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Title: LANSCE LINAC RF PERFORMANCE FOR A LONG PULSE SPALLATION SOURCE

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LANSCE Linac RF Performance for a Long Pulse Spallation Source

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Abstract

The present Los Alamos National Laboratory (LANL) Long Pulse Spallation Source (LPSS) design consists of a 1 MW neutron spallation target fed by a pulsed proton beam from the Los Alamos Neutron Science Center (LANSCE, formerly LAMPF) accelerator. This proton beam would have a repetition rate of 60 Hz and a pulse length of 1 ms for a duty factor of 6%. An average/peak current of 1.25 mA/21 mA would be required for an 800 MeV beam to provide this power at this duty factor. The spallation target would reside in what is now called Area A and would use the H+ beam. The LANSCE accelerator would also be required to simultaneously deliver H- beams to the Manuel Lujan Jr. Neutron Scattering Center (MLNSC) and the Weapons Neutron Research (WNR) facility at the requisite duty factors and currents.

Presently LANSCE delivers 16.5 mA peak of H+ beam at 120 Hertz, with a 625 µS beam pulsewidth. At the same time, H- beams are accelerated for use in MLNSC and WNR.

In November of 1995, operation of the linac shifted to the LPSS pulse parameters, except for the peak current- which remained at the 16.5 mA production level. In addition to delivering 800 kW of H+ proton beam to physics production targets, H- beams were simultaneously delivered to customers for the PSR feeding the Manual Lujan Neutron Scattering Center (MLNSC), and to researchers using the WNR facility. Performance of the RF powerplants for the 201.25 MHz drift tube linac, the 805 MHz side coupled linac, and the associated electronics is described.

The conclusion of the experiment is that the LANSCE linac can be upgraded through modest improvements to drive a 1 MW LPSS.

The LPSS Demonstration Experiment

The objective of this experiment was to simultaneously deliver an evenly spaced 60 Hz x 1 ms, 1 mA average , 800 MeV beam to Area A (800 kW, or 80% of LPSS design), an evenly spaced 20 Hz x 600 µs, 70 µA H- beam to the PSR/MLNSC, and 60 Hz x 625 µs, 1 µA H- beam to WNR. These criteria were chosen because they represent the present beam parameters. Also, the H+ peak current was a large fraction of the LPSS requirement and one which reflects our most recent reliable high-peak experience. The WNR and Area A beams (both at 60 Hz) were accelerated an the same RF pulses. The 20 Hz PSR/MLNSC beam was interleaved with those 60 Hz pulses. The parameters used during the test are shown in Table 1.

Table 1
Nominal Beam Parameters Used During LPSS Demonstration Test

Area	Beam	Current, avg.	Pulse width, µs	Rep rate, Hz	Duty Factor, %
Area A	H+	1 mA	1015	60	6.1
PSR/MNSC	H-	70µA	600	20	1.2
WNR	H-	1µA	625	60	3.8

To achieve the above beam parameters, we operated the RF at 80 Hz, spaced irregularly in a *three on, space, one on, space* pulse train. Refer to Figure 1. The reduced number of turn-on transients reduced the heating and amount of voltage stress due to reflected power. The overall duty factor was kept close to the 1995 operational values to minimize stress, and allow production to continue to the targets for the customers. Peak power was maintained near the operation values, as peak beam current did not increase.

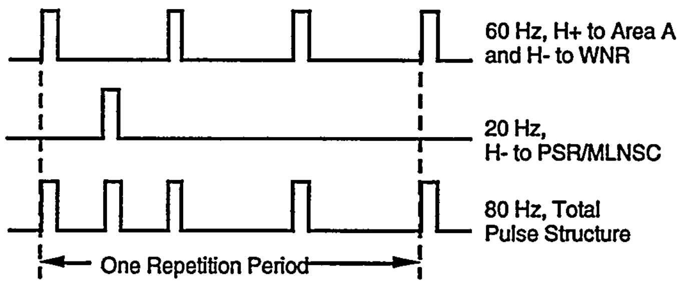

Fig. 1. 80 Hz Pulse Structure for LPSS Test.

The corresponding RF duty factor is based on 80 Hz operation, and the RF pulse width was constant for each pulse, despite variations in beam pulse width. The 805 MHz RF systems required a pulse width of 1185 µs, and therefore operated at a duty factor of 9.5%. The 201.25 MHz RF systems required more time at the start of each pulse to fill the cavities and stabilize the fields (1235 µs pulse width). The 201.25 MHz duty factor was thus 9.9%

201.25 MHz DTL RF Systems

A description of the 201.25 MHz RF systems is given in a companion paper (reference 1) In LANSCE, Modules 2 through 4 operate close to their maximum ratings. Using the same FPA tube at one sixth the power, Module 1 is not as critical. However, control stability on Module 1 is important since the resulting effects on the beam can impact performance throughout the linac.

