SPALLATION NEUTRON SOURCE HIGH POWER RF INSTALLATION AND COMMISSIONING PROGRESS*

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Abstract

The Spallation Neutron Source (SNS) linac will provide a 1 GeV proton beam for injection into the accumulator ring. In the normal conducting (NC) section of this linac, the Radio Frequency Quadupole (RFQ) and six drift tube linac (DTL) tanks are powered by seven 2.5 MW, 402.5 MHz klystrons and the four coupled cavity linac (CCL) cavities are powered by four 5.0 MW, 805 MHz klystrons. Eighty-one 550 kW, 805 MHz klystrons each drive a single cavity in the superconducting (SC) section of the linac. The high power radio frequency (HPRF) equipment was specified and procured by LANL and tested before delivery to ensure a smooth transition from installation to commissioning. Installation of RF equipment to support klystron operation in the 350-meter long klystron gallery started in June 2002. The final klystron was set in place in September 2004. Presently, all RF stations have been installed and high power testing has been completed. This paper reviews the progression of the installation and testing of the HPRF Systems.

RF SYSTEM OVERVIEW

The mission of the RF Group is to ensure that precisely controlled RF power is provided to the linac beam in a safe, highly reliable and cost-effective manner. RF Power Systems provide the pulsed energy to accelerate the H- beam to the accumulator ring. Fourteen High Voltage Converter Modulators (HVCM) supply power to twenty-five klystron transmitters used to control the ninety-two klystrons aligned parallel (figure 1) with the linac from the RFQ to the twenty-third cryomodule. Ninety-two Low Level RF (LLRF) systems, each with a klystron in their control loop, maintain the linac cavities at designed field and amplitude [1]. Four additional, but identical, LLRF systems control the four 20 kW triode amplifiers driving rebuncher cavities between the RFQ and the first DTL.

The SNS accumulator ring [2] is 248 meters in circumference with a revolution frequency of 1.058 MHz (945 nsec.). The 1ms linac beam pulse is chopped into 1060 mini-pulses that are stacked in the accumulator ring to form a single 695 nsec. long proton bunch. A dead time of 250 nsec remains to allow for the rise time of the extraction kicker system that extracts the beam and sends it to the target. The ring RF system shapes the particle bunch and ensures that the gap remains free of protons. It consists of four 0.5MW tetrode power amplifiers each driving a ferrite-loaded dual-gap cavity. Three cavities operate at 1.058 MHz and a single, second harmonic cavity, operates at 2.116 MHz.

SYSTEM INSTALLATION

The ORNL/SNS RF Group oversaw and prioritized equipment installation. Craft labor from local Tennessee unions was directed by the SNS Installation Group in placing equipment, pulling cables and water pipe fitting.

As installation progressed, conditioning of installed equipment was required. LANL specified and procured the components used in the HPRF transmitter. Standardization, modular design and simplification ensured the functional ability of this equipment at minimum cost. A rigorous acceptance-testing plan was incorporated in the specification. LANL personnel tested the critical high power klystrons [3], circulators and windows at their facility in Los Alamos and were also involved in bringing up the first klystrons of each type at the SNS site in Oak Ridge, Tennessee.

Figure 1: SCRF Klystron Gallery 550 kW klystrons

Five distinct klystrons at three peak pulsed power levels (550 kW, 2.5 MW, and 5 MW) from three klystron manufacturers are installed at SNS. Every RF system has undergone an extensive checklist during startup. After verifying electrical connections, fiber-optic arc detection, waveguide torques, subsystem startup checks and adjusting the transmitters thresholds for klystron cooling flow, magnet and filament current operating values, we were finally able to start bringing up the klystrons to high voltage. The results of the first time klystron power-up,

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RF leakage and xray surveys, and calibration procedures are recorded and become the basis for declaring the HPRF systems ready for operation at the Accelerator Readiness Review (ARR).

START UP PROBLEMS

The first two klystrons (RFQ, DTL1) had odd problems related to quality control and design issues. A slow water drip at an internal water fitting had caused water to leak into the HV oil tank under the klystron. It was repaired in-situ with expertise from the SNS Cryogenic group**

The second klystron had been switched into the RFQ location to allow time for the leak to be repaired. It started arcing as the RF power exceeded 350 kW peak. Inspection of the rectangular waveguide transition interface to the center conductor revealed the spacer that held the center conductor had arced. The klystron vendor (E2V, Chelmsford, UK) found a design error and resolved the problem.

A logic error allowed the DTL3 2.5 MW klystron to be turned on without the klystron's internal beam-confining magnetic field operational. This quickly punched a small hole in its second cavity. The ion pump showed about 75 microamperes (uA) of leakage (a good value is < 1uA). An expert from the vacuum group completely electroplated the cavity exterior, in-situ**. That klystron has been operating perfectly since. The logic error was swiftly and redundantly corrected.

The 5MW CCL klystrons arced at their outputs. This required the vendor (Thales ESD, FR) to redesign the output waveguide to contain SF6 high dielectric gas similar to the 5MW circulators. In addition, we configured the remaining waveguide system for internal forced air-cooling and fastidiously cleaned the guides and flanges to eliminate the arcing.

The CCL waveguides interfered with cable trays so the planned trombone phase adjustment to balance the phase at the CCL cavity ports had to be abandoned in favor of a waveguide post technique [4].

The DTL5 circulator developed an internal water leak. It was manifest by worsening power balance in the circulator legs. The unit was replaced and returned for warrantee repair. We inserted drain holes on the circulator ports to ensure a future leak would not damage a klystron or DTL window.

One SCL klystron and one magnet each developed water leaks after an accidental overpressure of 140 psi (~110 psi differentially). These units were returned to the vendor for repair.

