EXPLORING COUPLED-CAVITY LINAC UPGRADE WITH DISTRIBUTED-DRIVE LINAC AT LANSCE[*]

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Abstract

The Distributed-Drive Linac (DDL) concept allows independent control of the radiofrequency (RF) power and phase of each accelerator cell, realized by an RF power system consisting of discrete solid-state amplifier (SSA) units. The DDL concept is under investigation at Los Alamos Neutron Science Center (LANSCE) as a candidate for the future upgrade of the 805-MHz Coupled-Cavity Linac. Independently adjustable RF power and phase of each DDL accelerator cell allows using the same DDL architecture to provide a much higher beam energy at the linac exit, such as 2–3 GeV, for proton radiography (pRad). The DDL architecture would require significant upgrade of the RF infrastructure at LANSCE, including implementing a great number of coaxial transmission lines for 3000–5000 individual DDL accelerator cells. For the pRad operation mode, compact RF pulse compressors are also under investigation.

FROM CCL TO DDL

The 805-MHz Coupled-Cavity Linac (CCL) at Los Alamos Neutron Science Center (LANSCE) has been in operation since 1972, when it was commissioned as part of the Los Alamos Meson Physics Facility (LAMPF). Today, the CCL accelerates negative hydrogen ion (H^-) beams from 100 MeV to 800 MeV over approximately 700 m [1]. The CCL comprises 44 linear modules, each draws 0.6–1.0 MW from one klystron capable of producing up to 1.25 MW peak power. Each CCL module contains several linear multi-cell tanks. In recent years, operation of the LANSCE CCL has become increasingly sensitive to the condition of the aging klystrons.

A team at LANSCE is investigating a new-concept linac architecture, the Distributed-Drive Linac (DDL), as one candidate option for upgrading the CCL. The 805-MHz DDL concept uses independently controlled radiofrequency (RF) power source for each accelerator cell, operating with adjustable power and phase. The RF source under consideration is a unit of solid-state amplifiers (SSAs) with combined power output. The DDL will be able to operate with continuously adjustable output beam energy without compromising the beam-RF synchronization; the DDL will be able to provide beams with kinetic energy beyond 800 MeV, should mission needs arise; in the event of a faulty RF source unit, advanced control algorithms can be used to adjust the RF amplitude and phase of neighboring cells to compensate for the missing acceleration in the affected cell. Meanwhile, the spare management of the RF sources is expected to be significantly less challenging, compared to that of CCL.

When the DDL is implemented to replace the CCL at LANSCE, it is envisioned that each of the 3000–5000 accelerator cells will be powered individually from RF sources located on the second level of the accelerator building, currently used as the klystron gallery. Individual RF power transmission can be accomplished using Electronic Industries Association (EIA) standard 1-5/8-inch coaxial transmission lines.

The work presented in this paper benefits from the synergy with the ongoing Solid-State Power Amplifier (SSPA) effort at LANSCE investigating a multi-stage solid-state RF amplifier architecture with combined RF power output as a potential replacement for a single CCL klystron station [2–5].

DDL CELL OPTIMIZATION

Each individual cell in the DDL operates with a variable transit time of the beam; the RF source for each cell adjusts the initial RF phase that the beam witnesses as it enters the cell to maximize the energy gain. In other words, the phase advance per cell in the DDL is no longer a constant. In comparison, the side-coupled CCL operates in the $\pi/2$ mode, with adjacent accelerating cells operating with a constant, π phase advance.

We are currently optimizing the DDL cell profile for its Tank 1. To optimize the DDL Tank 1 shunt impedance, we performed individual-cell profile optimization using a Multi-Objective Genetic Algorithm (MOGA) on the High-Performance Computing (HPC) clusters at Los Alamos National Laboratory (LANL) [6]. Figure 1 shows a comparison of MOGA-generated designs; Fig. 1a used the existing CCL Module 5 Tank 1 (M5T1, first CCL tank) cell length, with similar shunt impedance but approximately half the peak electric field, compared to the CCL M5T1 cell design; Fig. 1b shows one of the initial attempts applying the DDL concept, exploring using the gap of the re-entrant features to match to the beam transit time over half an RF cycle. The optimization of the cell profile for the DDL concept is underway.

