Title: LANSCE 201.25 MHZ DRIFT TUBE LINAC RF POWER STATUS

Author(s): John T. M. Lyles
Carl C. Friedrichs, Jr.

Submitted to: Linac Conference '96
Geneva, Switzerland
August 25-30, 1996

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
Abstract

The Los Alamos Neutron Science Center linac provides high power proton beams for neutron science, Tritium target development, nuclear physics, material science, isotope production, and weapons research. The number of simultaneous beam users places heavy demands on the RF powerplant, especially the 201.25 MHz power amplifiers (PA) driving four drift tube linac cavities. Designed nearly 30 years ago, these amplifiers have operated at up to 3 Megawatts with duty factors of 12%. The large number of power tubes in the PA and Intermediate Power Amplifier (IPA) plate modulators, the age of the cooling and control subsystems, tube manufacturing problems, and operation near maximum PA tube ratings have all affected the system reliability.

By monitoring final power amplifier plate dissipation and tube vacuum, improved operating procedures have raised RF system reliability above 95% for operation periods in 1993-95. Higher beam current for a proposed Long Pulse Spallation Source (L.PSS) cannot be delivered simultaneously with other beams at high duty factor, however. Plans are underway to develop a new final power amplifier which can use low-level RF modulation for amplitude control. With only a few power tubes, the system will deliver high peak power and duty factor, with improved DC to RF efficiency, and a simplified cooling system.

Overview of Original 201.25 MHz RF Systems

A block diagram of the original 201.25 MHz RF system is shown in Figure 1. The maximum duty factor is 12% where the plate dissipation of the final amplifier tube (Burle Industries 7835 triode) is approximately 250 kW. A selection of the 7835 parameters is given in table 1. The peak power out of the final cavity amplifier is over 3.0 MW in some cases. The amplifier chain used a solid state preamplifier and a dual tube driver to provide 4 kW output. This output drives the IPA, a Burle 4616 tetrode, to achieve 130 kW. Finally the 7835 PA can deliver over 3 MW.

The 7835 cavity amplifier is unstable if operated with B+ but no RF drive, so the input high voltage is modulated by the amplitude control electronics in order to adjust the saturated output and thereby provide the amplitude control. This high voltage modulation technique requires 4 power tubes. This high voltage modulator has an internal voltage drop of 8 to 12 kV, so the high voltage capacitor bank must be maintained with that head room above the level needed by the 7835. At the present peak powers, the 7835’s require 19 to 21 kV, and the capacitor bank operates at approximately 30 kV. Operation above this level not only stresses the capacitor bank and power supply, but stresses the modulator tubes.

The IPA high voltage is derived from the same high voltage as the PA. The IPA operates as a linear amplifier, so the high voltage is only switched on and off. Its level is not modulated as in the case of the final amplifier. A tube-based modulator is used to switch the high voltage on the 4616, requiring 3 power tubes (Figure 1).

In the original configuration, the entire 201.25 MHz amplifier system required 13 power tubes per module times four modules, or 52 power tubes. The recent modifications (including a solid state driver) have reduced that number to 9 per module [1,2]. An upgrade is planned for the near future in
which the IPA will have its own high voltage power supply (HVPS). This will eliminate the 3-tube HV modulator and bring the total tube count per module to 6. When the IPA HVPS is installed the 201.25 MHz system will look as shown in Figure 2. This upgrade is just beginning with the purchase of a prototype HVPS, due for arrival in late 1996.

![Fig. 2. 'Upgraded' 201 MHz Amplifier System.](image)

### Modifications and Upgrades to 201.25 MHz RF Systems

#### Plate Power Dissipation Monitor

The original specification for the 7835 super power triode lists the average power limitation at 300 kW. We have operating experience which suggests that for safe operation, the limitation should be 250 kW. Real time monitoring of the average plate power dissipation of the FPA was installed in 1993. Using the temperature difference in the plate coolant manifold and the flow from a sensor, the power wasted in the plate coolant (plus a factor for filament and drive power) is computed with an imbedded controller and used for readout and interlock of the HV. We implemented administrative controls to limit the operation to plate dissipations of less than 250 kW. Catastrophic failures have been significantly reduced since then. This is especially effective during beam tuning and transient conditions when the RF power level is fluctuating and the resonance controller is moving the DTL tuning slugs.

#### Peak Power Monitors

A major improvement was the addition of peak power monitors (PPM) to diagnose what is happening in the entire amplifier chain for 201.25 MHz. The PPM replaced old uncalibrated detector diodes and homemade directional couplers which were only useful for indicating that a signal was present. We bought commercial directional couplers in 5 kW, 150 kW, and 3 MW sizes, for the driver, IPA, and PA outputs, respectively. We bought lowpass filters to eliminate harmonics from the power signals, and built the PPM timing gate to allow sample/hold of the peak anywhere in the RF waveform. These signals are fed to large LED displays, and to the central control room for logging. Both forward and reflected power are monitored.

#### Filament Power Regulator

The 7835 PA filament supply is an unregulated, variac-controlled supply. As noted in table 1 above, this supply delivers almost 7000A at 4V. A modern SCR supply was purchased for our test stand to see the benefits of filament current regulation. The regulation has been shown to be effective in stabilizing the 7835 operation, since the cathode current in the grounded-grid triode is proportional to emission from the filament. However, because of the cost of the filament supply and the desire to replace the 7835 amplifier stages in the near future (see below), we have chosen to modify our existing supplies rather than make new purchases. The modification consist of adding a control circuit to the variac controller which adjusts the variac as the supply output current varies. In order to avoid excessive brush wear in the triode, the control circuit is designed with an adjustable dead band. We have found that 50A is a suitable band. The regulation is sufficient, and the brush movement is not excessive.

