INSTALLATION AND TESTING FOR COMMISSIONING OF NORMAL CONDUCTING RF LINAC SEGMENT IN THE SNS *

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Abstract

The Spallation Neutron Source (SNS) linac will deliver a 1.0 GeV proton beam to its accumulator ring. The normal conducting segment of the linac has a radio frequency quadrupole (RFQ), six drift tube linac (DTL) tanks powered by seven 402.5 MHz klystrons and four coupled cavity linac (CCL) modules powered by four 805 MHz klystrons that deliver the 180 MeV beam to the superconducting section of the linac (SCL) that employs eighty one 6-cell cavities powered by eighty-one 805 MHz klystrons. The normal conducting accelerating linac segment has been completely installed in the linac tunnel and successfully conditioned and commissioned. Corresponding high voltage converter modulator (HVCM) and low level RF (LLRF) control systems have been installed and tested.

INTRODUCTION

Figure 1 shows the SNS RF linac with subsystems and the collaborated partner laboratories responsible for them. The front-end system that includes ion source, RFQ and medium energy beam transport (MEBT) systems was delivered by Lawrence Berkeley National Laboratory (LBNL). The high power radio frequency equipment including the DTL and CCL structures was specified, procured and partially tested by Los Alamos National Laboratory (LANL) and then delivered to ORNL for complete installation and testing. Thomas Jefferson Laboratory (JLAB) delivered the SCL structures. The normal conducting segment of the linac has accelerating structures powered with high power klystrons in 1.3 msec 60 Hz pulses: RFQ and DTL tanks powered by seven 2.5 MW, 402.5 MHz klystrons and CCL modules powered by four 5.0 MW, 805 MHz klystrons for delivering the 180 MeV beam to the SCL that employs eighty one 6-cell cavities powered by eighty one 550 kW, 805 MHz klystrons.

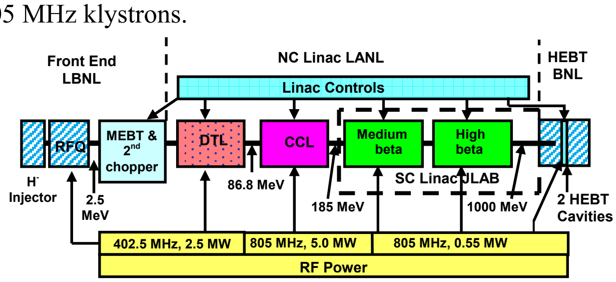


Figure 1: SNS Linac RF System.

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

In the normal conducting segment of the linac, seven HVCMs supply the pulsed power to the eleven klystrons with transmitter systems that control the klystron tubes to provide RF power to the structures that accelerate and deliver the H- beam to the accumulator ring through the SCL.

INSTALLATION AND TESTING

For initial installation and testing, a rigorous acceptance-testing plan was incorporated in the specification of the various HPRF components to assure robust system performance and reliability of the accelerator. RF conditioning and beam commissioning have been performed in the installed portion of the linac as installation progresses.

Accelerating Structures

The whole front-end system was commissioned [1] with first beam in 2002 and then successfully recommissioned along with all the DTL tanks and CCL modules by the end of 2004. The RFQ that worked reliably through most of 2003 developed a problem after a cooling water temperature control failure: the accelerating mode frequency shifted by about 500 kHz. The structure was retuned in originally installed position and its performance was restored.

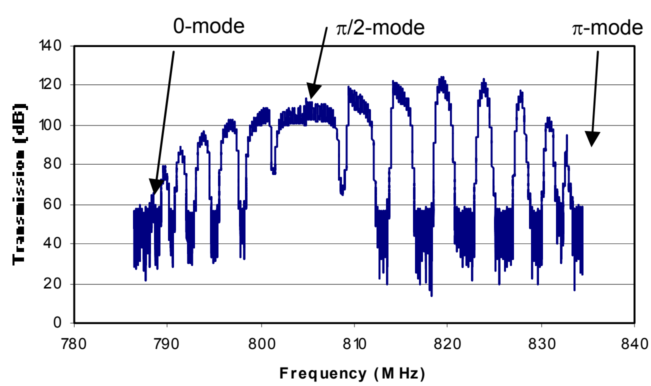


Figure 2: Measured mode spectrum in CCL Module 1 after tuning.

