Normal Conducting Linac RF Performance & Challenges

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RF Systems – Outline

- Introduction to the discussion on the normal conducting Linac
- Ion Source RF
- MEBT Rebuncher System
- DTL Circulators
- CCL Klystrons
- Klystron Spares & Vendor Engagement
- Transmitter Issues and Improvements
- LLRF
- DTL & CCL RF Window Status
- Downtime Overview
- Summary
Introduction to the 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 (arcing) at RF windows and/or within the cavity
  - vacuum degradation (bursts of outgassing)
  - inadequate vacuum pumping capacity
  - beam loss and, perhaps, field emission and/or multipacting
  - glitches in water flow and vacuum interlocks
  - excessive resonance error
Ion Source RF

- The 2 MHz QEI amplifier continues to operate at ground potential outside of the 65 kV enclosure.
  - Only downtime was attributed to a failed connection on the output circuit.
- The 2 MHz isolation transformer has required minimal maintenance since installation in July 2010.
- The Tektronix generator/control system has been trouble-free.
  - Implemented a frequency shift mode to better support plasma ignition.
- Use of the Tomco 2 MHz, 120 kW solid-state amplifier has been successful on the test stand.
  - The VSWR circuit was modified to improve reflected power operation.
  - A second Tomco solid-state amplifier is installed on the ITSF.
  - Desire to gain further experience before its use on the production ion source.
MEBT Rebuncher System

• MEBT Rebuncher RF amplifiers were upgraded in September 2010 to solid-state devices
• The amplifiers have performed well and cause minimal downtime
  – We have recently experienced two 4.2 kW amplifier module failures
  – One power supply has failed
  – One intermittent cable connection
MEBT Rebuncher Cavities

• MEBT chopper target failure resulted in water in the MEBT rebuncher cavities
  – All cavities required RF reconditioning
  – After reassembly the MEBT 3 tuner assembly developed a vacuum leak in the bellows
  – MEBT 1 field probe developed a vacuum leak

• Lack of cavity spare components was noted
  – Fabricated spare field probes
  – Cleaned and conditioned a spare fundamental power coupler
  – Procured C-seals for a cavity rebuild (if required)
  – Working to procure/repair a spare tuner assembly
DTL Circulator Issues

- Arcing was detected in the DTL-6 circulator on June 16th, 2014

- A leak was detected on the bottom pancake of the circulator assembly

- A spare circulator was removed from the RFTF test stand and installed to allow for continued operations
  - No unused spares were available

- Inspections of the remaining 6 circulators revealed similar issues with all installed devices
  - Some show significant corrosion
DTL Circulator Issues (cont.)

• Issue was isolated to the O-ring seals between the water inlet & outlet connections on the pancakes

• AFT was consulted and performed an on-site repair of the failed circulator and provided training on the repair techniques

• Three spare 402.5 MHz circulators are on order
CCL Klystron Failures

• Three of the four original Thales 5 MW klystrons have failed within 1 year
  – Two klystrons failed on filament open failures (CCL 2&3)
  – One klystron is unable to generate RF power above 3.5 MW (CCL4)
  – Operating hours for the failed klystrons range from 51000 – 57000 hours
  – The remaining original klystron is still in service and the emission curve has not shown degradation
  – The average time to replace a CCL klystron is 14 hours
  – A Thales 5 MW klystron is staged in the klystron gallery ready for installation
# 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>
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<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>
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<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>
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<td>Klystron</td>
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<td>5 MW</td>
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<tr>
<td>Klystron</td>
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<td>550-700 kW</td>
<td>CPI &amp; Thales</td>
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<td>57</td>
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<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 assisting with oscillation of one 5 MW klystron.
- Of the 57 spare 550-700 kW klystron, 12 are Thales
Klystron Lifetime and Vendor Engagement

- The majority of the klystrons presently used in the Linac have about 60,000 hours of run time.
  - lifetimes approaching 100,000 hours are likely, but uncertain
  - one cathode-based failure & 3 filament-based failures to date
  - More attention to cycling of the filaments to maximize lifetime

- Cathode emission data being collected to assist in monitoring and predicting lifetimes.
  - Data utilized to adjust filament settings to maximize cathode life

- 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.
Vendor Engagement (cont.)

