STATUS OF THE RFD LINAC PROTOTYPE*

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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, an einzel-lens-based LEBT, a 0.65-m-long RFQ linac to 0.8 MeV, and a 0.35-m-long RFD linac to 2.5 MeV. The two linac structures will be resonantly coupled together and powered by a collection of planar triodes. The entire assembly will be evacuated by 2 turbomolecular pumps and 1 ion pump. The alignment philosophy is based on precision machining and "hard socket" for installation of the drift tubes. Fabrication methods for achieving the required precision will be described. Installation of a Laboratory Building to house the prototype is nearing completion. The prototype is scheduled for completion in the fall of 1997. The status of this project after 7 months of funded activity will be reported.

1 INTRODUCTION

The RFD linac structure[1-5] 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", βλ. 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.

2 RFD DRIFT TUBE GEOMETRIES

The drift tube body and stem geometries, which are so fundamental to the RFD linac structure, continue to evolve. The transverse quadrupole fields, which produce the quadrupole focusing, are now pretty much isolated from the longitudinal gap fields by the drift tube bodies. That is, the four fingers, which produce the rf quadrupole fields, are now compleely enclosed within the bodies of the drift tubes, instead of being exposed to the gap fields as they were in previous designs. The stems that support the two halves of the drift tube must do so without shorting out the rf excitation of these electrodes. Now, instead of using the inductance of the stems to isolate the two halves of the drift tube, we plan to use the coupling of the stem geometry to the magnetic fields of the linac to provide an rf excitation equal to that derived from the coupling of the drift tube bodies to the electric fields of the linac.

We are designing for a drift tube diameter of 36 mm, a gap length (G) to cell length (L) ratio of 0.25, a quad length (Q) to cell length ratio of 0.5, and a bore hole radius of 1.5 mm. The energy range for the POP prototype is 0.8 to 2.5 MeV. The cell lengths, at 600 MHz, range from 21 mm to 36 mm. The cross section of the drift tubes for cell lengths of 22, 26, 30 and 34 mm are shown in Fig. 1. The upper half of the cross section shows the horizontal plane of a horizontally focusing quadrupole and the lower half of the cross section shows the vertical plane of the same quadrupole.

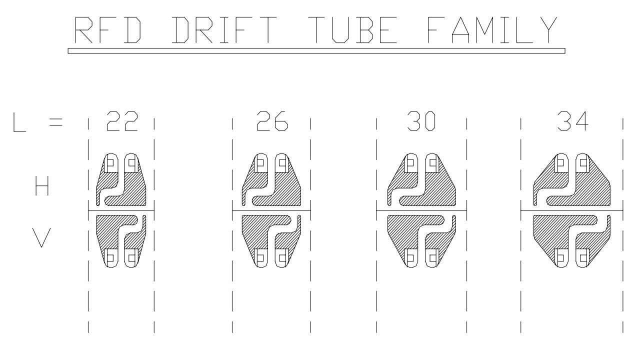

Figure 1: Cross Sections of RFD Drift Tubes.

The goal is for the RFD lens excitation derived from the capacitive coupling of the drift tube bodies to the electric fields of the linac mode to be equal to that derived from the inductive coupling of the drift tube stems to the magnetic fields of the linac mode. The latter is evaluated from SUPERFISH field information with the aid of the CHARGE-2D program. The former is evaluated with the aid of the CHARGE-3D program.

The desired lens excitation is determined by the beam dynamics. A constant voltage across the lens, independent of cell length, results in a constant phase advance per unit cell, which results in a constant beam diameter throughout the linac. A constant lens voltage

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implies a declining ratio of lens voltage to cell voltage as the cell length (and voltage) increases. We are designing for a lens voltage of 40.5 kV, which corresponds to a V_L/V_C ratio that ranges from 0.23 to 0.15 over the length of the POP prototype.

3 RFD BEAM DYNAMICS

We have decided to terminate RFD linac tanks at a mid-gap location. That is, the end cells are what we would call "half cells". This obviates the need to design special RFD lenses that would function properly on the end walls. We have recently modified the RFD linac beam dynamics program, PARMIR, to accommodate that decision.

The acceleration and focal properties of these end cells can be determined from the electric field distribution along the axis of the cell and adjacent beam pipe. SUPERFISH calculations reveal that these fields reach their maximum intensity near the center of the "half gap" and that the tails of the distribution lack the symmetry of normal linac cells. This lack of symmetry poses the question of where best to apply the transverse and longitudinal "kicks" to simulate the action of these fields on the beam. We have decided to adopt the point about which the S integral vanishes as the effective center of the cell, leaving us with the normal linac energy gain expression, where the T, TP, and SP integrals are evaluated about this same point.

SUPERFISH runs are made for half-cell/bore-tube geometries corresponding to energies where tank ends are expected to occur. The locations of the effective centers of these cells are determined and the T, TP, S and SP factors are evaluated about these effective centers. The value of E_0 is independent of the choice of origin over which it is integrated and will be the same as that of its neighboring full cell. As the effective gap of the half cell is smaller than that of a normal "full cell", the transit time factor (T), will be higher than that of the neighboring full cell. These data are extracted from a series of SUPERFISH runs and the result are presented to the beam dynamics code, PARMIR, in tabular form as a function of the particle velocity, β. When PARMIR encounters the need to generate an end cell of a tank, it interpolates the data in this table to the β of the end cell to get the data needed for generating the half cell.

