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RF AMPLIFIER SYSTEM RECONFIGURATION PLANS FOR NEW DTL AND RFQ*

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Abstract

The first 100 MeV of acceleration for protons and H- ions at the Los Alamos Neutron Science Center (LANSCE) is presently accomplished with a Cockroft-Walton generator (750 keV), followed by four Alvarez drift tube linac (DTL) cavities commissioned in 1970. The RF duty factor is 12 %, leading to significant thermal loading in the room temperature copper structures. Increasing obsolescence and structural reliability problems have created the need for replacements to these systems. The LANSCE Modernization Project (LAMP) developed a conceptual design for the Medium Energy Beam Transport (MEBT) and the Drift Tube Linac (DTL) using new accelerator components. This approach utilizes a Radio Frequency Quadrupole (RFQ) and six replacement DTL cavities. The current 201.25 MHz radio-frequency power amplifier system was replaced 10 years ago and has demonstrated high reliability with Diacrode tube lifetimes over 60,000 hours. We propose an RF amplifier topology that leverages this RF system to provide the required power for the LAMP conceptual design through innovative reconfiguration of the amplifiers.

INTRODUCTION

The LANSCE accelerating structures have been largely unmodified since their installation in 1972. In recent years, the initial Cockcroft–Walton accelerating structures and DTL cavities [1] have suffered significant downtime affecting the beam production. The LAMP efforts are dedicated to developing a conceptual upgrade to the front-end portion of the linac that ensures the continuing operation of the accelerator into 2050. This paper describes the proposed upgrade for the high-power RF amplifiers providing the accelerating voltages for the new structures.

CURRENT SYSTEM

LANSCE's current front-end is composed of Cockcroft–Walton direct-current accelerators (for H+ and H-) that allow injection at 750 keV into the DTL. This is one of the last operating structures of this topology world-wide.

The current DTL consists of four cavities for which the exit energy and required peak RF power (data from 2024 production) is captured in Table 1. The cavities were originally constructed with their maximum length determined by the in-house accelerator design facilities, which were eventually repurposed for testing different accelerator components. From 2014 to 2021, the high-power triode-based RF amplifiers that had been operating for 45 years were progressively upgraded. Module 1 (feeding the first linac cavity) is powered by a 20 kWpk solid-state device driven tetrode amplifier [2] (Fig. 1). Because of the cavity's power requirements are close to the amplifier ratings, a circulator was added for the protection of the amplifier against reflected power spikes caused by arcs in the accelerating structure or transmission line. The amplifier produces its RF output by drawing direct current (DC) from a 480 VAC-15 kVDC power supply feeding a capacitor room that stores the energy consumed during the RF pulse without producing excessive droop (Fig. 2).

Table 1: DTL Cavities' Current Exit Energy [3]

Cavity	Exit Energy (MeV)	RF excitation power [MWpk]
1	5.39	0.28
2	41.33	2.3
3	72.72	2.1
4	100	2.4

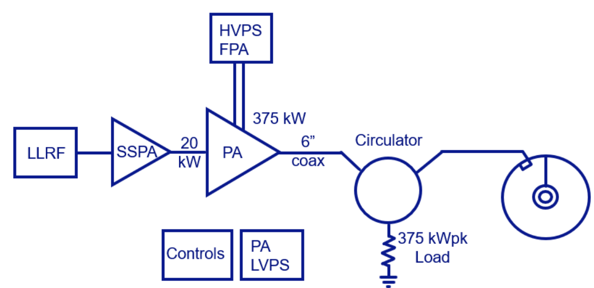

Figure 1: Block diagram of the current amplifier chain feeding the first DTL cavity (Module 1).

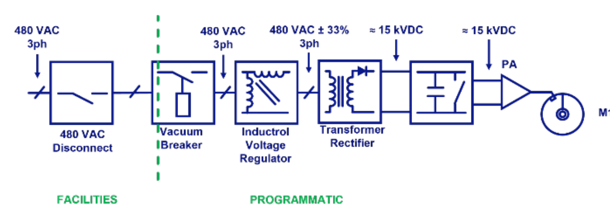

Figure 2: Block diagram of the power supply for Module 1.

Modules 2-4 consist of a 5 kWpk solid-state amplifier feeding a 200 kWpk capable intermediate power amplifier (IPA). The output of the IPA is divided through a hybrid splitter and power provided to two-Diacrode® final power amplifiers (FPAs). Their outputs are recombined to produce the required cavity power (Fig. 3)[4].

Each module has its own capacitor bank and is fed by its own transformer/rectifier (TR), inductrol voltage regulator

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(IVR) and vacuum breaker. The 4.16 kVAC incoming into the vacuum breaker originates from a 13.2-4.16 kVAC transformer common to all three Diacrode® amplifiers, as shown in Fig. 4.

Additionally, with the upgrade, all DTL amplifiers were upgraded to fast field programmable gate array (FPGA) controls capable shutting off RF within 10 µs and mordern cRIO controllers ensuring proper turn-on of the amplifier chain.