- CPI produced the vast majority of the SC Linac klystrons
  - We have recently received 6 new 700 kW klystrons
  - Completed the 1st rebuild of a failed 550 kW, 805 MHz klystron
  - CPI has expressed interest in producing 5 MW 805 MHz & 2.5 MW 402.5 MHz klystrons

- Thales quality has been less than ideal
  - Final two 5 MW klystrons delivered have required vendor involvement
    - One klystron experienced oscillations above 3.8 MW
    - One klystron required extensive conditioning
  - Reluctant to support rebuild of failed klystrons. The quoted price to rebuild was 97% of the price of a new tube.
  - Vacuum issues experienced with the recently delivered spare production RF windows
Transmitter Issues & Improvements

- The magnet power supplies in the warm linac transmitters have been updated
  - Use of COTS supplies – reduced costs
  - Lowered the temperature in the hottest rack by ~18º F
- Replaced low-flow flowmeters with ultrasonic meters
  - Minimize nuisance trips
- Significant increase of solid-state amplifier failures
  - Majority of the failures are traced to the power supply
  - Implemented on-site repair and testing program
Filament Power Supply Issues

• Fourteen filament power supplies have failed since last AAC review
  – 53 filament power supplies are installed

• Vendor involvement discovered a series of defective parts with the same date-code
  – Waiting for detailed failure analysis from vendor
  – Repaired and returned to the SNS

• Development of a stand-alone test stand is underway for improved bench testing
  – Allows for a realistic test without cycling of actual klystron filaments
Transmitter Temperature Measurement System

• Installed temperature measurement system to monitor critical chassis temperatures

• Currently installed in Warm Linac & four SCL racks
  – Rack temperatures were unavailable
  – Supports troubleshooting
LLRF Performance & Issues

• The LLRF system continues to operate within specification
• The adaptive feed-forward is sufficient but the learning time of the algorithm could be improved
• The output amplifier IC for the RF output circuit has shown issues with the bond wires
  – multiple failures in the past year
  – All amplifier ICs are being replaced during the calibration cycle of the system
• System has several obsolete components to include the FPGAs
  – Adequate spares are available
  – Resources will be needed to redesign in the future
DTL & CCL RF Vacuum Windows

• No DTL or CCL window failures since July 2012
  • Improved RF conditioning techniques
  • Increased attention to detail

– DTL Window Status
  • Six DTL windows are in use
  • Two windows are processed and stored under vacuum
  • Two new windows have been purchased (TH20616)
    – The windows arrived with vacuum issues and were returned for repair
  • One new prototype window has been tested and fully conditioned

– CCL Window Status
  • Eight CCL windows are in use
  • Two windows are processed and stored under vacuum
  • Six new windows have been received and are scheduled for testing and RF processing
    – One window was returned to the manufacturer for repair
  • One new prototype window is currently under test
RF Downtime – May 2013 to Present

• Total Downtime 265 hours out of 10303 scheduled Accelerator Physics/Neutron Production hours (2.57%)
RF Downtime (cont.)

• Occasional major event quickly adds to the system downtime but this is only ~20% of the total RF downtime
  – DTL 6 circulator failure – 17 hours (June 2014)
  – CCL2 klystron failure – 14 hours (May 2014)
  – CCL3 klystron failure – 16 hours (Oct 2014)

• Majority of trips are ~ 20 – 30 minutes in duration
  – Cavity and window arcing
  – Vacuum excursions/bursts

• Overall reliability of the RF systems is very good
  – Continue to seek ways to improve the systems
Summary

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

• Starting to see an increase in system failures, we need to continue to seek alternative COTS solutions

• Reasonable supply of klystrons but we would like to engage with CPI for the high power klystrons

• Implementation of better RF conditioning practices have paid off with no new broken RF windows