4 RF CAVITY FIELD CALCULATIONS

For a complete analysis of the RFD linac structure, some 3D rf calculations are needed. Outside the drift tubes of the RFD linac structure, the geometry and fields are axisymmetric; inside the drift tubes, the geometry and fields are highly three-dimensional. Although the three-dimensional portion of the problem occupies less than 1% of the total cavity volume, the fields in this region represent a majority of the fields that the particles see. The effect of this region on the resonant frequency of the structure is important. The rf efficiency of the structure depends, to some extent, on the power dissipation in this region of the structure. The design of the drift tube cooling circuit requires some knowledge of the distribution of the power losses in this region. The allowable excitation will be limited by the electric field intensities on the surfaces of this region.

The common 3D rf codes are MAFIA, ARGUS, HFSS, and SOPRANO. To date, calculations of the field distributions and power losses in the RFD linac structure have been made with MAFIA, HFSS, and SOPRANO. All calculations confirm that the structure performs as expected. SOPRANO[REF] has an enormous advantage over MAFIA in that it can have a fine mesh in one portion of the problem volume, surrounded by a coarse mesh for the rest of the problem volume. Vector Fields has produced a sample calculation of this geometry for us.

5 RFD DRIFT TUBE BODY AND STEM DESIGN

The RFD drift tube body and stem design comprises two half-body electrodes, with a total of four fingers to create the rf quadrupole field along the axis, supported on two water-cooled support blades that emanate from a single stem that mounts in a single hole through the linac tank wall.

The stem/blade assembly will be a 4-layer stainless steel sandwich requiring two hydrogen-furnace braze cycles for completion. In the first braze cycle, two halves of the blades will be joined together to form a support blade complete with a machined cooling channel. In the second braze cycle, two blade assemblies will be brazed together to form a complete stem/blade assembly with connections to the parallel blade cooling channels. The stem portion of this assembly will be machined to a circular cross section and precision ground to a cylindrical surface for installation into a reamed hole in the tank wall. The stem and hole will be keyed to control the angular orientation of the drift tube. At this point, portions of the stem/blade assembly will be copper plated.

To achieve the required precision in the location of the body halves relative to the stem base, the stem/blade base will be held in a precision jig, coolant will be circulated through the stem/blade assembly, and the inner surface of the circular annuli at the end of the blades will be cut by the wire EDM process to form a precision seat for the body halves, accurately located relative to the precision ground cylindrical surface of the stem base.

The body electrodes are made from oxygen-free copper. The body electrodes for each drift tube will be different to accommodate the changing velocity of the accelerated particles, whereas the two halves of each drift tube will be identical. The drift tube half-bodies will be joined to the stem/blade assembly by a third hydrogen-furnace braze cycle. A trial run at the fabrication of several drift tubes is underway.

6 RFD LINAC TANK DESIGN

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 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 is made for further alignment of the drift tubes.

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.

7 ION SOURCE

The ion source will be a scaled-down version of an early LAMPF duoplasmatron. Some attempts to scale this source to smaller sizes have suffered from magnetic field saturation problems and duty factor limitations. Improvements in the magnetic and cooling circuits promise to rectify these problems.

The ion source will operate at a potential of 25 kV and produce a proton beam of at least 15 mA at a duty factor up to 2%. The filament power will be about 175 W (35 A at 5 V). The magnet power will be about 60 W (2.5 A at 25 V). The hydrogen gas flow is estimated at about 2 SCCM. It will have a length of 152 mm and a diameter of 210 mm. The ion source is currently under design at JP Accelerator Works, Inc. It is scheduled for delivery in the fall of 1997.

8 RF POWER SYSTEM

The rf power system, based on a multiplicity of high power planar triodes, will produce a peak power of 240 kW at a pulse duty factor of 0.5%. It will consist of a chain of two intermediate power amplifiers (IPA1 and IPA2) and one final power amplifier (FPA). The IPAs will be rack mounted while the FPA will be mounted in close proximity to the accelerator. IPA1 will use one YU-141 planar triode and IPA2 will use two YU-141s. The FPA will utilize an all new single cavity configuration of 12 planar triodes in parallel.

This system is currently under development at JP Accelerator Works, Inc., features easy tube replacement (individual cathode assemblies), a broadband cathode circuit (no tuning required), a light weight cavity assembly, built-in phase and amplitude control, and a PC-based control system with fiber-optically isolated control modules and professional controls software. The system is scheduled for delivery in June, 1997

9 VACUUM, COOLING, AND CONTROLS

The vacuum system for the proof-of-principle prototype 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 two rotary vane roughing pumps. These pumps have been procured.

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 ±1ºC 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 requirements for RFD linac systems are understood to be very modest. The control system for a production system will involve a PC-based computer with commercially available control modules and commercially available control-oriented software. The plan for the prototype is to implement a skeleton of such a system to establish its potential. 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 equipment on the prototype will be accomplished manually in the course of developing the required controls procedures.

A new 1200 square foot laboratory has just been completed to support the development of the RFD linac structure. Newly acquired equipment includes a network analyzer, a vector voltmeter, an rf power meter, and a bead perturbation setup. The support structure for the POP prototype have been installed in the new laboratory.

10 REFERENCES

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