

## PROTOTYPE OF THE RFD LINAC STRUCTURE\*

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### Abstract

A 2.5-MeV prototype of a "Compact 12-MeV Proton Linac for PET Isotope Production" is under construction at Linac Systems. This unit will serve as the "proof of principle" for the revolutionary new Rf Focused Drift tube (RFD) linac structure. Both the prototype and the production unit will operate at 600 MHz. The prototype comprises a 25-keV proton ion source, a short LEBT, a 0.65-m-long RFQ linac to 0.8 MeV, and a 0.35-m-long RFD linac to 2.5 MeV. Because of the similarity of the accelerating and focusing properties of the RFQ and RFD linac structures, no matching section is required between them. The two linac structures will be resonantly coupled together and powered by a collection of planar triodes. The prototype is scheduled for completion in the fall of 1997.

### Introduction

The RFD Linac Structure<sup>[1-5]</sup> resembles a drift tube linac (DTL) with radio frequency quadrupole (RFQ) focusing incorporated into each "drift tube". As in conventional DTLs, these drift tubes are supported on single stems along the axis of cylindrical cavities excited in the  $TM_{010}$  rf cavity mode. The RFD drift tubes comprise two separate electrodes, operating at different electrical potentials as determined by the rf fields in the cavity, each supporting two fingers pointing inwards towards the opposite end of the drift tube forming a four-finger geometry that produces an rf quadrupole field distribution along the axis. The fundamental periodicity of this structure is equal to the "particle wavelength",  $\beta\lambda$ . The particles, traveling along the axis, traverse two distinct regions, namely gaps between drift tubes where the acceleration takes place, and regions inside the drift tubes where the rf quadrupole focusing takes place.

Most proton and light-ion linac systems start with an RFQ linac section to capture the beam from the ion source and to bunch it for acceleration in more efficient linac structures. The RFD linac structure provides a graceful way to accelerate the small diameter, tightly bunched beams that come from RFQ linacs to higher energies. Because of its rf electric focusing, the RFD linac structure operates well at much lower energies than the conventional magnetically focused DTL linac. Consequently, the transition energy between the RFQ linac, required to capture the unbunched beam from the injector, and the RFD linac can be in the range of 0.5 to 1 MeV, significantly lower than for conventional RFQ/DTL combinations.

### The Prototype

The "Proof-of-Principle" prototype, under construction at Linac Systems, involves acceleration of a 25-keV proton beam from the ion source to 0.8 MeV in a 0.65-m-long RFQ linac and on to 2.5 MeV in a 0.35-m-long RFD linac structure. The experimental setup, made possible by an SBIR Grant from the National Institute of Mental Health, is shown in Fig. 1. At this relatively low transition energy, the acceleration and focal properties of the RFQ are very close to that of the RFD. Consequently, little or no matching is required between the structures. The RFQ structure can be bolted directly to the RFD structure and resonantly coupled to it. The extreme simplicity of the interface between the two structures contributes to the practicality of this operational test on a limited budget. The entire length of the two linacs, including their interface, is only one meter. We believe that this new structure will become the structure of choice to follow RFQ linacs in many applications.

The ion source and LEBT system can be of conventional design. The ion source will be a simple duoplasmatron of the type used in the PIGMI program at Los Alamos in the late '70s. This design is readily available in the public domain. The LEBT will consist of a drift space to let the beam expand followed by one or two einzel lenses for focusing the beam into the aperture of the RFQ linac. A current toroid at the entrance to the RFQ will provide a measure of the beam current at that point. An ultra-thin vacuum valve will provide vacuum isolation between the LEBT and RFQ regions.

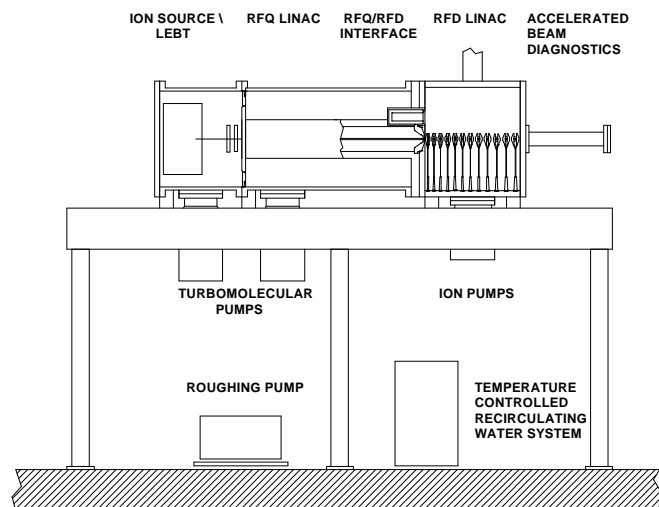


Fig. 1. The "Proof-of-Principle" Prototype.

