NEW HIGH POWER 200 MHZ RF SYSTEM FOR THE LANSCE DRIFT TUBE LINAC*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) linac provides an 800 MeV direct H^+ proton beam, and injects H^- to the upgraded proton storage ring for charge accumulation for the Short Pulse Spallation Source. Accelerating these interlaced beams requires high average power from the 201.25 MHz drift tube linac (DTL) RF system. Three power amplifiers have operated at up to three Megawatts with 12% duty factor. The total number of electron power tubes in the RF amplifiers and their modulators has been reduced from fifty-two to twenty-four. The plant continues to utilize the original design of a tetrode driving a super power triode. Further increases in the linac duty factor are limited, in part, by the maximum dissipation ratings of the triodes. A description of the system modifications proposed to overcome these limitations includes new power amplifiers using low-level RF modulation for tank field control. The first high power Diacrode® is being delivered and a new amplifier cavity is being designed. With only nine power tubes, the new system will deliver both peak power and high duty factor, with lower mains power and cooling requirements. The remaining components needed for the new RF system will be discussed.

1 PRESENT HIGH POWER RF SYSTEM

The Los Alamos Neutron Science Center (LANSCE) linac provides high power proton beams for neutron science, Tritium target development for APT, 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 final power amplifiers (FPA) driving four Alvarez DTL tanks for 0.75 to 100 MeV. 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 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.

For the past six years we have designed and installed system upgrades that have reduced the number of power tubes in the system from fifty-two to twenty-four [1,2]. A block diagram of the present RF system is shown in Figure 1. The maximum duty factor is rated at 12% where the plate dissipation of the final amplifier tube, a Burle Industries 7835 triode, is approximately 250 kW. The peak power from the final cavity amplifier for the largest DTL tank (tank 2) is slightly over 3 MW for some tunes. The triode FPA is unstable if operated with plate voltage but no RF drive. Consequently, the FPA is driven with constant RF drive from the IPA, using a Burle Industries 4616 tetrode. The plate voltage is simultaneously pulsed on and varied by the amplitude controller in order to adjust the saturated output and provide tank field control. This high voltage modulation technique requires four additional power tubes. The modulator has an internal voltage drop of about 10 kV when fully on, so the high voltage capacitor bank must be maintained above the level needed by the FPA by at least this amount. This causes an additional power dissipation of nearly 250 kW each, in three of the four plate modulators. The forth RF system drives DTL tank 1, which requires less than 500 kW of peak RF, relatively low power compared to the other units. In this report, this unit is not shown in the diagrams for simplicity.

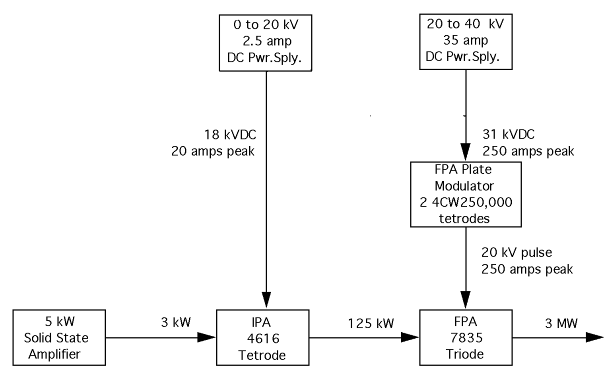

Figure 1. Present configuration - high power RF modules

The FPA triode has an output ceramic seal length of 7.62 cm. This requires that it be operated within a pressure vessel operating with 2.4 bar dry air at Los Alamos (2120 meters above sea level) to maintain voltage standoff. Because of the high average power, the pressurized air must be circulated through the cavity and cooled. The high-pressure turbine and pressurized heat exchanger require annual maintenance, and have contributed to system down time. Replacement of the FPA tube takes approximately 16 hours due to the enormous pressure vessel that must be removed first.

Higher beam current for new linac applications such as the proposed Long-Pulse Spallation Source [3] cannot be

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delivered simultaneously with other beams at high duty factor. Table 1 shows the RF power requirements for the present 18 mA and proposed 21 mA peak current needs. The RF pulse parameters are for up to 1350 microseconds width at 120 pulses per second repetition rate, resulting in up to 16.2% duty factor for the RF amplifiers. These requirements are within the fundamental capabilities of the 805 MHz RF System for the coupled-cavity linac that accelerates from 100 to 800 MeV; only the 201 MHz system needs this substantial upgrade.

