STATUS OF THE SNS LINAC RF SYSTEMS*

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Abstract

The SNS linac will deliver a 1 GeV proton beam for injection into its accumulator ring. The normal conducting section of the linac has the RFQ and drift tube linac (DTL) powered by seven 2.5 MW, 402.5 MHz klystrons and the coupled cavity linac (CCL) powered by four 5.0 MW, 805 MHz klystrons. The superconducting section of the linac employs eighty one 6-cell cavities power by eighty one 550 kW, 805 MHz klystrons. In the tunnel after the successful commissioning of the front end, three DTL tanks, two CCL modules, and eight medium-beta cryomodules have been installed. Corresponding high voltage converter modulators (HVCM) and low level rf (LLRF) control systems have been installed and tested.

INTRODUCTION

Figure 1 shows the SNS RF linac subsystems and the partner laboratories responsible for them. The system uses rf power in 1.3msec 60 Hz pulses. The front end system that includes ion source, radio frequency quadrupole (RFQ), and medium energy beam transport (MEBT) system was delivered by Lawrence Berkeley National Laboratory (LBNL) and commissioned successfully [1]. The high power radio frequency (HPRF) equipment including the normal conducting drift tube linac (DTL) and coupled cavity linac (CCL) segments was specified, procured and tested by Los Alamos National Laboratory (LANL) before delivery to ORNL. Rf power systems provide the energy to accelerate the H- beam to the storage ring. Fifteen high voltage converter modulators (HVCM) supply the pulsed power to twenty seven transmitter systems used to control the ninety four klystrons aligned parallel with the linac from the RFQ to the high energy beam transport (HEBT) system. Ninety four LLRF control systems, each with a klystron in their control loop, maintain the linac cavities at designed field amplitude, phase, and resonance.

Thomas Jefferson National Accelerator Facility (TJNAF) manufactures and delivers the superconducting linac cavities structures in cryomodules. Brookhaven National Laboratory (BNL) will deliver the HEBT and the accumulator ring. The ORNL/SNS RF group oversees and prioritizes equipment installation, testing, conditioning, and commissioning.

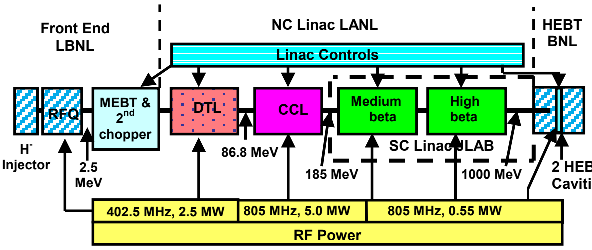

Figure 1: SNS Linac RF System.

INSTALLATION AND TEST

As installation progresses, rf conditioning of installed equipment is required. A rigorous acceptance-testing plan was incorporated in the specification of the various HPRF components. This assures near ‘plug & play’ performance although some improvements are needed for the very large accelerator construction.

Accelerating Structures

SNS linac employs various RF accelerating structures: an RFQ, four MEBT rebuncher cavities, six DTL tanks, four CCL modules, and eighty one superconducting linac (SCL) 6-cell structures in eleven medium-beta and twelve high-beta cryomodules.

The whole front-end system was commissioned with first beam in December 2002 and then recommissioning with the first DTL tank was also successfully completed in 2003. A hot spare ion-source station that is virtually identical to the one in line is continuously used to improve the performance and reliability of the design. The RFQ that worked reliably through most part of 2003 developed a problem when cooling water temperature control failed for few hours. The accelerating mode frequency shifted by almost 500kHz. The structure was retuned in installed position and it’s performance was restored.

All six DTL tanks have been delivered to ORNL. Three tanks 1, 2, 3 have been installed in the tunnel. In late 2003 tanks 1 and 3 were conditioned and commissioning with beam was completed through the tank 1. Thank 2 is yet to be conditioned and commissioned with the beam through. The three tanks have been rf tuned at ORNL with technical lead from LANL and the rest three tanks are being assembled and rf tuned at ORNL. Two CCL modules, CCL1 and CCL2, have been installed in the tunnel. The CCL1 has been completely prepared for rf conditioning: the field distribution and resonance

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frequencies have been tuned and input couplings matched and tested. CCL2 still requires final rf tuning.

