LANSCE RF SYSTEM IMPROVEMENTS FOR CURRENT AND FUTURE PROGRAMS*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) is in the midst of an upgrade of the RF systems. This project will return LANSCE to its historical operating capability and sustain facility operations into the next decade. The LANSCE accelerator provides pulsed protons and spallation neutrons for defense and civilian applications. This project involves replacing all the existing 201-MHz RF stations and 805-MHz klystrons. LANSCE is also currently in the conceptual design phase of a program called the Material Test Station (MTS) to establish a 1-MW target station to irradiate fast reactor fuels and materials. A pre-conceptual design is also in progress to extend the capabilities of MTS to a 2-MW target that will enable the first in a new generation of scientific facilities for the materials community. The emphasis of this new facility is "Matter-Radiation Interactions in Extremes" (MaRIE) which will be used to discover and design the advanced materials needed to meet 21st century national security and energy security challenges. The design and test results of the new RF systems will be presented as well as the RF system changes required to support the new missions.

INTRODUCTION

The LANSCE accelerator complex currently supports a broad user base including the neutron scattering community, isotope production, basic science, and national security programs by providing multiple beams to several diverse experimental areas. The LANSCE linac accelerates negative hydrogen ions (H^-) and protons (H^+) simultaneously. An 800-MeV H^- beam is delivered at 20 Hz to the proton storage ring/moderated neutron production target at the Lujan Center for a suite of neutron-scattering instruments. H^--beams are also delivered to other experimental areas at 800 MeV for proton radiography, ultra-cold neutron production, semi-conductor chip irradiation, and for nuclear physics cross-section measurements. Protons are used for medical isotope production at 100 MeV. High-power operation using the 800-MeV, H^+-beam was halted in 1998. Historical high-power operation (10% total RF duty factor; 100 Hz x 625 µs; 16.5-mA peak proton beam current) resulted in 800-kW average beam power at an 800-MeV final energy.

RF SYSTEM UPGRADES

LANSCE is currently in the 3rd year of an 8-year effort to upgrade the four, 201.25-MHz, gridded-tube RF stations and the forty four 805-MHz klystron installations.

At present, the linac is limited to 60-Hz operation, due in part to degraded high duty factor performance of the Burle 7835, power triode of the amplifier system for each module of the drift-tube linac (DTL). Based on analysis of historical data, we expect to run out of 805-MHz klystrons spares in the next three years. The RF upgrade includes replacing the1950's era 201.25-MHz RF systems with a modern system, procuring spare klystrons, and upgrading select components of the klystron electronics. The short-term goal of the upgrade is to enable a return to high-power 120-Hz operation (100 Hz H^+, 100 Hz H^-) in FY2016 and the longer term goal is to ensure long-term reliability.

201.25- MHz RF Systems

The LANSCE proton linac uses an Alvarez DTL powered at 201.25 MHz to accelerate beams from 0.75 to 100 MeV in four tanks for injection into an 805 MHz coupled-cavity linac. The highest power DTL tank requires a nominal peak RF power of 3.2 MW at a 10 percent duty factor.

A prototype RF Final Power Amplifier (FPA) has been designed, fabricated, and tested [1] using a Thales TH628 Diacrode. The cavity amplifier has met the design goals of generating 2.5 MW peak and 250 kW of average power. The amplifier is designed with tuneable input and output transmission line cavity circuits, a grid decoupling circuit, an adjustable output coupler, transverse electric (TE) mode suppressors, blocking, bypassing and decoupling capacitors, and a cooling system. The tube is connected in a full-wavelength output circuit, with the lower main tuner situated ¾λ from the central electron beam region in the tube and the upper slave tuner ¼λ from the same point. The prototype FPA assembly is shown in Fig. 1.

Figure 1: TH628 Diacrode® under test.

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A pair of FPAs of this design will be power-combined for each of the three high-power DTL tanks resulting in significant headroom for both peak and average power over the existing 201.25- MHz systems. In addition, as the existing triode systems are replaced with a linear amplifier capable of low-level drive modulation, the anode modulators these systems use for cavity field control will no longer be required. This will reduce the number of vacuum tubes in the 201.25-MHz gallery from 24 to 10, with only two unique types of vacuum tubes in service versus 5 at present.

