LANSCE RF SYSTEM REFURBISHMENT

D. Rees, G. Bolme, J. Bradley, S. Kwon, J. Lyles, M. Lynch, M. Prokop, W. Reass, K. Young
LANL, Los Alamos, NM 87544, U.S.A.

Abstract

The Los Alamos Neutron Science Center (LANSCE) is in the planning phase of a refurbishment project that will sustain reliable facility operations well into the next decade. The LANSCE accelerator was constructed in the late 1960s and early 1970s and is a national user facility that provides pulsed protons and spallation neutrons for defense and civilian research and applications. The refurbishment will focus on systems that are approaching "end of life" and systems where modern upgrades hold the promise for significant operating cost savings. The current baseline consist of replacing all the 201 MHz RF systems, upgrading a substantial fraction of the 805 MHz RF systems to high efficiency klystrons, replacing the high voltage systems, and replacing the low level RF cavity field control systems. System designs will be presented. The performance improvements will be described and the preliminary cost and schedule estimates will be discussed.

LANSCE MISSION

LANSCE supports four significant experimental areas. The Weapons Neutron Research (WNR) Facility, which uses the H^- beam to produce an unmoderated source of neutrons in the keV to multiple MeV range, is this country's only broad-spectrum, intense source. The Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) uses a time-compressed proton beam on a spallation target to make a moderated neutron source (meV to keV range). It is the highest operating power spallation neutron source in the United States. The Proton Radiography Facility (pRad), which uses the pulsed H^- beam, is unique in the world and provides time-sequenced radiographs of dynamic phenomena with nanosecond time resolution. Finally, the Isotope Production Facility (IPF), just completed in 2004 uses the 100-MeV proton beam to provide medical radioisototopes.

EXISTING RF SYSTEM

The LANSCE linac is an 800 MeV proton linac with the acceleration partitioned into two systems. The first 100 MeV of acceleration comes from four 201.25 MHz drift tube linacs (DTLs) followed by forty-four 805 MHz coupled cavity linacs (CCLs) to increase the energy to 800 MeV. The existing high-power RF plant consists of klystrons and gridded tubes.

Each of the four tanks of the 100 MeV DTL is driven by a power system consisting of a solid state driver stage, a tetrode (Burle Industries 4616) intermediate power amplifier (IPA) and a triode (Burle 7835V4) final power amplifier (FPA). The RF stage for the first tank operates at greatly reduced power, while in tanks 2 through 4 the power levels are approximately 3.5 kW for the driver, 120 kW for the IPA, and 2.5 to 3 MW for the FPA. The FPA amplfier is shown in Fig. 1.

Control of the cavity field in the DTL tanks is provided by modulating the anode voltage of the FPA. The plate voltage is simultaneously pulsed on and adjusted by the amplitude feedback controller in order to regulate the tank fields. This requires an additional four power tubes in each floating deck high voltage modulator.

Figure 1: 201 MHz cavity amplifier and filament supply for the Burle 7835 triode.

The 805 MHz CCL cavities receive power from 44 klystrons rated at a maximum peak RF power of 1.25 MW at a 13.2% electron beam duty factor and a 12% RF duty factor. The klystrons have a maximum voltage of 86 kV and operate at a nominal beam current of 29 A to produce the rated peak power. In service at LANSCE, typical operation is nominally 1 MW peak at a 120 Hz pulse repetition frequency and a 10% RF duty factor. The klystrons are directly coupled to the accelerating structure without an intervening circulator. The waveguide length and a tuning iris have been adjusted to present a safe phase to the klystrons to prevent instability and damage due to the poor impedance match during the cavity fill time. The klystrons receive their high voltage from a capacitor bank and have a modulating anode and supporting modulator to provide the pulsed klystron beam current. A picture of an existing LANSCE klystron in its socket is shown in Fig. 2.

The lifetime of the existing LANSCE klystrons is unprecedented [1]. If infant mortality is not included in October, 2006, the average klystron installed on LANSCE had in excess of 142,000 filament hours and 119,000 HV hours. The average predicted life from our failure statistics, excluding infant mortality, is 129,000 filament hours. The klystron age is considerably in excess of what has been achieved at other facilities and the klystrons are unarguably approaching end of life. This is one of the primary motivations for the refurbishment of the RF

1-4244-0917-9/07/$25.00

system. More information on the performance and reliability of the existing gridded-tubes and klystrons at LANSCE can be found in reference [4].