Test Conditions

We chose RF module 2 of the DTL to make a modification to the RF amplifier chain. It had been noted during a development test in 1993 with odd-spaced pulse trains that some of the power supplies had output ripple components related to 60 and 120 Hz powerline frequencies. The IPA (intermediate power amplifier) screen power supply was suspect since it is an unregulated, LC-filtered power supply. During the LPSS test, we substituted a high-frequency switching power supply and storage capacitor. It was suspected that this would attenuate the line frequency components further, leaving only minor droop from the pulse as the predominant artifact.

The phase and amplitude controls, capacitor bank voltages, and drive level controls were only adjusted as needed to maintain proper operation with the new pulse timing. It was found that only the highest powered module, number 2, required any adjustment, and this only for the capacitor bank voltage.

Results for DTL RF Systems

We measured the waveform of the voltage on the HVDC capacitor bank for Modules 2 - 4, the highest power systems. Module 2 was the only system requiring increased HV for adequate headroom. This module was operating at the highest peak power, nearly 3.1 MW, so it also had the highest plate current. During the H+ beam it required 225 Amperes of peak current, while modules 3 and 4 required 200 Amperes and 210 Amperes respectively. With H+ beam on, the peak power for modules 2, 3 and 4 was 3.05, 2.54, and 2.71 MW, respectively. Because of the higher plate current, the plate modulator of module 2 had a large voltage drop across the pass tube elements. This is seen in the comparative modulator voltage drops in the oscilloscope traces in Figure 2.

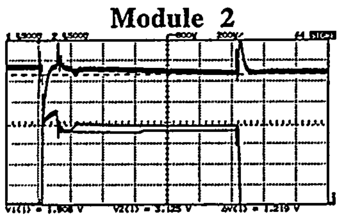

Fig. 2. Capacitor Bank Voltage *(top trace)* and Plate Voltage *(bottom trace)* for Module 2. Vert. Scale = 5 kV/Div, Horiz. = 200 μs/Div.

The ripple on the capacitor banks was observed for each module. A representative waveform for module 2 is shown in Figure 3. Note that the stairstep for each pulse starts at a different voltage, repeating after 50 milliseconds (one repetition period for the complete pulse structure). During the normal production of 1995, the capacitor bank was operated at 31.5 kVDC. During the LPSS test it was raised to 33 kVDC, which is the RMS level of this waveform.

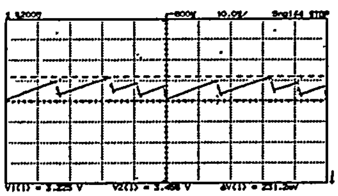

Fig. 3. Capacitor Bank Voltage for Module 2. Vert. Scale = 2 kV/Div, Horiz. = 10 mS/Div.

During the beam production period in 1995, the 7835 triode power amplifiers for Modules 2 - 4 operated at about 90% of their administrative limit of 250 kW plate dissipation. It was estimated that for a constant duty factor, operating with lower repetition rates and longer pulses would result in lower dissipation. Indeed this was true for no-beam conditions where the amplifiers supplied the linac copper power only. As the repetition rate was reduced on Nov. 28 from the original 120 Hz to the new 80 Hz condition, dissipation was found to drop as shown in Table 2. This 8 to 10 kW reduction was more than could be accounted for by the slight adjustment in DF alone.

Table 2
7835 Plate Dissipation versus RF Timing, Beam Off

	Module 2	**Module 3**	**Module 4**
835 ms, 120 Hz 10.02% D.F.	201 kW	204 kW	206 kW
1000 ms, 100 Hz 10% D.F.	196 kW	200 kW	204 kW
1235 ms, 80 Hz 9.88% D.F.	191 kW	195 kW	198 kW

Summary

The DTL RF powerplant worked remarkably well, considering its power limitations. Dropping the pulse repetition rate to 80 Hz from 120 Hz was a slight improvement for plate dissipation. Accelerating higher peak beam current will be significantly harder than this test, because of the increased peak power required. The 201.25 MHz RF will not be able to pulse at 10% DF while maintaining higher peak power, due to the plate dissipation explained earlier. This is the fundamental limitation which precludes operating the LANSCE linac at the full LPSS power (1 MW) while continuing to deliver beams to PSR-MLNSC and WNR.

805 MHz SCL RF Systems

Background

Recent studies which assessed the performance of the present SCL/RF systems provide some estimates on peak beam current limitations in the SCL. One study stated that the SCL should be capable of operating with up to 26 mA peak, when chopped to 17 mA average. (reference 2) RF control systems are a limitation and probably will need upgrading. In a series of tests in 1993, it was shown that the klystron amplifier duty factor limit (≈12%) comes from the maximum current of the HVPS.