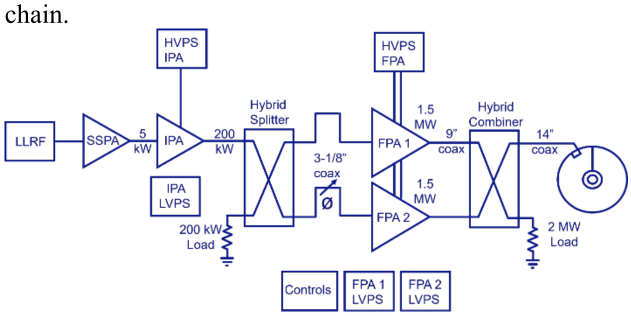

Figure 3: Block diagram of the current amplifier chain feeding DTL cavities 2-4.

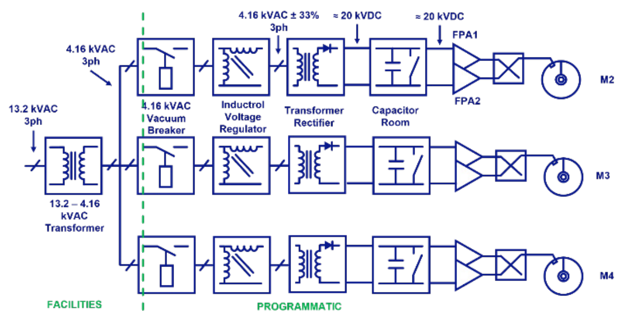

Figure 4: Block diagram of the power supply for DTL cavities 2-4.

Previous to their replacement, the amplifier vacuum tubes' operational life was the main reason for the linac downtime, to the point that the repetition rate of the DTL was lowered to 60 Hz until the replacement of Module 2 in 2014. In 2024, Module 2's Diacrode's reached 60,000 hours of operation.

PROPOSED MODIFICATIONS

Modern and recently upgraded ion linacs use a lower voltage direct current (DC) injection section followed by an RFQ that accelerates the beam into the DTL section. Installation of cavities as long as the current ones would not be feasible based on the tunnel's entry points, which is why the LAMP conceptual design is proposing the replacement of the DTL with six shorter cavities.

The proposed RFQ will require an RF source capable of delivering 1.8 MWpk of RF power, but due to the length of the structure and the estimated dimension of the RFQ walls, a single RF coupling loop would not be feasible. For that reason, the amplifier proposed consists of a solid-state amplifier capable of driving 72 kWpk into a single Diacrode® amplifier. The amplifier will provide power to a hybrid splitter that will then feed two separate smaller coaxial lines into the RFQ's coupling loops. Additional coupling loops may be necessary and may require modifications to the power feed structure. To prevent premature failure of the amplifier due to arcing and subsequent reflected power (caused in turn by transmission line or RFQ arcing), a circulator will be added after the amplifier. The entire amplifier chain is shown in Fig. 5.

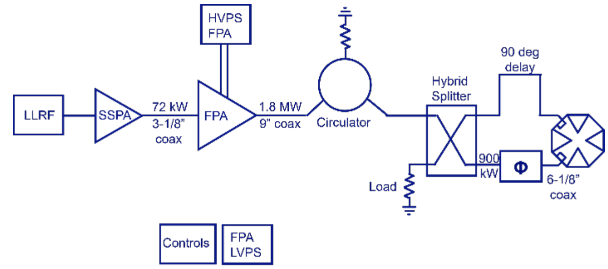

Figure 5: Block diagram with the proposed amplifier driving the new RFQ.

The proposed amplifier for the six DTL cavities is derived from separating the current dual amplifier, by installing a solid-state driver capable of producing 80 kWpk to feed a single Diacrode® amplifier which will in turn output 2 MWpk. In similar fashion to the current Module 1 amplifier and the proposed RFQ, to prevent premature failures due to arcing, a high-power circulator is proposed between the amplifier and the cavity. The amplifier chain is presented in Fig. 6.

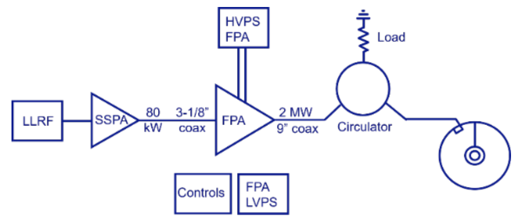

Figure 6: Block diagram with the proposed amplifier driving each of the new DTL cavities.

Since the driver requirements and circulator requirements for the RFQ and DTL amplifiers are similar, a single solid-state driver and high-power circulator are proposed for both types of systems (Fig. 7).