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Because of the exceptional low-energy capabilities of the RFD structure, the RFQ linac need only go to 0.8 MeV. The cross section of this 0.65-m-long RFQ structure is shown in Fig. 2. The width of the assembly is only 0.16 meters. It will be built out of tellurium copper in four pieces as shown in the figure. The cooling channels will be gun drilled. The vane tips will be contoured by a “v-shaped” die in a die-sinker type of EDM machine. The four pieces will be pinned and bolted together (copper bolts), and hydrogen furnace brazed together, using the wire alloy technique tested recently by LANL. It will also be brazed to its stainless steel mounting flange at the same time. As the RFQ is surrounded by an aluminum vacuum jacket, these brazes and penetrations (monitor loops, coupling slots, etc.) need not be vacuum tight.

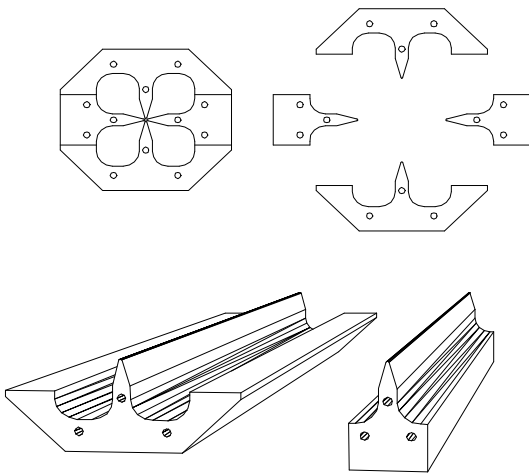


Fig. 2. Components of the RFQ Assembly.

Enclosing the RFQ structure inside of a vacuum jacket simplifies some facets of the design and complicates others. Special provisions have to be made for electrical and cooling services and their connections. The cooling water will come in and out through the bottom edge of the RFQ mounting flange and be routed to supply and return manifolds running the length of the RFQ inside the vacuum jacket. The electrical connections (monitor loops, thermal couples, etc.) will terminate on a panel that seals to a window frame in the vacuum jacket that is on the back side of the RFQ.

The RFQ/RFD interface is extremely simple. The RFQ structure will be bolted directly to the RFD structure. There will be no provision for beam manipulation (steering), beam diagnostics, or vacuum isolation at this interface.

A resonant coupler, designed to couple the excitation of the two linac structures together by locking their fields in phase and amplitude, will be employed. This resonant coupler will extract precisely the right amount of rf power from the RFD structure to excite the RFQ structure. Such couplers operate in the  $\pi/2$  rf cavity mode and are well understood. They have been employed in many standing-

wave linac applications since the discovery of their potential by researchers at Los Alamos in the mid '60s.

The RFD linac structure will be relatively short (0.35 m) as it need only go to 2.5 MeV. The linac tank, consisting of a thick-walled (22-mm) aluminum tube with a rectangular bar of aluminum welded to one side, represents the principal structural element of the linac. The linac tank for this prototype is 0.38 meters in diameter and weighs 42 kg. The tank is copper plated on the inside and anodized on the outside.

The average rf power dissipation in the structure is 3 kW, approximately 2 kW of which are dissipated in the tank wall. The cooling channels are gun drilled in the tank wall. Provisions are made at the ends of the tank to put some of these channels in series. All water connections to the tank will be near the bottom of the structure.

The tank will be oriented with the welded bar at the bottom. The purpose of the welded bar is to provide a thicker wall on which to mount the drift tubes. After all the tank welds are finished and it has been heat treated, the mounting holes for the drift tubes will be precision bored through the thickened tank wall. These holes represent “hard sockets” for the drift-tube stems. No provision will be made for further alignment of the drift tubes. This, of course, requires that the drift tubes be built with adequate precision to achieve the required alignment.

