Lifetime - Emission Data**

- Emission data offers a sensitive way to determine condition of klystrons
- Have taken emission data on half of the installed klystrons
- A few klystrons are operating too far into the current limited emission region – Similar to SCL-1A
  - Lowering the filament voltage on these klystrons will increase their lifetime
- Most klystrons show good agreement with factory data – Similar to SCL-2C
  - No sign of degraded performance
- A few klystrons show some cathode degradation – SCL-9C
New Problem: Failure of DTL klystron de-Q-ing load caused output instability

Drift Space

2\textsuperscript{nd} Harmonic Cavity

2\textsuperscript{nd} Cavity

Cable to External Load

Drift Space

Input Cavity
Introduction to Discussion on Normal Conducting Linac

- RF systems reliability is sufficient to achieve neutron production availability >90%.

- Recovery from RF faults in the NC Linac is significantly longer than in the SC Linac due to the long thermal time constants of the copper structures and cooling systems
  - 20-30 minutes compared to a few minutes

- RF faults in the NC Linac are correlated with (or caused by):
  - voltage breakdown (arching) at RF windows and/or within the cavity
  - vacuum degradation (bursts of outgassing)
  - beam loss and, perhaps, field emission and/or multipacting
  - glitches in water flow and vacuum interlocks
  - inadequate vacuum pumping capacity
  - excessive resonance error
Fault/Risk Mitigation in the NC Linac

- Spare RFQ is under production.
- Water flow sensors are being upgraded for increased reliability.
- Vacuum system is being upgraded for increased pumping capacity and improved serviceability/redundancy of vacuum gauges.
- Infrared window temperature interlock is being developed.
- Additional spare RF windows are under production.
- A new window design is under development at alternate vendor.
- Transmitter temperature monitoring is being implemented.
  - Addresses failures that may be induced by hot spots in the klystron gallery
Three DTL RF Vacuum Windows Replaced to Date

- DTL6 window replaced 1/21/10 because of suspected flange or o-ring vacuum leak
- DTL4 window replaced 4/26/11 because of arcing
- DTL4 window replaced 12/26/11 because of water leak to vacuum

Figure 1 - DTL Window with water leak into vacuum
Five CCL RF Vacuum Windows Replaced to Date

- CCL2b window broken 11/2/07
- CCL3b window broken 2/3/11
- CCL4b window broken 1/28/12
- CCL1b & CCL4b windows replaced due to excessive arcing and vacuum activity July 2012
Actions Taken to Prevent Further RF Window Failures

- RF Structures team commissioned to investigate problems and create a Risk Mitigation Plan → Completed June 2012

- Key elements:
  - Order additional spares from Thales (3 each for DTL and CCL)
  - Develop alternative window designs with experienced RF vendor
  - Implemented more conservative procedure for in situ RF conditioning
  - Develop interlock based on infrared measurement of window temperature

- Significantly, nearly all of the CCL ion pumps were replaced during the summer 2012 shutdown due to poor performance

- Numerous vacuum system improvements are planned for the DTL
IR Window Temperature Measurement

- Utilizes commercially available system
- Indirect measurement of surface window temperature
  - allows for tracking temperature changes in window
  - plan to implement interlock
- Integrated into EPICS via transmitter PLC
- Prototype system – installed on CCL3 & 4

Raytek Controller
(in transmitter rack)

Sensor in waveguide
(in Linac tunnel)
Transmitter Temperature Measurement

• Temperature measurement of the transmitter racks and individual chassis is currently not available
  – Add 4 temperature sensors to the warm linac transmitters
  – Add 6 temperature sensors to the cold linac transmitters

• Allows tracking of temperatures on key subsystems and overall rack temperatures
  – Solid state amplifier
  – Filament supply
  – Magnet supply

• Use of available PLC inputs to interface with EPICS

• Implementation scheduled for completion August 2013
RF Structures Issues and Concerns

- Spare RFQ nearing completion
- DTL & CCL: no spare structures, but an assortment of spare parts
- Input Couplers:
  - 1 each on DTL tanks
  - 2 each on CCL structures
  - Couplers are removable and therefore replaceable.
  - There is no clear evidence to date indicating upgraded couplers are needed to achieve 1.4 MW beam operation.
- RF windows have been somewhat problematic, but generally perform well if adequately protected via interlocks and procedures
- Water leaks are a concern, especially in the DTL, where the drift tubes are water cooled. Need to monitor and control water chemistry throughout the facility.
RF Structures

• The DTL utilizes many o-rings in its vacuum envelope
  – The DTL tanks exhibit a significant vacuum degradation upon turning off the RF for maintenance periods
  – The reason is uncertain, but seems to be related to RF heating of the tank
  – Is this a precursor of a failure that will require – at minimum – replacement of o-rings?
Technical Risks

• Failure to maintain adequate key spares; obsolescence
  – Obsolescence is specially concerning for Low-Level RF and Transmitter electronics.

• Physical Integrity of NC Linac structures (vacuum, water, RF windows)

• Variability of SC Linac klystron lifetime
  – what is an acceptable number of spares?

• Overall performance of the NC Linac
  – what limitations may arise as we increase beam power?
Summary

• RF systems reliability is sufficient to achieve neutron production availability >90%.

• Good supply of spare klystrons, but we would like to purchase additional units for the SC Linac.

• Solid-state upgrades have proven to be very reliable.

• Numerous risk mitigation activities are in progress.

• Looking forward to increasing the beam power and addressing any related performance limitations.