# STATUS OF THE RFI LINAC PROTOTYPE*

D.A. Swenson and W.J. Starling, Linac Systems, Albuquerque, NM 87109, USA

*Abstract*

A prototype of the Rf Focused Interdigital (RFI) linac structure is currently under construction at Linac Systems. The RFI linac structure is basically an interdigital (or Wideröe) linac structure with rf quadrupole focusing incorporated into each drift tube. The 200-MHz RFI Prototype, consisting of a short RFQ linac followed by a short RFI linac, will accelerate a 20-mA beam of protons from an injection energy of 25 keV to an output energy of 2.50 MeV in a total linac structure length of 1.44 meters. The linac structures are designed for continuous (cw) operation, and will be tested initially at a 33% duty factor. The peak structure power of 66 kW and peak beam power of 50 kW will be supplied by a 144-kW, 33% duty rf power system. A microwave ion source will supply the proton beam and an articulated Einzel lens will steer and focus the beam into the RFQ aperture. The mechanical design of the linac structures will be presented, the calculated performance will be described, the status of the components will be reported. The prototype is scheduled to come into operation in the fall of this year.

## THE RFI PROTOTYPE

The Rf Focused Interdigital (RFI) linac structure[1,2] represents an effective combination of the Wideröe (or interdigital) linac structure, used for many low frequency, heavy ion applications, and the rf electric quadrupole focusing used in the Radio Frequency Quadrupole (RFQ) and Rf-Focused Drift tube (RFD) linac structures[3,4]. As in the RFD linac structure, rf focusing is introduced into the RFI linac structure by configuring the drift tubes as two independent pieces operating at different electrical potentials as determined by the rf fields of the linac structure. Each piece (or electrode) of the RFI drift tube supports two fingers pointed inwards towards the opposite end of the drift tube forming a four-finger geometry that produces an rf quadrupole field along the axis of the linac for focusing the beam.

The RFI linac structure is two-to-six times more efficient and three times smaller in diameter than the conventional Drift Tube Linac (DTL) structure in the energy range from 0.75 to 12 MeV. It is ten times more efficient than the RFQ linac structure in the 0.75 to 6 MeV range. This high efficiency reduces the rf power dissipation in the rf structures and the problems associated with cooling them, thereby promoting the prospect for cw operation, which in turn, allows large increases in the average beam currents. This linac structure promises to have significant size, efficiency, performance, and cost advantages over existing linac structures for the acceleration of low energy ion beams of all masses (light to heavy).

An operating prototype of the RFI linac structure, shown in Fig. 1, is under construction at Linac Systems. The RFI Prototype will be designed for an output energy of 2.5 MeV and an output current of 20 mA. It is designed for both pulsed and cw operation. This prototype will serve to verify the performance of the RFI linac structure and demonstrate its capabilities.

The RFI Prototype consists of a microwave ECR ion source, a low energy beam transport (LEBT) system, an RFQ linac section, an RFI linac section, a short beam diagnostics section, an rf power system, a vacuum system, a cooling system, and a computer control system.

## ION SOURCE

A 2.45-GHz Microwave Ion Source, similar to the IUCF Ion Source[5], a lower current derivative of the LEDA Ion Source[6], is under construction[7] for the RFI Prototype. The source is designed for a peak proton current of 30 mA at 25 keV, and can be operated in either a continuous (cw) mode or a pulsed mode, with pulse lengths adjustable from 10 to 100 μs and repetition rates adjustable from 10 to 3000 Hz. The magnetic field is supplied by two water-cooled 15,000 A-turn solenoid magnets. The microwave power is adjustable up to 800 W and is capable of cw or pulsed operation.

The performance of the source was analyzed and optimized to the desired parameters with the PBGUNS

Figure 1: The 2.5 MeV, 20 mA RFI Prototype.

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code. The extraction geometry consists of four elements, namely a plasma electrode, a puller electrode, an electron suppressor electrode, and a final ground electrode. The extraction aperture is 7 mm in diameter and all four electrodes are conical with a cone angle of 56 degrees from the axis. A steel flange is mounted close to the source exit to limit the extent of the magnetic field along the beam path.