PROGRESS

H- Beam has been transmitted up to a beam stop at the end of the normal conducting section. The RFQ, four 20 kW MEBT rebunchers, six DTL and three of four CCL RF stations have contributed to beam operation. Preparations for beam through the SCL are underway. All cryomodules have been characterized with respect to resonant modes, coupling to the field and higher order mode damper probes. [5].

The Ring RF system has been installed and preliminary integration testing has begun.

EPICS RF screens have been created that are powerful and intuitive. They give a global overview yet yield detailed parameters with a click.

The PLC controller programming for the transmitters has been modified for both increased safety and functionality. For example, the klystron magnets will now turn on when the filaments are turned on [6]. This eliminates the possibility of developing a beam within the klystron without a confining magnetic field. A planned enhancement is the ability to operate with one or more SCRF klystrons off line. PLC and hardware changes will be necessary, but it is essential to enhance availability.

AVAILABILITY

We have made some design and logistical changes to reduce mean time to repair (MTTR). Spacer plates were installed under the SCL klystrons (figure 2) to allow the klystron/magnet assembly to be removed as a unit and without draining the HV tank oil.

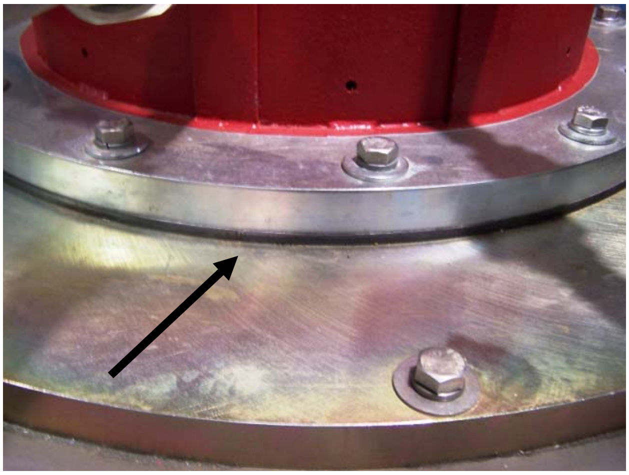

Figure 2: Spacer Plates under klystron.

Klystrons will be pre-positioned on tanks in the NC klystron gallery, ready to exchange with a failed unit. In the SC gallery, three klystrons will be stored in stand-alone HV tank sockets. Tools and electronic spares are being pre-positioned in the gallery. A much longer list of modifications to improve operability, ease of repair, and reliability is developing with operational experience.

To reduce the demand on the HVCM power supply, the cathode voltage is reduced to a level that yields just enough RF power to provide about 12% margin over cavity requirements. Practical values of operation are approximately 60-69 kV rather than the design rating of 75 kV. Typical peak power requirements for the medium beta cryo-cavities through the higher power high beta units range from ~200kW through 515 kW at 6% duty cycle (1.3ms, 60 Hz). The last three (of seven) SCRF

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stations power eleven rather than twelve klystrons to avoid exceeding the HVCM power capacity.

CONFIGURATION CONTROL

Organization of RF specific parameters for the entire system is on-going. We have started compilation of a database with klystron parameters such as operating levels, hours of operation, emission curves, phase characteristics, gain, bandwidth and efficiency. Key RF operating parameters are continuously archived by EPICS and automatic trend analysis criteria are being developed and implemented to warn of impending problems. With good records of parametric changes over time, with respect to the original factory test data, the SNS RF systems will provide a wealth of information to the accelerator community on klystron reliability and failure mechanisms.

Although constants and limits are stored in EEPROMs in the transmitter, occasionally values change either for testing or updates. To prevent erroneous values from being left in the transmitter, a routine is being developed that compares each transmitter with benchmark parameters before a major start-up. This cross check will become part of the EPICS automated start-up routine for the entire linac RF system.

RF TEST FACILITY (RFTF)

The RFTF shares a building with the cryogenic plant. This has the advantage of eventually allowing testing of cold cryomodules in the test facility. The test facility consists of one HVCM klystron power supply and two HV tanks each supporting one klystron [7]. The planned configuration is to operate one 805 MHz 5 MW tube and one 402.5 MHz, 2.5 MW tube. Presently an 805 MHz 550 kW tube is installed for cryo-coupler testing and a beam stick (klystron diode) is in the 402 HV tank to balance the HVCM load. The RF Test Facility has been used for testing the Modulator power supply (HVCM) and test/conditioning more than half of the JLAB cryo-couplers [8]. Five man-weeks of effort allowed the JLAB test stand to be resurrected and operating within four days after arriving at the SNS site. Cryo-couplers were conditioned at 650 kW peak pulsed power generated by a CPI (Communications Power Industries, Palo Alto, CA) 805 MHz klystron rated at 550 kW. Three spare Thales 402.5 MHz, 2.5 MW klystrons are to be factory certified on the RFTF test stand and site accepted.

SAFETY

SNS has had several million-hour accident free periods during the construction phase. By ensuring all RF team members are properly trained and are safety conscious we intend to maintain this record. An example of using both administrative and engineering protection, shown in figure 3 is a fiber optic arc detector mounted to the shorting plate of a waveguide in the tunnel. If the shorting plate is removed, the RF drive will be inhibited to prevent exposure to dangerous levels of RF power.

Figure 3: Waveguide Flange Locked Out

RF GROUP

The relatively small size of the SNS RF group (~18) means cross training is crucial. Each member of the RF team must be competent in operating the entire system (HPRF and LLRF) at a level consistent with effective basic diagnosis of any part of the system. This also extends to members of the SNS Operations Group who can support RF maintenance as the second person required in some troubleshooting tasks.

We are now progressing along a path of incremental enhancements to improve reliability as we push the SNS operational parameters out toward the design envelope.

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