Table 1. RF power requirements for DTL

RF Operating Levels						
Module	Energy	Tank Pwr.	21 mA Beam Pwr	8% margin	Peak Req'd	Ave. Req'd
	MeV	MW	MW	MW	MW	kW
1	4.64	0.37	0.10	0.04	0.51	82
2	35.94	2.57	0.75	0.27	3.59	582
3	31.39	2.10	0.66	0.22	2.98	483
4	27.28	2.23	0.57	0.22	3.03	491

2 POWER AMPLIFIER REPLACEMENT

We plan to install a new cavity amplifier, which will operate as a linear amplifier and eliminate the need for modulation of the high voltage. Output power control will be accomplished by varying the low-level RF drive to the preamplifier stage. This eliminates four more tubes in each system, leaving only two RF amplifier tubes per module (three in module 2), or nine for the entire DTL RF powerplant. In addition, the voltage overhead of the plate modulator will disappear, as the tube will operate with DC plate voltage and be pulsed into conduction with the control grid bias.

2.1 RF Power Tube Selection

Until very recently, there has been no reasonable alternative to the 7835 for the LANSCE 200 MHz DTL. Thomson Tubes Electroniques embarked on a program to develop a tube capable of delivering 3 MW peak, 600 kW average RF power, at 200 MHz. The tube was proposed for fusion heating as early as 1991 [4]. Employing double-ended RF geometry (as in the 7835 triode) can extend the frequency-power limits of gridded tubes. The TH628 Diacrode® is a double-ended tetrode, derived from the single-ended TH526 tetrode. The tube uses pyrolytic graphite grids, a thoriated-tungsten mesh cathode, and a multiphase-cooled anode rated to dissipate 1.8 MW. Pyrolytic graphite grids allow elevated grid operating temperatures without seconday electron emission. This allows for higher screen power dissipation, and higher output power without adverse effects. The first cathode-driven TH628 Diacrode® has recently passed acceptance tests at the factory, and is being delivered to LANSCE. No other modern tetrode has delivered this level of high power 200 MHz performance. Table 2 lists significant results from the tests.

Table 2. Thomson TH628 Test Results – June, 1998

Peak Power Output	3 MW peak
Average Power Output	600 kW
RF pulse duty cycle	20 %
DC-to-RF Efficiency	>60%
DC plate voltage	26 kV
Screen (G_2) Voltage	1.6 kV
Filament Power	18 VDC, 910 A.
RF Power Gain	>14 dB
Zero Drive Stability	No emissions 0 to 1 GHz
Coolant Flow	360 l/min deionized water

The planned configuration for DTL modules 3 and 4 is shown in figure 2. Two combined amplifiers may be required only for module 2, and this scheme is shown in figure 3. The upgraded system will employ circulators between the FPA and DTL. Air pressurization is not planned for these amplifier cavities, as the ceramic seal is longer on the TH628. Tube replacement time will be decreased from about 16 hours to 2 hours.