Two designs of 6-cell π-mode cavity structures are used in the SCL section of the SNS linac: the medium-beta and high-beta, β=0.61 and β=0.81, respectively. A medium-beta cryomodule houses three 6-cell β=0.61 cavities and a high-beta cryomodule houses four 6-cell β=0.81 cavities. Eight cryomodules manufactured at TJNAF have been delivered and installed in the tunnel so far. The cold tests of the more than twenty medium-beta cavities and few high-beta have shown that the 6- cell performances can exceed the fundamental design specifications: Q-factors $> 5\times10^9$and the accelerating field gradients [2]. Coaxial fundamental power couplers for the 6-cell cavities have been tested successfully.

Klystrons

Klystrons at three power levels (2.5 MW, 5 MW, 550 kW) from three klystron manufacturers, CPI, E2V, and Thales, are used in the SNS. In klystron gallery, all seven 402.5 MHz klystrons, two 5 MW klystrons, and thirty six 550 kW klystrons have been installed so far (Figure 2.)

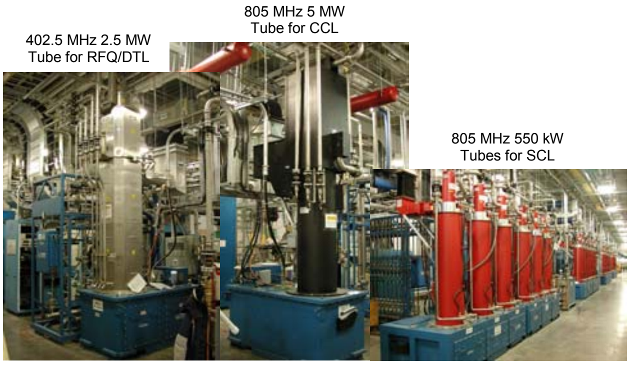


Figure 2: Three types of SNS klystrons being installed and tested in the klystron gallery.

The first two klystrons for 402.5 MHz operation had some problems related to quality control and design issues. A water leak at an internal water fitting had caused water in the high voltage oil tank under the klystron. A second klystron had arcing that started as the rf power exceeded 350 kW peak. Inspection of the transition interface to the center conductor revealed the spacer that held the center conductor had arced and damaged. Rf performances of these 2.5 MW klystrons improved significantly in the tubes delivered later and are considered satisfactory.

The 5 MW tubes have gone through extended testing periods that required various fixes and preparations to make them run reliably at the high power level. The klystron output window areas as well as the ferrite circulators were designed to have SF6 gas charged. The tubes can make full 5 MW with 140 kV cathode voltage. Figure 3 shows the measured transfer characteristic of the first 5 MW tube at 137 kV cathode voltage: Efficiency is 52 % and the gain is ~ 52 dB. At 4 MW output, 1 dB Bandwidth is 2.7 MHz. In the linear region, the phase deviation was ±1 degree.

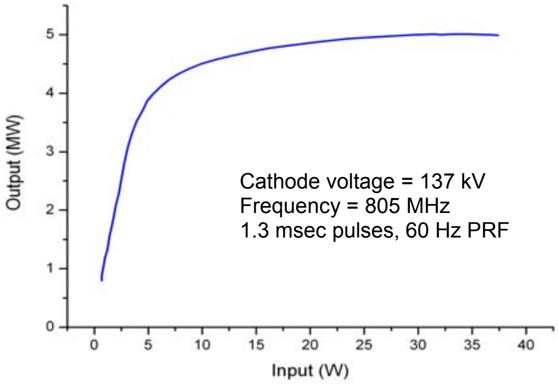


Figure 3: 5MW klystron test result.

550 kW klystrons are manufactured by CPI and Thales and presently installed CPI tubes have shown little problems. Installation and testing of this type of klystrons were relatively straight forward. LANL tested the critical high power klystrons, circulators and windows at their facility in Los Alamos [3], culminating with a 96 hour klystron heat run before shipment to ORNL. LANL personnel are also involved in bringing up the first klystrons of each type at the SNS site in Oak Ridge, Tennessee.

HVCM

The SNS High Voltage Converter Modulator (HVCM) design is compact and can be configured for one HVCM-multiple klystrons with 11 MW peak power and 1 MW average power capacity [4]. All together, fourteen HVCM's are needed for the linac system and nine units have been installed and six units have been operational with satisfactory results. Installation of three modulators in DTL, two in CCL, and one in SCL, and one in rf test facility (RFTF) are complete. Another CCL unit requires checkout and the second unit for the SCL is almost ready. Tests are being done to check and improve the performance of the design. With a DTL klystron, ripple was measured 0.37% p-p. Another DTL klystron measurement showed -52 dB, 20 kHz sideband at 1500 kW output forward power with the LLRF loop closed. SCR controller still has 8000 operational hours goal that is getting close and should speed up during the next beam commissioning. Plan initiated for full average power testing, stalled due to system upgrades.