805 MHz Low Level RF Controls

Operation in the 805 MHz RF portion of the machine went fairly smoothly. The staggered operating conditions *(3 on, 1 off, 1 on, 1 off)* required that the control loops operate over a wider dynamic range than the previous operating conditions. Once the fast-protect gate was corrected, most of the control loops performed relatively well. However, the wider dynamic range did require some adjustments to be made due to klystron differences.

Overall, control loop errors in the 805 MHz RF powerplant were about the same as in the 201.25 MHz RF powerplant; only on a few of the more difficult modules did they approach the 0.5%, 0.5° levels in amplitude and phase, respectively. Exact reasons for some modules being more difficult to control are not fully understood. Some modules have traditionally been difficult to control while in others the problems seem to have come and gone as klystrons were changed. The resonance controllers functioned normally during the test.

HV Capacitor Bank Voltage

Due to the increased demands on the RF powerplant, the 805 MHz RF capacitor banks experienced significant voltage droop. This droop problem was exacerbated by the irregular pattern of pulses. For example, Figure 4 depicts the droop and pattern of klystron cathode current for Module 48. The relationship of cathode current, I_k, to capacitor bank voltage, V_c, is $I_k=kV_c^{3/2}$. A reduction in capacitor bank voltage results in reduced klystron cathode current and overall gain. This requires the control system to operate over a larger dynamic range than in past operational modes.

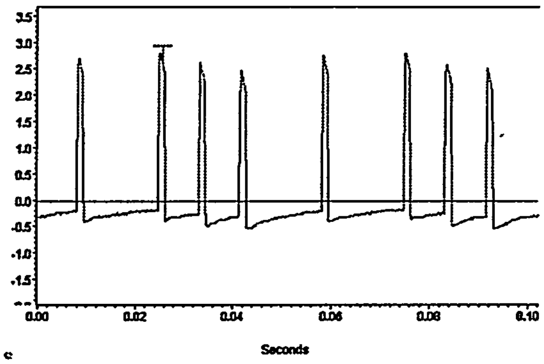

Fig. 4. Module 48 Klystron Relative Cathode Current.

Path Forward for RF Systems

Need for High Peak Current Test in 1996

The LPSS study did point out the need for more development time under peak beam conditions observed during these tests. The beam related noise, though not a serious problem at 16.5 mA peak, should be analyzed for the higher peak currents of LPSS. Additional tests in 1996 will prove useful to examine operation at higher peak beam current.

201.25 MHz DTL RF System

Changes to the system such as new IPA screen power supplies will improve performance for irregular RF timing as proposed for LPSS. A plan to eliminate the IPA plate modulator and operate the tubes from stand alone DC power supplies has been proposed to improve reliability and simplify the RF power systems. It will raise IPA tube reliability by reducing the plate voltage to a more optimal value. A properly implemented adaptive feedforward controller in the sensitive module(s) could improve the low level amplitude and phase controllers in response to repetitive beam transients, temporal and cyclic drifts in tune, and component changes or gain drifts inside the controlled loop.

For 21 mA LPSS operation, we have proposed a new RF amplifier chain (reference 1). These systems would not require high-level plate modulation for amplitude control. Without the modulators, the plate voltage drop would disappear, raising the peak power capacity of modules 2 through 4 while maintaining low capacitor bank voltages. Duty factor would not be a limitation.

The tank window will be examined with improvements to handle the higher peak voltages and currents. RF circulators are proposed to eliminate troublesome reflected power at the FPAs.

805 MHz SCL RF System

Better knowledge is needed of where the non-linearities are for each klystron, as well as where the operating points are at the SCL. Waveguide coupling into the SCL needs to be measured and possibly adjusted for more uniform operation of all modules. The klystron focus magnet currents need to be characterized better with respect to linac operation. There is inadequate absolute power monitoring instrumentation. With the 44 operating klystrons, these are large scale problems.

DC filament current for the klystrons has been recommended but never installed. A test of this concept is proposed for 1996. It is expected that operation of the cathode heater with DC would eliminate another source of 60 Hz powerline noise, as well as improve the gain uniformity of each klystron module along the SCL, irrespective of the AC powerline phase chosen and the Master Timer pulse pattern.

Installation of new feedback controllers or adaptive feedforward controllers may be the ultimate solution for the SCL modules. Due to the large number of systems in the SCL powerplant, any proposed modification must be analyzed for performance and the individual unit cost. This has limited the overall upgradability of the SCL RF systems in the past to minor improvements. Upgrades must be reviewed in light of this philosophy. There is much more room for significant modification in the 201.25 MHz DTL powerplant, with only four modules.

Acknowledgments

The LPSS experiment was carried out through the combined efforts of the AOT-6 Beam Delivery and Physics Teams and the AOT-5 RF Team. They were instrumental in making the adjustments and changes in a timely and coordinated manner, over a continuous period encompassing 48 hours.

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