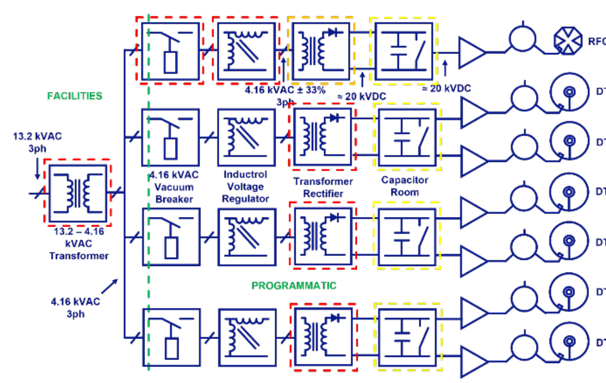

Figure 7: Block diagram with the proposed amplifier, vacuum breaker, IVR, TR for the RFQ and the DTL cavities. Red is used to mark components to be replaced, orange, components to be reused and yellow, components to be modified.

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HIGH VOLTAGE MODIFICATIONS

Some of the notable proposed changes are to the high-voltage AC/DC converter stage. Most of the converter components are placed outside the building in what is called the HV Pad which can be seen in Fig. 8.

Due to the increased requirements on the amplifiers, the capacitor banks will require the addition of parallel capacitors to deal with the excess droop. Currently Module 1's capacitor bank has 72.5 µF and Module 2-4 have an equivalent 216 µF. The required capacitance for the conceptual design's RFQ and DTL amplifiers is estimated to be 125 µF and 280 µF, respectively. Changes to the capacitor rooms include the installation of a new discharge crowbar device to deal with the increased energy stored and a higher heating due to a higher current through the resistance in series with the amplifier.

Voltage regulation is accomplished through Inductrol voltage regulators (IVRs). These devices are composed of three mechanically coupled rotor/stator sets that present a series and parallel magnetically coupled inductors and provide a brushless ±33% voltage regulation. The HV Pad (Fig. 8-10) has limited space available, so the preservation of the existing IVRs was considered optimal for the proposed solution.

Figure 8: Photograph of the High Voltage Pad or collection of 13.2-4.16 kVAC transformer, vacuum breakers, IVRs and TRs for all current DTL cavities.

Figure 9: Photograph of the Module 1 High Voltage Pad.

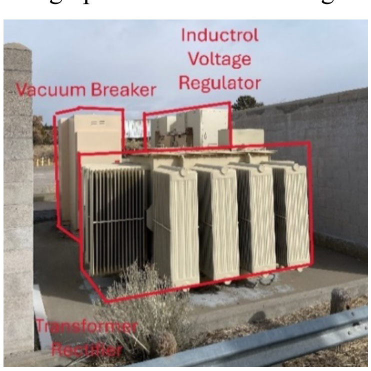

Figure 10: Photograph of the Module 2 High Voltage Pad.

It is estimated that the RFQ amplifier will require a TR capable of 18 A at a maximum voltage of 26 kVDC. Using one of the existing M2-M4 TRs is being considered as a cost saving alternative. This TR will require a small three-phase IVR capable of delivering 30 A. The existing vacuum breaker can handle the required voltage and current, but the mechanical structure will have to be modified due to the additional safety requirements associated with the 4.16 kVAC feed. The current M2-M3 TRs can deliver 35 A, but the proposed DTL amplifiers will require 40 A, which will require modifications or redesign of these units. With these modifications, the IVRs will stay intact, but since all modules will now need 4.16 kVA, the incoming transformer will need to be resized for the 4.1 MVA power consumption.

RF MODIFICATIONS

The entire amplifier now installed in Module 1 would be substituted to a modified version of the Diacrode® amplifier (Fig. 11) to provide RF power to the RFQ. In the case of the DTL amplifiers, the hybrid combiner and associated imbalance load would be replaced by dual circulators and waster loads. The existing 14" diameter coaxial line feeding the DTL cavities and their supporting structures would become two 9-3/16" diameter coaxial lines (Fig. 12) that would run parallel into the tunnel housing the accelerator. The control electronics will also require an upgrade to drive both amplifiers separately.

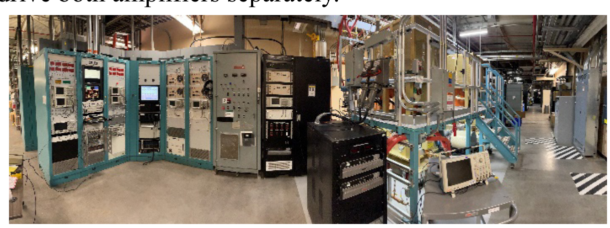

Figure 11: Panoramic view of the dual Diacrode amplifier now installed in M2-4.

Figure 12: 14" coaxial line into the accelerator tunnel feeding Module 2.

CONCLUSION

A cost-effective solution to the RF power needs of the conceptual LAMP upgrade is being developed rearranging and only occasionally replacing the recently upgraded amplifier systems to accommodate the new RFQ and DTL requirements. As the design of the cavities evolves, the LAMP project is developing the process to quickly respond to design changes that require small changes in the amplifier chain design.

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