### Table 2

<table>
<thead>
<tr>
<th>DTL Tank #</th>
<th>Operating Copper Power (MW)</th>
<th>Beam Power (MW, for 13 mA Beam)</th>
<th>FPA Plate Dissipation (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.330</td>
<td>0.100</td>
<td>0.065</td>
</tr>
<tr>
<td>2</td>
<td>2.450</td>
<td>0.450</td>
<td>0.223</td>
</tr>
<tr>
<td>3</td>
<td>1.950</td>
<td>0.360</td>
<td>0.181</td>
</tr>
<tr>
<td>4</td>
<td>2.360</td>
<td>0.320</td>
<td>0.238</td>
</tr>
</tbody>
</table>

Module 1 is a very short Alvarez tank and requires much less power than the other three tanks. It uses a 7835 cavity amplifier primarily for compatibility and ease of maintenance. Approximately 200 μs of additional time is required for each pulse for the RF power to fill the tanks and stabilize. Another 40 μs is needed for settling time when the beam is injected. The corresponding beam and RF parameters are:

- **Beam DF** = 7.6% (620 μs, 120 Hz)
- **RF DF** = 10.3% (860 μs, 120 Hz)
Modifications to the PA Plate Modulators

In 1992, analysis of the modulator output waveforms showed an undershoot of about 5 kV after pulse shutoff. We believe the cutoff 7835 triode was acting as a rectifier for the returning RF power from the DTL tanks during decay. A high power clamp diode was back biased from the floating deck to ground, eliminating the negative transient which was charging the deck. This modification dramatically reduced nuisance crowbars due to modulator tube faults. Diagnostics were also added to monitor the video driver current pulse and the plate current in each tube. These diagnostics have allowed us to predict when a video driver tube is weakening and plan a changeout in advance [1, 2].

We have installed new bias power supplies for the 4CW250000B tetrode modulator tubes which allow a higher bias: 500 versus 350 volts. This cuts off the tubes more completely during the beam-off time, to minimize cutting of the anode of the tube from the e-beam, which is focused at this condition. In addition the new bias supply is a modular unit which is very easy to remove and change. With the old supply, one had to climb under the deck, on top of the 1700 VAC isolation transformer and lie there in a cramped position to remove the old bias power supply.

Solid State Amplifier

The second stage of solid state amplification in Figure 2 was a recent upgrade which replaced a dual-tube amplifier. The original Burle 7651 tetrode driver tubes for the 4616 had a short lifetime due to a cooling design limitation. They were adequate at low duty factor, but the present duty factor raised the ceramic seals in some units to near 250°C. New water-cooled solid state amplifiers, using 32 Motorola MRF141G MOSFETs combined to deliver up to 5500 W, were installed in 1993 and 1994. Reliability is now excellent with these units. In addition, an entire rack of power supplies, blowers, and amplifier cavities has been eliminated for each 201.25 MHz amplifier system.

Capacitor Room and Crowbar Upgrade (Module 2)

The first level of arc protection for the FPA and IPA RF tubes is provided by a modulator blocking circuit. That is, in the event of an RF tube arc, the modulator switch tubes are shut off as rapidly as possible. In addition, the crowbar trigger circuit waits on the order of 10 µs for the modulator to extinguish the fault current before commanding the crowbar to fire. This long delay time forces a requirement for a 10Ω fault limiting resistor which must dissipate about 70 kW in normal operation. The resistor is immersed in an oil tank, and the oil is cooled by a heat exchanger external to the capacitor room. Maintenance costs and environment and safety concerns have pushed us to consider an air cooled resistor. Toward that end, we developed a 3µs crowbar, with an amplitude threshold of about 3 kA to work in conjunction with the existing crowbar. The fault limiting resistor is reduced to 3Ω , dissipates 21 kW, and is air cooled. In addition to the crowbar and limiting resistor improvements, we fitted each capacitor with a spring loaded fuse to isolate the capacitor in the event of an internal short. The new crowbar circuit will protect a 30 gauge wire, but a more significant data item is that after 3 months of full operation, there has been no increase in the number of crowbar faults in Module 2. The remaining modules are scheduled for similar upgrades in late 1997.

Proposed 201.25 MHz Amplifier Replacement

We are beginning to look into options for replacement of the 7835 PA stage. The primary goal would be to install a new cavity amplifier which will operate as a linear amplifier and thereby eliminate the need for modulation of the high voltage. Modulation of the output power will be done with the RF drive to the amplifier. This will eliminate 4 more tubes in the system. In addition, the voltage overhead of the high voltage modulator will go away (about 10 kV), so the cap bank and HVPS can operate at reduced levels. We hope to be able to replace the 7835 with a single tube amplifier, but we are also considering the use of two tubes which are summed together in a hybrid combiner. This work is in the early stages of conceptual design.

Cathode-driven tetrodes are the probable choice, as there exists no other super-power VHF triode similar to the 7835. With this power source, we expect to be able to deliver up to 3.8 MW of peak RF power at a duty factor of 15%. This would provide enough RF for long pulse operation of the H+ beam at 21 mA, interleaved with the H- beam for our proton storage ring.

References


[2] W.M. Parsons, J.T.M. Lyles, and H.W. Harris, "Upgrading the LAMPF 201.25 MHz RF Generators", LA-UR-93-823