## LEBT

The LEBT is based on a single articulated Einzel lens. The total distance from the ion source extraction aperture to the RFQ entrance aperture is 24.2 cm. The length and aperture of the Einzel lens electrode are 6.3 cm and 6.6 cm respectively. This electrode is centered about two thirds of the way from the ion source aperture to the RFQ aperture and mounted on a 3-axis stage controllable manually through the side of the LEBT vacuum tank. The range of motion is ±5 mm in the two transverse directions and ±20 mm in the longitudinal direction. The transverse motions will be used to steer the beam into the RFQ aperture. The lens voltage and longitudinal motion will be used to optimize the capture of the beam by the RFQ linac.

The 3D beam dynamics code, SCALA[8], and the 2D beam dynamics code, AXCEL, were used to analyze and optimize the performance of the LEBT. Both codes gave similar results, where the beam reaches a diameter of about 5 cm inside the Einzel lens. This arrangement suggests the capture and transmission of about 84% of the 30-mA beam from the ion source through the RFQ linac.

## RFQ LINAC

The RFQ linac for the RFI Prototype is of the four-bar type. It will capture and bunch the ion beams from the ion source and accelerate them to a suitable energy for acceptance by the RFI linac. Because of the exceptional low-energy capabilities of the RFI linac structure, the RFQ linac section need only accelerate the beam to an energy of 0.75 MeV.

We have chosen to employ a radial strut design, where the individual bars are supported by radial struts emanating from the walls of the cavity with four-pole symmetry. The RFQ linac structure is mounted inside a vacuum tank that provides the high-vacuum conditions required by the beam, the rf power, and the linac structure. The RFQ vacuum tank is pumped by a 400 l/s turbomolecular vacuum pump and typically operates in the $5\times10^{-7}$ Torr range.

The bore radius is 3.6 mm. The rf cavity inner diameter is 256 mm and a strut spacing of 160 mm results in a resonant frequency of 200 MHz. The rf dipole mode for this configuration is several MHz above the quadrupole mode and does not present a problem with rf field stability.

The rf efficiency of the RFQ is expressed in terms of a transverse shunt impedance, $Z_{TR}$ (MΩ-m), defined as $V^2/P_L$, where V is the bar-to-bar voltage and $P_L$ is the rf power per unit length in the structure. The shunt impedance of the radial strut design is 0.12 MΩ/m, about twice the value of conventional four-bar RFQs.

## RFI LINAC

The RFI linac section is designed to operate at 200 MHz and accelerate the beam from 0.75 MeV to 2.5 MeV. It is 0.54 m long and involves 13 unit cells, ranging in length from 3.1 to 5.4 cm in length. In general, the inner radii of the cells must increase with energy to maintain resonance. However, the tank termination scheme requires the radii of the first two and last two cells of a tank to be increased to achieve a flat field distribution in the vicinity of the tank terminations.

The two-part drift tubes of the RFI structure comprise a minor piece (upstream) supported on a minor stem and a major piece (downstream) supported on a major stem, each with two fingers that form a four-finger geometry, which when excited with rf energy produces an rf quadrupole field along the axis for focusing the beam. In order to excite the four-finger geometries, it is necessary to couple to some of the longitudinal rf magnetic fields in the structure. This requires the minor stems be offset to one or both sides of the major stems. For symmetry and mechanical rigidity, we choose a minor stem geometry that extends symmetrically on both sides of the major stem.

We have adopted a radial stem approach, where the minor stems are essentially radial members extending from the tank wall, and offer unlimited coupling (from 0% to nearly 100% of the cell voltage) to the magnetic fields of the structure. We have adopted what we call the "Stacked Cell" approach, shown in Fig. 2, where the basic unit of the structure is a single cell, complete with a two-piece drift tube, supported by major and minor stems in a short section of the outer wall. The linac structure is assembled by stacking up a sequence of these cells, each with the proper dimensions. The stack is held together by tie-bolts running along the structure or by welding the cells together into a single unit as shown also in Fig. 2. The 13 unit cells for the RFI Prototype are nearing completion.

## RF POWER SYSTEM

The peak rf power requirement for the 2.5-MeV, 20-mA RFI Prototype is 122 kW. The rf power system, currently under construction[7], will be capable of producing a pulsed output of 192 kW at 25% duty, a pulsed output of 144 kW at 33% duty, or a cw output of 48 kW. This will allow testing of both the RFQ and RFI linac sections, independently, at full power and duty without beam, and running the combination, complete with 50 kW of beam, at a 33% duty cycle.