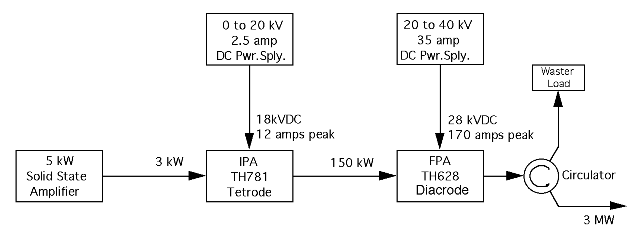

Figure 2. New configuration for RF modules 3 and 4

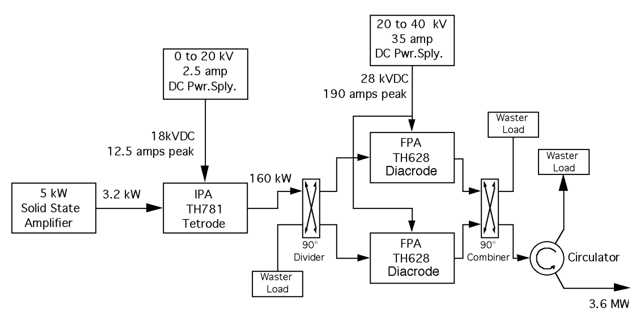

Figure 3. New configuration for RF module 2

2.2 Intermediate Power Amplifier

The existing 4616 tetrode intermediate power amplifier is capable of 150 kW peak power at our present duty factor. The statistical lifetime of these tubes has varied with variations in manufacturing, including component changes such as different filament alloys and sources of mica. As a grid-driven tetrode, the 4616 is capable of very high gain. Along with this high gain is a system sensitivity to variations in the screen emission and VHF resonances or back-cavity modes from the internal mica screen bypass capacitor assembly. We have a choice of continuing to utilize the existing amplifiers, or converting to a cavity amplifier using a Thomson TH781 tetrode, which has pyrolytic graphite grids, a thoriated-tungsten mesh cathode, and a multiphase-cooled anode rated to dissipate 250 kW. A nearly identical tetrode (TH681) is in successful operation driving the CERN PS 40 MHz bunching cavity [5].

2.3 Power Supplies

The existing plate HV power supply/capacitor banks are adequate for the conversion, after the plate modulators are removed. The HV power supplies for DTL modules 2 through 4 are rated for 40 kV maximum, at 35 Amperes DC. With the existing capacitor banks, they were designed to drive the FPAs at 120 Hz, with 1200 uS pulses. The DC voltage will be reduced from the present charging level. The module 1 power supply will also be reused.

The 7835 triode requires 6900 Amperes of DC filament current. The original filament power supplies are very large. Removal of the present power supply will provide much floor space for the upgrade. The TH628 requires less than 1000 Amperes, supplied from a small power supply without water-cooled cables.

2.4 RF Output Components

The new FPA will be isolated from reflected power from the DTL by using a coaxial Y-junction circulator. Advanced Ferrite Technology has proposed a 35.5 cm coaxial device, which has less than 0.16 dB of insertion loss and 25 dB of isolation. This is especially important for the combined amplifiers for module 2, driving the high Q DTL. A water-cooled dummy load will be connected to the third port.

The power splitter and combiner for module 2 will be 3 dB hybrids, available from several manufacturers. Examples of the successful use of power combiners of this size are found at the MIT/Lincoln Labs ALTAIR radar in which two super-power triodes are combined at 160 MHz. At the CERN SPS, sixteen 35 kW tetrodes are successively combined at 200 MHz for 500 kW, and four 125 kW CW tetrodes are combined for 500 kW of total power [6]. A water-cooled dummy load (waster) will be required on the combiner, rated at one quarter of the overall power.

The full output power is to be transmitted to the DTL through the existing 35.5 cm diameter coaxial line. This line is theoretically capable of 40 MW peak and over 600 kW of average power at 200 MHz when pressurized with dry nitrogen, according to the manufacturer. The Brookhaven National Laboratory AGS Linac has used 30.5 cm line for up to 6 MW peak at low duty factor [7].

The present RF window seals the DTL vacuum while passing through the coaxial center conductor to connect to the drive loop. It is made of crosslinked polystyrene, or Rexolite®. Presently these windows are replaced about every 2 years of service, or when the following damage is noticed during inspection: Excess radiation darkening, evidence of streamer tracks, mechanical deformation, or evidence of sputtered metallization on the vacuum side. Further work is anticipated to improve the voltage standoff and lifetime of the windows for the higher peak and average powers proposed for LANSCE.

2.5 Cooling Plant

The cooling requirements will not add additional load to the plant, as the modulator heat load will be removed, and the waster loads on the circulators and combiner are only dissipating transient loads during tuning and unbalances. The water flow though each new FPA tube is 36% less than the present tubes, due to the more efficient multiphase cooling regime in the tubes.

3 CONCLUSION

The proposed upgrade to the LANSCE DTL RF powerplant is based on changing the FPA to a new type of tetrode, which has demonstrated excellent performance during testing. The other system changes will require RF, electrical, mechanical and thermal engineering, but nothing appears to be significantly challenging to prevent long term success. This project will be a significant improvement to the LANSCE linac RF system.

ACKNOWLEDGEMENTS

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