Procurements are currently in process to support the replacement of the first 201.25-MHz RF station during the LANSCE fiscal-year 2013 maintenance outage. The details of the mechanical design package for the TH628 cavity assemblies are also being finalized and are anticipated to be purchased early in fiscal year 2012.

805- MHz RF Systems

The 805-MHz Coupled Cavity Linac (CCL) receives 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. 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 lifetime of the existing LANSCE klystrons is unprecedented. The average klystron installed on LANSCE had in excess of 125,000 filament hours at the start of 2010. Based on a Weibull fit of our failure data, there is a 50% probability that we will utilize our five, remaining spare klystrons within the next 3 years [2].

Therefore, 45 replacement klystrons are currently on order with Communication and Power Industries (CPI) with the prototype tube [Fig. 2] currently in the test stand with a scheduled delivery in September, 2011. These new klystrons are almost identical in design to the original LANSCE klystrons manufactured in the early 1970's by CPI. All physical interfaces and performance specifications are the same. A handful of modifications to address safety issues and to improve reliability were implemented in the new klystron design including:

- BeO RF windows are being replaced by Alumina RF windows.
- The x-ray specification for the klystron was reduced to 1 mr/hr from 12 mr/hr and the radiation shielding is now included as an integral klystron assembly.
- The isolated collector, which had been a source of RF leakage, was eliminated.
- The rubber hoses on the body exterior were changed to copper pipe to minimize water leaks into the modulator tank.

With a successful prototype test in August, Los Alamos will begin receiving approximately two klystrons per month from CPI by December of 2011.

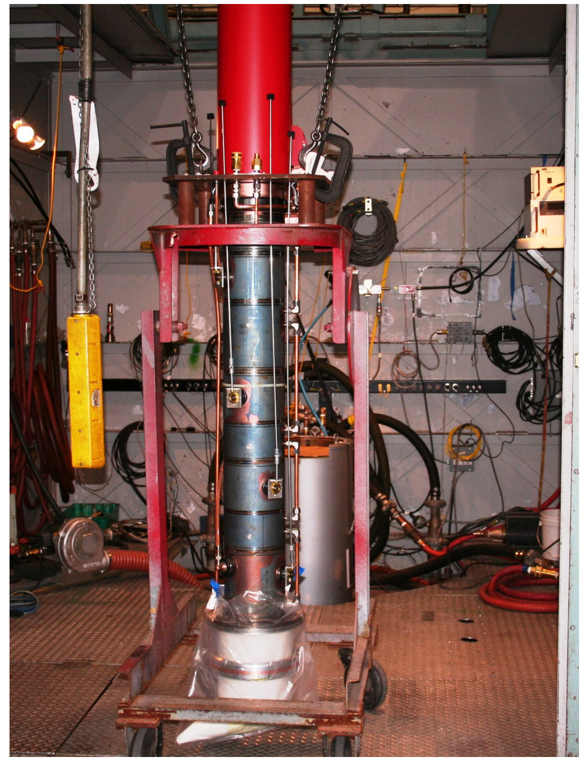

Figure 2: CPI VA-862A1 prototype klystron being installed in the test stand.

FUTURE MISSIONS

Emerging missions for the LANSCE accelerator include the application of a high-power proton beam capability to generate neutrons for users of the planned Materials Test Station (MTS) [3] and the MaRIE Fission Fusion Materials Facility (FFMF). The concept for the FFMF irradiation area is based on the MTS spallation target design and an upgrade to the LANSCE proton beam power to 2.0 MW. Experiments performed at MTS/FFMF are intended, for example, to address fundamental radiation damage phenomena with the goal of improving materials for future fission and fusion reactors. All upgrades must preserve beam delivery to the existing users.

Operation at an average beam power on target of 1 MW is the baseline requirement for the MTS, achieving 4.5% per calendar year fuel burn-up in highly enriched fuel and 18 dpa/year damage in steel. Historically, LANSCE has provided an average beam power on target of 800 kW.

An average power upgrade to 2 MW would achieve neutron flux and irradiation volume equivalents similar to those expected to be achieved by the IFMIF [4]. The neutron flux and material damage rates associated with these two new missions can be found in reference [5].