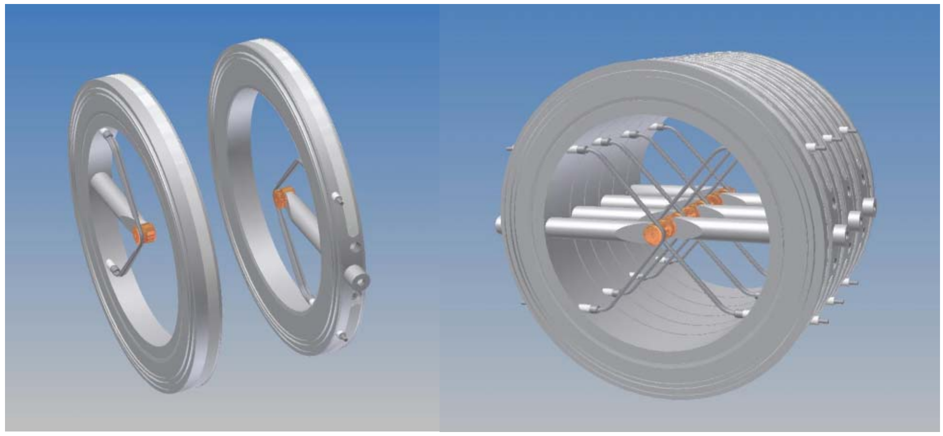

Figure 2: The "Stacked Cell" Approach to RFI Linac Fabrication.

The final power amplifier (FPA) for this system is based on the same parallel planar triode concept used in the rf power system for our previous prototype of the RFD linac structure at 600 MHz. This time we will use GB-35B planar triodes, which are rated for operation as high as 1000 MHz and have an anode power rating of 2.5 kW in water-cooled operation. The basic configuration involves a total of 24 tubes, in two 12-tube arrays, in a push-pull configuration, driving a double-ended output cavity. The tubes in each array are attached to separate heat sinks in each end of the double-ended output cavity.

The intermediate power amplifiers (IPAs) will use the same GB-35B tubes. The first unit (IPA1) uses a single tube. Its output will be split two ways to drive two additional intermediate power amplifiers (IPA2). Each two-tube IPA2 amplifier will drive one ring of 12 tubes in the FPA. A phase shifter in one of the IPA2 inputs will provide the 180° phase shift required for push/pull operation.

The IPA2 and FPA tubes will operate at 4 kV for cw operation and at 8 kV for pulsed operation. The dc power supply will be configured as a multiplicity of 1 kV units, each with an insulated gate bipolar transistor (IGBT) series switch. The 1-kV units will be series connected as two 4-kV supplies for 48 kW cw or pulsed operation, or series connected as one 8-kV supply for 144 kW pulsed operation. The IGBT switches will eliminate the need for crowbar switches to protect the equipment. In the event of a load fault, current sensing circuitry in the IGBT control logic will turn off the IGBT switches so rapidly that the peak rating of the devices are not exceeded.

## COOLED FOR CW OPERATION

The RFQ and RFI linac structures are designed for CW operation. In this mode, the total rf power dissipation in the RFQ is 40 kW and the total rf power dissipation in the RFI is 26 kW. Both structures are cooled by a large number of parallel cooling circuits. The total coolant flow through each structure is independently controlled by a throttle valve.

The RFQ consists of a cylindrical rf cavity and four bar assemblies, each supported on five struts. Thirty percent of the power (12 kW) is dissipated on the cylindrical body of the structure, while the remaining power is dissipated on the four bar/strut assemblies (7 kW per bar/strut assembly). There are 8 cooling channels bored through the length of the cylindrical body. The average power associated with each of these cooling channels is 1.5 kW. There are 5 cooling circuits in each bar/strut assembly. The average power associated with each of these cooling circuits is 1.4 kW.

The RFI consists of 13 unit cells, each with three separate cooling circuits, namely the cell wall, the major stem/drift tube assembly, and the minor stem/drift tube assembly. Fifty-four percent of the power is dissipated on the cell walls for an average of 1.2 kW per unit cell wall, forty-two percent of the power is dissipated on the major stem/drift tube assembly for an average of 0.9 kW per major stem assembly, and four percent of the power is dissipated on the minor stem/drift tube assembly for an average of 0.1 kW per minor stem assembly.

A pressure of 4.4 psi across the RFQ cooling manifold will push 44 GPM of water through the 28 parallel cooling circuits of the RFQ for a temperature rise of about 2.5 C. A pressure of 1.6 psi across the RFI cooling manifold will push 53 GPM of water through the 39 parallel cooling circuits of the RFI for a temperature rise of about 2.0 C.

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