Figure 2: LANSCE klystron mounted in its modulator tank.

The LANSCE HV system for the klystron utilizes inductrol voltage regulators (IVRs) to feed a transformer/rectifier which provides DC voltage to a capacitor room with a crowbar. The capacitor room is up to 54 uF utilizing 45 kV capacitors arranged in a parallel/series configuration, supplying power to 6 or 7 klystrons. With this design configuration, each capacitor is operated at 96% of its rated voltage. Unless capacitors are matched in value and manufacturer, unequal voltage division and pulsed current sharing can result. A triggered spark gap crowbar is utilized to protect the klystron in the event a tube arc.

The HV system has been extremely reliable but is over 30 years old and is beginning to show signs of age related degradation. Dissolved gas analysis of the transformer oil is used to determine the maintenance needs. The dissolved gas levels can be used to determine the condition of the transformers. On five of the 8 transformers at LANSCE we exceed the IEEE recommended limit certain gas species. The dissolved gas levels indicate age related degradation of the cellulose products that provide transformer insulation.

The current LANSCE RF control system consists of analog phase-amplitude control systems that modulate the system reference signal to provide the high power RF amplifier drive signal. The control electronics for both phase and amplitude control are similar throughout the system. The technique for phase control is common to the entire accelerator but the amplitude control methods are unique to the DTL and CCL sections of the accelerator. The phase and amplitude control signals are calculated separately and applied through independent control devices. The phase control signal is derived from a phase comparator driven by the reference system and the cavity pickup loop. It generates a video signal into the analog proportional-integral (PI) controller that drives a fast 400 degree electronic phase shifter fed by the RF reference signal.

The amplitude control of the DTL directly modulates the anode voltage of the FPA to control the amplitude of the drive to the cavity. This series modulator tube is extremely nonlinear and introduces some instability into the control loop at higher gains. The four modulators waste approximately 600 kW of DC power to provide anode voltage control.

The CCL portion of the accelerator modulates the amplitude of the drive signal at milliwatt power levels. This modulation is achieved through two different methods: the first is achieved by modulating the collector voltage of an RF power transistor to provide the amplitude control and the second was developed because of the nonlinearity of the first method and uses a mixer as a modulator to provide very linear control. It is used on about 30% of the systems in the CCL section.

Each control system requires hand tuning via potentiometers having a single fixed set point. The LANSCE accelerator delivers multiple species at various currents to its experimental areas. Both the H+ and H- beam species are used, and the production beam currents range from 1 mA to 21 mA and 10 pA to 14 mA, respectively. This wide variation of currents and fixed control parameters is less than optimal control for certain species and current combinations. The present system also has no inherent built-in data collection capability for diagnostics, analysis or development.

PROPOSED RF SYSTEM CHANGES

Details of the refurbishment of the individual subsystems are described below. In some instances, funding has not allowed for complete system replacements and for these cases, our approach is to do a partial replacement and the units that are replaced become spares for the remaining systems.

201.25 MHz RF

All the 201.25 MHz RF amplifiers are being replaced. A new RF power system is under development for increasing both peak power and duty factor [2]. The FPA uses a Thales TH628 Diacrode using pyrolytic-graphite grids. It does not require the large anode modulator of the present triode system. Lower AC power consumption and reduced water-cooling requirements are some advantages of this scheme. A TH781 tetrode has been tested as an intermediate stage, using a Thales cavity amplifier [3]. The new system accommodates cavity field control by modulating the RF drive to linear power amplifiers, thus the four tubes in each anode modulator will be eliminated. When installed, the new system will reduce the total number of gridded power tubes from twenty-four to seven for the LANSCE DTLs.

805 MHz RF

The 44 klystrons at LANSCE are grouped into 7 sector buildings. Five of the sectors contain 6 klystrons and two of the sectors contain 7 klystrons. As was pointed out above, the existing LANSCE klystrons are extremely old and approaching their end of life. Our primary goal in refurbishing the 805 MHz RF systems is to eliminate this end of life issue, improve our reliability and improve our efficiency. Thirty five of the LANSCE klystrons will be replaced. In four of the sectors we will replace the klystrons with a new design that offers higher efficiency. In the remaining one and a half sectors, we will replace the klystrons with a klystron that is identical in outline and operating parameters to the current tubes. These tubes will be a modern version of the original tubes purchased for LANSCE and will use the existing support systems.