DDL BEAM DYNAMICS

We are currently performing DDL beam simulations to maximize the energy gain of the input, 100-MeV H^- beam through the DDL Tank 1, which has identical length to that of the CCL M5T1 [7]. The optimization takes care of Twiss

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[*] Work supported by U.S. Department of Energy through the Laboratory Directed Research and Development program of Los Alamos National Laboratory, under project number 20260114ER.

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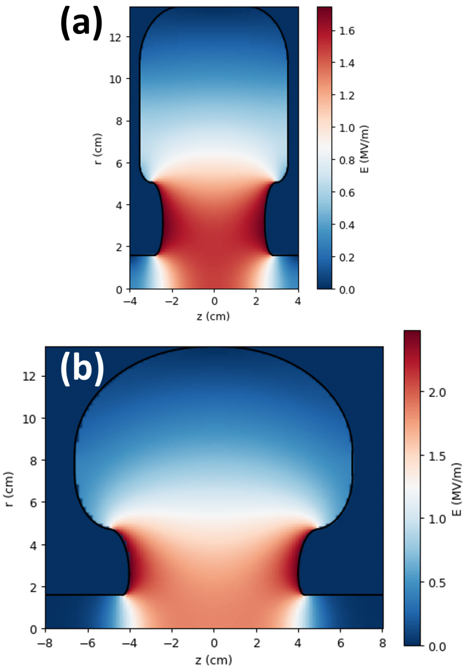

Figure 1: Cell profiles generated by the MOGA framework for (a) π-mode linac and (b) DDL-concept linac.

parameter matching and emittance growth management. The beam emittances at 100 MeV at DDL entrance referred to the results of the LANSCE Accelerator Modernization Project (LAMP) [8, 9].

Beam dynamics design will be carried out iteratively in conjunction with optimization of the DDL cell profiles across the entire DDL. The beamline will be optimized to produce a nominal output beam energy of 800 MeV. Based on this nominal design, the upper limit of the achievable beam energy will be explored by adjusting the RF power and phase of individual cells, taking into account reasonably achievable peak surface electric field in the DDL cells.

TWO-CELL DEMONSTRATION

We are planning a demonstration using a two-cell DDL cavity at 805 MHz with independent RF control for each cell. The two cells will have an identical design, and the individual cell design adopted the aforementioned optimized profile with the cell length equal to that of the CCL M5T1. The progress of the RF cavity design is provided in Fig. 2. The RF power is critically coupled through a WR1150-port taper. Opposite to the coupler, a coaxial transmission line RF probe is applied for measuring the field strength and phase in the cell.

Special design considerations included blending the coupling slot edges, the longitudinal location of the RF probe, its insertion depth into the cell, and design as well as tuning range of tuners. As addressed in the next section, the intended maximum peak RF power is 29 kW; the probe was designed with a transmission of −45 dB to allow around 1-W peak probe power.

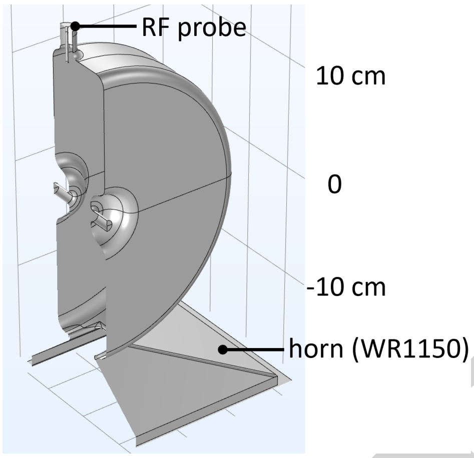

Figure 2: Test cavity RF design progress.

We are meanwhile investigating applying an alternative, lower-cost RF coupling scheme using commercial off the shelf (COTS) RF feedthrough, as invented at Arizona State University. This RF coupling design is currently under invention disclosure and therefore not addressed in this paper.