MTS

In order to achieve a test volume with a sufficiently high neutron flux, a 1.25-mA time-averaged current of 800-MeV protons needs to be delivered to the target. To achieve such a current, MTS must receive beam at 100 Hz, with a beam current of 16.5 mA during the macro-pulse. The 201.25-MHz RF amplifier upgrade described above will support the acceleration of a maximum peak beam current of 18.5 mA, at a beam-pulse length of 1225 μsec. The beam-pulse length is consistent with the amplifier ratings, but is not consistent with the pulse structures currently supported by the LANSCE linac.

The design requirement for the current upgrade is to support a 120 Hz pulse waveform with 20-Hz H^- pulses being delivered to the Lujan Center, up to 40 Hz of H^+ pulses delivered to the medical Isotope Production Facility (IPF), leaving an additional 60 Hz of H^+ pulses available for MTS. In order to provide MTS the required 100 Hz of H^+ pulses to achieve 1 MW of beam power, the existing 625 μsec H^- pulse for the Lujan Center is going to be immediately followed by a 760 μsec H^+ pulse for IPF, leaving 100 Hz of 775-μsec pulses available to MTS, resulting in an average current of about 1.28 mA, and a beam power of about 1.023 MW.

Because of the higher average power capability of the TH628 Diacrode, additional RF-system modifications required for MTS are minor. The duty factor on the 201.25-MHz RF system will be increased from 9.3% to 12.4%. Since the IPF target station is situated before the beam enters the 805-MHz cavities, the 805-MHz duty factor will remain unchanged. Capacitance must be added to the output filters of the 201.25-MHz HVDC power supply to support the longer pulse width. In addition, the anode power supply for the intermediate power amplifier, a Thales TH781 tetrode that provides the drive for the FPA, must be replaced because of the increase in duty factor.

FFMF

Delivering a 2-MW beam will require nominal upgrades to the LANSCE linac, including replacement of the existing proton Cockcroft-Walton (CW) injector system with a radio-frequency quadrupole (RFQ) based injector to improve beam quality and eliminate additional beam losses associated with this high-peak/high-average current operation. Several options for upgrading to this power level are discussed in Reference [5]. The preferred approach is the replacement of sections of the CCL with superconducting cavities to increase the final beam energy while operating at conservative peak beam currents and duty factors to deliver a 2-MW beam.

This option makes use of the existing 201.25-MHz DTL (0.75 MeV to 100 MeV) and the CCL up to approximately 500 MeV. The CW injector will be replaced with a 0.75-MeV 201.25-MHz RFQ and a new matching section for injection into the DTL. For the baseline design, the last 18 CCL modules of the existing linac will be replaced with 18 SNS-like high-β (β=0.81; E_0T=15.8MV/m) superconducting (SC) cryomodules to reach a final beam energy of ~1.5 GeV. This is a one-for-one replacement option that makes use of existing klystron galleries and waveguide penetrations into the beam tunnel.

Providing RF power to the SC cavities requires replacement of existing high-power RF systems with 72 (18 x 4; 4 cavities/cryomodule) lower-power klystrons. The maximum peak power per klystron required by the loaded SC cavities is approximately 296 kW. Allowing for a 40% margin for transmission loss and control, 414 kW klystrons will be purchased for these 72 sockets. This is well within the capability of the 805-MHz klystrons delivered by Los Alamos to power the SNS SC linac. The SNS-style klystrons provided 550 kW of pulsed RF power at 65% efficiency. The high-voltage DC (HVDC) required for these 72 new klystrons can be provided by the existing LANSCE klystron HVDC power system, capacitor bank, and crowbar and will underutilize the existing capacity of the HV system by approximately 10% relative to historical operations. The SNS klystrons, having a diode gun, will need to be modified to include a modulating anode, but this is a minor change, well understood by the klystron manufacturers, and is a typical feature of klystrons of this style. Reuse of the HVDC systems is a large cost savings because the HVDC system is typically the largest cost component of the RF system.

The transmitters that support the SNS klystrons would be adopted for these 72 new klystrons and the existing LANSCE modulators would be reused with each modulator driving 4 klystrons. The number of waveguide feeds into the tunnel would need to be increased from 18 to 72, but space is available in the existing waveguide chases to accommodate this change. Fitting 72 klystrons into the space previously occupied by 18 will be a challenge, but the fill factor in the klystron galleries is very small and initial measurements indicate that sufficient space is available.

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