In the four sectors where the klystrons are upgraded to a new high efficiency design (65% efficiency) with an operating voltage of 95 kV, the addition of circulators and loads to the waveguide systems will be required. The new LANSCE klystrons are a little over twice the power of the klystrons Los Alamos provided for the RF stations for the superconducting portion of the SNS linac. The physics design of these SNS klystron was tested to the power levels needed for LANSCE and demonstrate the required efficiency. Upgrading the existing system to these high efficiency klystrons will save approximately $ 650 k per year of electricity cost for the four sectors. For the high efficiency klystrons, it is necessary to replace the klystrons HV power supplies. The power supplies currently in use cannot provide the operating voltage required for the high efficiency klystrons and are also facing obsolescence and end of life issues. Cost constraints have limited us to only 4 sectors of high efficiency klystrons because we have 4, nearly new, high voltage power supplies left over from the Accelerator Production of Tritium (APT) program that are consistent with operating a high efficiency klystron for LANSCE. The klystrons will be modulating anode klystrons operating at a maximums cathode voltage of 95 kV, a nominal peak RF output of 1.2 MW, and a nominal duty factor of 10% (120 Hz RF pulse train with 800 usec pulses).

These klystron replacements will free up 35 klystrons that will be used as spares for the remaining nine klystron sockets.

805 MHz HV DC Systems

For the four sectors of new high efficiency klystrons, the high voltage systems and capacitor bank are being replaced. SCR controlled, 12 pulse power supplies purchased, installed, commissioned, and tested for the APT program will be used to provide the high voltage for the new, high-efficiency, LANSCE klystrons. These power supplies are designed to deliver -95 kV and 21 A (2 MW) of DC power to the klystron. These power supplies provide the average power required by the klystrons to an intervening capacitor bank that delivers the peak current to the klystrons during the RF pulse. The klystron cathodes operate at -95 kV DC and the modulating anode is pulsed to gate the klystron beam current.

The existing capacitor bank will be upgraded to address safety and reliability concerns. The current capacitor bank uses old style, paper-foil capacitors in a distributed configuration. Voltage stand-off considerations forced a capacitor bank design that requires the use of two series capacitors to stand off the full operating voltage of the klystrons. The current design has a history of energetic failures, occasionally accompanied by fire, which requires mitigation without benefit of the engineered safety controls. This capacitor bank design will be replaced by a new, "self-healing" capacitor design that does not energetically fail. Because of a higher capacitor voltage rating, we will be able to eliminate the series configuration in the current bank. To help eliminate the potential for long downtime failures, we also are planning to allow the capacitor banks to receive redundant high voltage feeds, either from the existing, lower voltage, LANSCE supplies or the new APT supplies and allow for quick reconfiguration in the event of a failure. Since the high-efficiency klystrons use a modulating anode, we would still be able to support operations at lower efficiency at the lower voltage of the existing LANSCE supplies by increasing the klystron beam current. This would require operation at a reduced duty factor, but would enable us to avoid a long down time repair.

RF Controls

The proposed LANSCE-R RF control system consists of a digital I-Q controller with direct control over the RF drive signal. This system will down convert both the reference and cavity signals at the cavity to a common intermediate frequency (IF) to reduce transport errors to the electronics in the equipment area. There the IF signals are sampled to provide I-Q data streams that are processed using FPGA-based digital PI controller. This controller has the ability to modify set points and control parameters on a pulse-to-pulse basis so that wide variations of pulse current can be handled more optimally. Also included in the controller is adaptive feed-forward control and amplifier nonlinearity compensation. The feed-forward control compensates for the beam loading and cavity fill deterministic errors using an iterative learning controller and includes enough internal memory to handle up to 8 different species/current combinations. These can be switched on a pulse-to-pulse basis so that the feed-forward compensation is unique to each species/current combination.

REFERENCES

[1] M. Lynch, "The LANSCE 805 MHZ RF System History and Status," PAC'05, Knoxville, May 2005, http://www.jacow.org.

[2] J. Lyles, "A New 201.25 MHz High Power RF System for the LANSCE DTL," EPAC'02, Paris, June 2002, p. 2329, http://www.jacow.org.

[3] J. Lyles, "Test Results for the 201.25 MHZ Testrode Power Amplifier at LANSCE," EPAC'04, Lucerne, July 2004, p 1078, http://www.jacow.org.

[4] K. Young, "The LANSCE 201 MHz and 805 MHz RF System Experience," PAC'07, Albuquerque, June 2007, http://www.jacow.org.