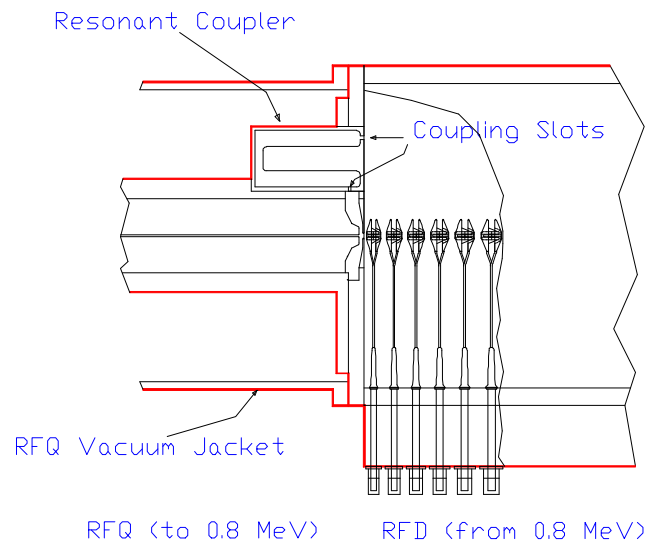


Fig. 3 The RFQ/RFD Interface Region with Resonant Coupler.

To achieve the required precision in the drift-tube fabrication, the drift tubes will be built in two stages, each ending with a hydrogen furnace braze. In the first stage, the stainless steel stem base will be joined to the stainless steel tubing of the inductive stem, a stem-stiffening frame, and a copper annulus that forms the central portion of the drift-tube body.

After this assembly is furnace brazed, the stainless steel parts are copper plated and the stem base is precision ground to its final length and diameter. In the second stage, the precision-ground portion of the stem base is held in a precision jig, coolant is circulated through the drift tube body, and a precision seat is machined into the copper annulus by the die-sinker EDM process. Then precision end caps (different for each drift tube) are positioned in these precision seats and the final assembly is furnace brazed together.

The finished drift tube assemblies are inserted into their hard sockets from the inside of the tank. This requires that the completed drift tube assembly be somewhat shorter than the inner tank diameter. We insist on being able to remove and reinstall any drift tube without disturbing its neighbors. The principal drift-tube-stem vacuum seal is a proprietary copper seal. A secondary elastomer seal on each stem provides for vacuum-checking convenience and a backup vacuum capability.

Approximately 1 kW of rf power is dissipated in the 12 drift tubes of the structure, implying an average of 80 W/drift tube. They will all be cooled, in parallel, from supply and return headers running along the top of the support cabinet below the linac.

The 600-MHz rf power system for the proof-of-principle test must have a peak rf power output of 250 kW with an average value of 3 kW. This kind of power can be obtained from a collection of 6-to-8 Eimac Planar Triodes (YU-141). One of the authors (JMP) has extensive experience in this field and has conceived of a new geometrical configuration to facilitate this combination. We expect JP Accelerator Works, Inc. to supply the rf power system for this test.

The vacuum system for the proof-of-principle test will consist of one turbo pump on the ion source/LEBT, one turbo pump on the RFQ linac structure, one ion pump on the RFD linac structure, and one roughing pump shared by all systems through a set of valves. We will strive for metal seals where they are convenient or where they involve critical components that are hard to replace (drift tubes, for example). We will accept elastomer seals on some of the large joints between tank sections and end plates.

The cooling system for the proof-of-principle test will be a recirculating system, based on a single commercial unit with a temperature control capability of  $\pm 1^\circ\text{C}$  and a capacity of 3 kW. Some deionized cooling capacity will be needed for the high voltage parts of the rf power system. An additional 5 kW of cooling, without sophisticated temperature control, will suffice for the rest of the system.

The control system for the proof-of-principle prototype will be PC-based. It will utilize commercially available control and equipment oriented software. Its principle function will be to support important personnel safety and equipment protection functions, some beam diagnostic measurements, and some data-logging functions to assist in accident reconstruction. The control of most accelerator parameters will be accomplished manually in the course of developing the required controls procedures.

The beam diagnostics for the proof-of-principle test will be based on beam transmission measurements (current monitors), beam profile measurements (wire scanners), beam loading measurements (rf power monitor), and energy discrimination measurements (absorber foil).

### Potential RFD Applications

We expect the RFD linac structure to form the basis of a new family of compact, economical, and reliable linac systems serving a whole host of scientific, medical, and industrial applications. The principal medical applications include the production of short-lived radio-isotopes for the positron-based diagnostic procedures (PET and SPECT), the production of epithermal neutron beams for BNCT, and accelerated proton beams for injection into proton synchrotrons to produce the energies required for proton therapy. S-Band versions of the structure might prove economical enough to serve as 70-MeV injectors to 250-MeV coupled cavity linacs (CCL) for the proton therapy application.

The principal industrial and military applications include the production of intense thermal neutron beams for Thermal Neutron Analysis (TNA), Thermal Neutron Radiography (TNR), and Nondestructive Testing (NDT). High duty factor RFD linac systems could produce nanosecond bursts of fast neutrons to support Pulsed Fast Neutron Analysis (PFNA).

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