LLRF System

The system consists of field resonance control module (FRCM), high power protection module (HPM), clock distribution system, frequency reference system, and others. Two generations of LLRF controllers have been developed at LBNL: 1st generation was used in MEBT rebuncher LLRF controller, and 2nd generation used in RFQ and DTL LLRF controller. 3rd generation controller is under development by three-lab team: digital front end (DFE), analog front end (AFE), rf output (RFO), VXI carrier board.

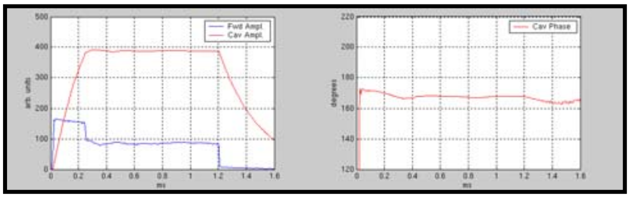


Figure 4: SCL cavity amplitude and phase with feedforward & feedback control.

Test at TJNAF in March 2003 using 2nd generation control chassis for the SCL achieved field regulation specifications of ±1% and ±1degree at 10 MV/m in 1.2 ms, 60 Hz operation (Figure 4.) 3rd Generation FCM has been installed and tested on DTL1 in October 2003 without beam and the amplitude and phase regulations of ±0.2 %, ±0.2 degrees were achieved.

RF CONDITIONING AND COMMISSIONING

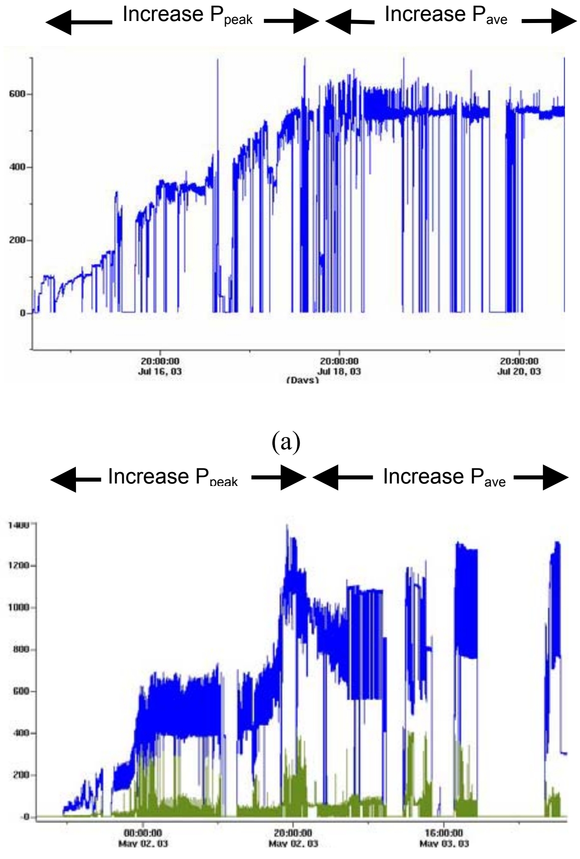
The RFQ has been tested to full rf power under LLRF closed loop control with design peak current into a beam dump. DTL tank 3 has undergone preliminary rf conditioning. Then, tank 1 was conditioned and later included in commissioning with the beam through. Now tank 2 is completely assembled, tuned, and readied in the tunnel and is about to be conditioned. After the tank 2 conditioning, the linac will be commissioned to the DTL tank 3 with the beam through.

Tank 3 was conditioned to full field gradient at ~45% of the design duty factor in less than 3 days. Then, the Tank 1 was conditioned to full field at ~45% of the design duty factor in 5 days. First, the peak power was increased at low duty and then the average power was increased at higher duty. Figures 5(a) and 5(b) show the archived rf power profiles of tanks 3 and 1 during their initial rf conditioning periods. RF conditioning of the CCL module 1 is about to start.

CONCLUSIONS

Since the SNS linac employs the ninety four klystrons, with corresponding 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. We have started compilation of a data base with klystron parameters such as operating levels, hours of operation, emission curves, phase characteristics, gain, bandwidth and efficiency.

The normal conducting portion of the linac is halfway complete and shows the system performs as designed. The superconducting portion of the linac rf system is now being installed and preliminary integration testing continues toward an operational goal in mid 2006. Rf system performance analysis will help determine trade-offs when designing upgrades to maintain and enhance the value of installed equipment.



(a)

(b)

Figure 5: Rf power profiles of DTL tanks 1 and 3 during the initial rf conditioning.

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