SSA RF SYSTEM

The SSA-based RF system provides power individually to the two DDL cells in the test cavity, with a maximum peak power of 29 kW per cell. Low-power RF is generated by a synthesizer, amplified by a pre-amplifier (stage one) and then split in half, with one split including a phase shifter. Each half of the split power is pre-amplified again (stage two) and further divided to eight equal portions by an eight-way RF divider, respectively. Each eighth of the split power is amplified by one SSA unit individually, then combined by an eight-way combiner. Each DDL cell is powered by the RF output from one combiner, respectively.

The project team is actively procuring RF components for the system. Each SSA test pallet will use one RF circulator with the associated load; a circulator with a load will be used at the output of the combiner as well. A bi-directional coupler will be used to monitor the forward and reflected power for the two cells, respectively.

The fundamental element of the SSA-based RF system will be the individual SSA test pallets. Each pallet incorporates a high-electron-mobility transistor (HEMT) based on gallium nitride (GaN) on silicon carbide (SiC) technology, capable of providing a saturated amplification of 15–17 dB [5]. We will use the Ultra High Frequency (UHF) test pallets manufactured by Integra Technologies [4], each capable of producing a pulsed peak power of 3.6 kW, as shown in Fig. 3, a setup in the SSPA Laboratory at LANSCE.

The gate (G), source (S), and drain (D) connections for one test pallet is also shown in Fig. 3. A pulsed control signal is applied to the gate-source electrodes simultaneous with the matched RF input power input. A capacitor bank is placed in parallel with the drain-source electrodes to limit the voltage droop to the nominally 100 V of drain voltage

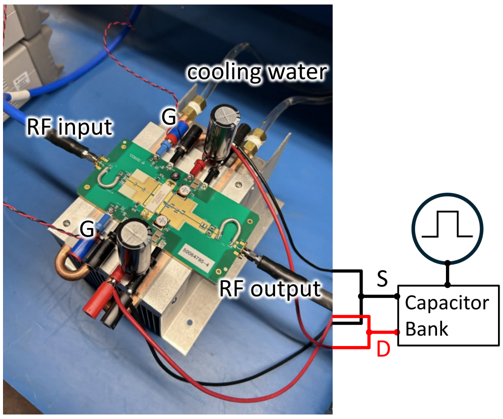

Figure 3: Integra Technologies test board measurement setup.

and maintain the amplifier operating within specified limits during the RF pulse. The nominal operating pulse length is 100 µs. The capacitor bank was prototyped by the SSPA team, and a picture of the internal assembly is provided in Fig. 4. The capacitor bank consists of twenty 5-mF aluminum electrolytic capacitors (0.1-F total capacitance, 500-J total stored energy); each discharge will consume about 1 % of the stored energy. We will operate the experiment with very low duty.

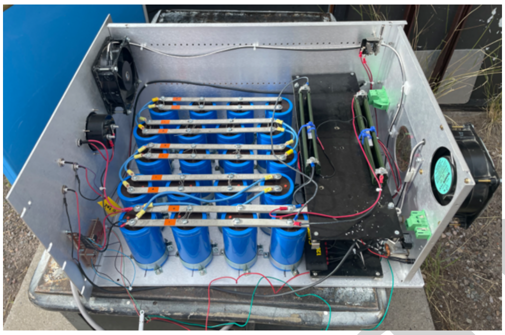

Figure 4: Inside view of the prototype capacitor bank.

CONCLUSIONS

The Distributed-Drive Linac (DDL) concept is under investigation as a candidate option for upgrading the LANSCE Coupled-Cavity Linac (CCL). The DDL, powered by individual RF source units for each of its cells, will present operational flexibility and reasonable fault tolerance, enabling continuously adjustable beam energy, while ensuring robust spare management of the RF source components.

A Multi-Objective Genetic Algorithm framework for optimizing RF accelerator cell profiles was established and implemented to generate DDL designs for beam dynamics simulations. Ongoing work focuses on the first tank of the DDL, exploring optimal operating conditions taking into account maximizing energy gain, balanced by control of beam emittance growth.

A demonstration of individual RF control of DDL cells is under preparation, involving a two-cell DDL cavity and a pulsed, solid-state-amplifier-based RF power system.

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