All six DTL tanks have been completely installed and tested at ORNL. The first three tanks were RF tuned at ORNL with technical lead from LANL and the remaining three tanks were assembled and RF tuned at ORNL by

 0-7803-8859-3/05/$20.00

ORNL personnel. Figure 2 shows the resonance spectrum of the CCL module 1 after complete RF tuning. All four CCL modules have been RF tuned and installed in the tunnel. The accelerating field distribution and resonance frequencies were tuned and input couplings were matched to the design. Subsequently, the CCL structures were RF conditioned and commissioned with beam. Figure 3 shows the completely installed four CCL modules in the tunnel.

Figure 3: Completely installed four CCL modules in the linac tunnel.

Klystrons and HVCM

The eleven klystrons are being used in the normal conducting linac segment: seven 402.5 MHz, 2.5 MW tubes supplied by E2V and four 805 MHz, 5 MW tubes supplied by Thales. 402.5 MHz Thales tubes have been ordered for spares. LANL tested most of the critical high power klystrons, circulators and windows at their facility in Los Alamos [2], with a 96 hour heat run before shipment to ORNL.

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 leakage into 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 was 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 high power levels. The klystron output window areas as well as the ferrite circulators were designed to have SF6 gas charged for high peak power handing. The tubes can achieve full 5 MW with 140 kV cathode voltage [3].

The SNS HVCM design is compact and can be configured for one HVCM to multiple klystrons with 11 MW peak power and 1 MW average power capacity [4]. All together, fourteen HVCMs are needed for the linac system and all units have been installed, tested, and are operational: three in RFQ/DTL, four in CCL, and seven in SCL. All units have been upgraded to provide more reliable performance after initial operation and testing with a DTL klystron measured ripple of 0.37% peak to peak. SCR controllers operation has seen improvements from increased reliability. Full average power testing of the HVCMs will be conducted after complete system upgrades.

Transmitter Controls, and LLRF System

The control system of the linac is based on the Experimental Physics and Industrial Control System (EPICS). The vendor of the transmitters supplied the programs for the programmable logic controllers (PLCs) with collaboration from LANL who supplied the programs for the input-output controllers (IOCs.) A standard SNS PLC consists of an Allen Bradley PLC interfaced to the equipment via ControlLogix. The PLCs and the IOCs communicate using the EtherNet/IP driver written by K. Kasemir [5]. All of the high power RF systems have local PanelView displays.

The IOCs are MVME2101 power PCs running EPICS under VXWorks in VME crates. The engineering screens are simple mimics of the PLC PanelView screens. However, these screens are currently being updated to be more user-friendly. The use of PLCs has given a clear interface separating the control system responsibilities and modularizing the controls. The use of EPICS has afforded an integrated way to bring together many different pieces and to use components created by others.

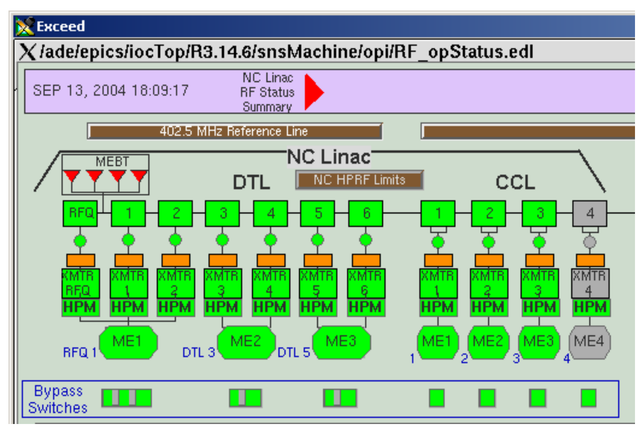


Figure 4: Normal Conducting Linac portion of the Status Screen in EPICS.

Each SNS LLRF control system [6] consists of a field resonance control module (FRCM), a high power protection module (HPM), a clock distribution system, frequency reference system, a resonance control cooling system (RCCS) and others. RCCS keep the DTL and CCL at their design frequencies, 402.5 MHz and 805 MHz, respectively, by controlling the temperature during operation. The RCCS has been tested and improved its performance after many months of high power testing at various heat loadings on the normal conducting accelerating structures [7]. Two generations of LLRF controllers were developed at LBNL and were initially used in the front-end and DTL/CCL LLRF systems. Now the 3rd generation system that was developed by a three-lab team is used for all linac LLRF controllers. This system consists of digital front end (DFE), an analog front-end (AFE), an RF output (RFO), and a VXI carrier board [6].

