

CONTINUED DEVELOPMENT OF THE RFI LINAC STRUCTURE*

D.A. Swenson, W.J. Starling, F.W. Guy, and K.R. Crandall
 Linac Systems, LLC Albuquerque, NM 87109, USA

Abstract

The Rf-Focused Interdigital (RFI) linac structure is under development at Linac Systems. It promises very efficient acceleration of protons, light ions, and heavy ions to tens of MeV in relatively small packages. Recent developments include the discovery of effective geometries for the support of the two-part drift tubes, which provide the rf focusing, and efficient geometries for the end terminations of the interdigital linac tanks. These developments required extensive use of our 3d rf cavity calculational capability. A “cold model” of an RFI linac has been fabricated and tested. The measured and calculated field distributions are in reasonable agreement. The beam dynamics of the structure has been studied with TRACE-3D and a modified version of PARMILA. The structure is capable of remarkably high beam currents (space charge limits). The results of these studies will be presented. The high rf efficiency of the structure promotes the possibility of cw operation. A prime application for the RFI linac structure is the challenging job of providing intense fluxes of epithermal neutrons for the boron neutron capture therapy (BNCT) application. Mechanical designs of the RFI linac structure for that application will be presented. Other applications for the RFI linac structure will be described.

INTRODUCTION

The Rf-Focused Interdigital (RFI) linac structure^[1,2] represents an effective combination of the interdigital (Wideröe) linac structure^[3] and the rf electric quadrupole focusing used in the Radio Frequency Quadrupole (RFQ) and Rf-Focused Drift tube (RFD) linac structures^[4,5]. This linac structure is two-to-six times more efficient and three times smaller than the conventional Drift Tube Linac (DTL) structure in the energy range from 0.75 to 6 MeV. It is ten times more efficient than the RFQ linac structure in the 0.75 to 6 MeV range. A comparison of the rf efficiencies for these three structures is shown in Fig. 1.

The rf efficiency and size advantages of this new structure will reduce the capital and operating costs of small proton, deuteron, and heavy ion linac systems. The high efficiency will reduce the rf power dissipation in their structures, thereby promoting the prospect for cw operation, which in turn, offers the possibility of large increases in their average beam currents. These features will increase the number and types of applications for which small linac systems are suitable.

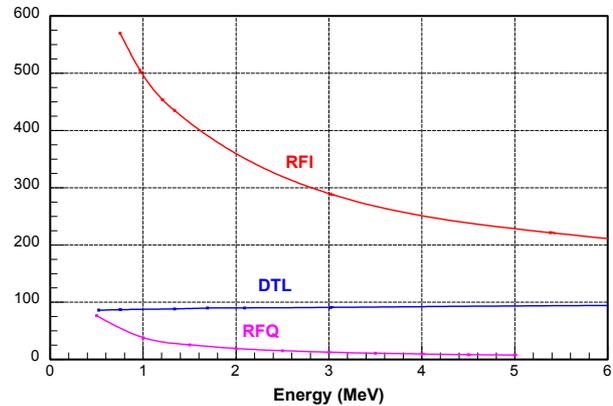


Fig. 1. Effective Shunt Impedance (MΩ/m) for the RFI, DTL and RFQ Linac Structures at 200 MHz.

THE RFI LINAC STRUCTURE

In an interdigital linac structure, the electric fields in the gaps between drift tubes alternate in direction along the axis of the linac. The longitudinal dimensions of the structure are such that the particles travel from the center of one gap to the center of the next gap in one half of the rf cycle. Hence, particles that are accelerated in one gap will be accelerated in the next gap because, by the time the particles arrive there the fields have changed from decelerating fields into accelerating fields. In the interdigital linac structure, it is common to support the drift tubes alternately from the top and bottom (or left and right side) of the cavity to achieve the desired alternation in field direction. This same practice has been adopted for the RFI linac structure.

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) supports two fingers pointed inwards towards the opposite end of the drift tube forming a four-finger geometry, which produces an rf quadrupole field along the axis of the linac for focusing the beam.

The longitudinal distribution of the acceleration, focusing, and drift actions are quite different between the RFD and RFI linac structures. In the RFI structure, when the accelerated particles are two thirds of the way between the centers of the gaps, the electric fields are passing through zero strength as they change sign and are not suitable for focusing the beam. As a result, the focusing action must be pushed upstream to lie as close to the accelerating gap as possible, leaving the latter portion of the drift tube solely as a drift action (no focusing, no

* Work supported by the U.S. Department of Energy.

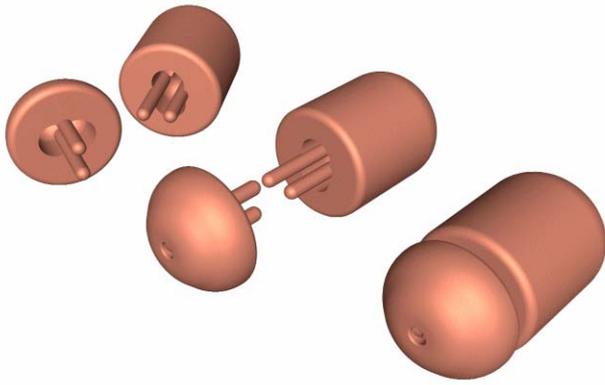


Fig. 2 RFI Drift Tubes, Exploded and Assembled.

acceleration). Hence, the drift tubes of the RFI linac structure are asymmetrical, consisting of a minor piece and a major piece as shown in Fig. 2.