As shown in Figure 5, the SNS vacuum control system is built with three layers of classic distributed real-time control system: a Device Control Layer, equipped with Allen-Bradley ControlLogix programmable logic controllers (PLCs) to monitor gauge and pump set point outputs and control valves; a Global Control Layer, equipped with an EPICS Input Output Controller (IOC) to overlook multiple subsystems; and an Operator Interface Layer, equipped with Linux boxes to provide machine operation interface.

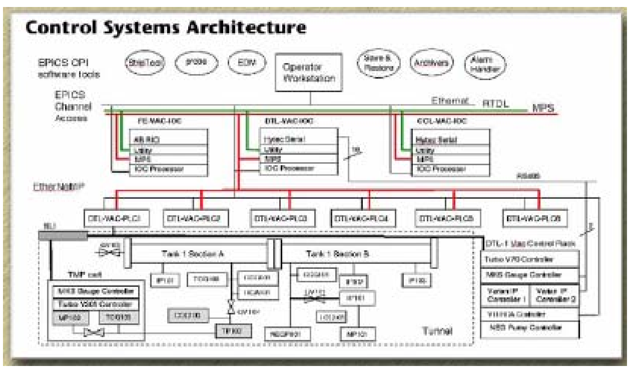
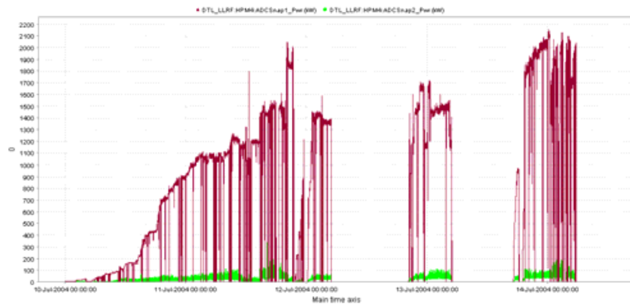


Figure 5: Control system architecture for the normal conducting cavity structures.

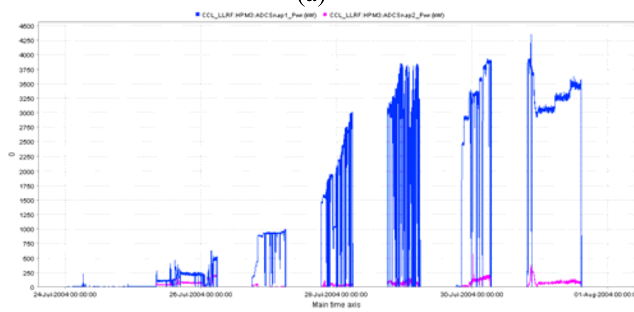
RF CONDITIONING AND COMMISSIONING

The RFQ, DTL, and CCL have been RF conditioned and tested to full RF power under LLRF closed loop control with design peak current into a beam dump. The DTL tanks and CCL modules were conditioned to full field gradient at ~50% of the design duty factor usually in 3-5 days. The RF conditioning is usually done by increasing peak power in short pulses at low duty cycle to the maximum peak power and then by increasing the average power to maximum duty cycle. Figures 6(a) and 6(b) show the archived RF power profiles of DTL tank 4 and CCL module 3 during their initial RF conditioning periods, respectively.

The normal conducting segment of the linac has been completed and showed that the RF systems perform well for the initial low duty beam commissioning. RF system performance analysis, system improvement, and upgrade is being made for the next full duty cycle operation. Commissioning with the beam accelerated from RFQ through CCL3 and drifted through CCL4 to the beam stop was made in September, 2004 with a beam current of ~22 mA in 50 μsec, 1 Hz pulses.



(a)



(b)

Figure 6: Forward and reflected RF power levels (peak in kW) in DTL tank 4 (a) and CCL module 3 (b) during the initial RF conditioning.

ACKOWLEDGEMENTS

The authors are grateful to the LANL staff and other ORNL/SNS personnel who delivered the accelerating linac structures, pulsed power systems, and other related subsystems for the normal conducting linac segment of the SNS. A well-organized effort between the collaborating laboratories and the groups in the SNS made the RF system installation at the SNS timely for successful testing and commissioning.

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