The analysis of the RFI linac structure breaks conveniently into two parts, namely the analysis of the interdigital feature of the structure and the analysis of the rf focusing feature. For the first part, we analyzed and optimized the interdigital feature of the structure with simple, one-part drift tubes, having no provisions for rf focusing. For the second part, we incorporated two-part drift tubes into the optimized interdigital structure in order to analyze the rf focusing properties of the structure. As the RFI linac structure is highly three dimensional, these analyses made heavy use of the 3D rf cavity calculational program, SOPRANO^[6].

THE INTERDIGITAL FEATURE

One form of the interdigital linac structure is a cylindrical tank, loaded with drift tubes, positioned along the axis of the tank and spaced by one half of the particle wavelength, supported on drift tube stems extending alternately from the top and bottom (or left and right sides) of the tank. Of concern are the rf field distribution

within the structure, the stability of this rf field distribution, the cavity mode spectra in the vicinity of the operating mode, and the rf efficiency of the structure.

The analysis and optimization of the interdigital feature of this structure involved studies of the structure properties as a function of the rf frequency, the beam particle, the particle velocity, and the geometry. We chose to optimize the structure for proton acceleration at an rf frequency of 200 MHz in the energy range of 1 to 20 MeV. These results can be scaled to other beam particles and rf frequencies.

The significant features of the geometry that we chose to study are the cell length (L), the cavity radius (R_c), the drift tube length, the drift tube radius (R_d), and the support stem radius (R_s). For a given proton energy and rf frequency, the cell length is equal to $\beta\lambda/2$ and the drift tube length is three quarters of the cell length. The cavity radius is used to satisfy the frequency constraint. Hence, for a given proton energy and rf frequency, the geometrical parameters to be optimized are R_d and R_s .

Figure 3 presents an array of data for an interdigital linac structure at 200 MHz for cell lengths of 4, 6, 8, 10, 12, 14, and 16 cm, corresponding to proton energies of 1.34, 3.02, 5.38, 8.45, 12.25, 16.79, and 22.11 MeV, a drift tube radius of 1.2 cm, and a stem radius of 2.0 cm. Two important features of the RFI linac structure, resulting in part from its interdigital configuration, are immediately obvious from this data, namely its exceptionally high effective shunt impedance (ZT^2) and its small transverse size (cavity radius).

THE RF FOCUSING FEATURE

The acceleration gaps (between the drift tubes) and the focusing gaps (within the drift tubes) form capacitive dividers that place a portion of the rf acceleration voltage on each rf focusing lens. In order not to short out this focusing potential, the two pieces of each drift tube are supported on separate stems, a major stem for the major piece and a minor stem for the minor piece. These stems form inductive dividers that couple to the rf magnetic

Cell Length (cm)	4	6	8	10	12	14	16
Beta (velocity/c)	0.0533	0.0800	0.1067	0.1333	0.1600	0.1867	0.2133
Proton Energy (MeV)	1.34	3.02	5.38	8.45	12.25	16.79	22.11
Cavity Radius (cm)	14.0	16.1	17.7	18.7	19.4	19.9	20.2
Stored Energy (J)	0.0011	0.0026	0.0047	0.0074	0.0107	0.0147	0.0194
Shunt Impedance (MΩ/m)	468.2	313.5	240.5	188.9	155.3	130.5	111.3
Transit Time Factor	0.960	0.960	0.960	0.960	0.960	0.960	0.960
ZT ² (MΩ/m)	431.5	288.9	221.6	174.1	143.1	120.3	102.6
Quality Factor	15738	16961	17542	17581	17439	17214	16925
Power Loss (Total) (W)	85.4	191.4	332.6	529.5	772.9	1073.2	1437.9
Power Loss (Outer Wall)	49.5	104.2	168.0	250.2	342.6	448.5	571.6
Power Loss (Bars)	34.6	85.2	160.5	171.1	415.1	597.7	821.7
Power Loss (Drift Tubes)	1.3	2.0	4.1	8.2	15.2	27.0	44.6

Fig. 3. Geometrical and Rf Properties of the Interdigital Structure.

fields of the structure. The geometry of these stems must be configured to yield the same potential difference to the rf lenses that the capacitive dividers do. This prevents the drift tube supports from shorting out the rf focusing lenses.

It is convenient to describe the rf lens excitation as the ratio of the lens voltage (V_L) to the cell voltage (V_C). The desired lens voltage is beam dynamics dependent. A good choice is to have a constant lens voltage throughout the linac. With a constant acceleration gradient (a common design choice), the cell voltage is proportional to the cell length. With these choices, the V_L/V_C ratio decreases throughout the linac. In some of our designs, this ratio begins as high as 40% and decreases to something like 10% at the end of the structure.

Originally, we had planned to couple to the magnetic field surrounding each major stem. This lent itself to a two stem configuration emanating from a single base, with the minor stem being located a short distance upstream from the major stem. This would allow the two pieces of each drift tube to be accurately aligned in the manufacturing process and to be installed as a single unit in a "hard socket" in the outer wall of the linac tank. After considerable study, we found that the total flux surrounding the major stem was not sufficient to yield the lens excitations that we needed.

At this point, we realized that we needed to couple to some of the longitudinal magnetic fields in the structure. This requires that the minor stem be offset to one or both sides of the major stem. For symmetry and mechanical rigidity, we choose a minor stem geometry that extended symmetrically on both sides of the major stem. Once again, we tried to achieve a design where both stems (major and minor) emanated from a single base to facilitate the manufacture and installation of the drift tubes. However, these geometries, when pushed to the maximum desired lens excitations, had detrimental effects on the rf efficiency of the structure.

This led to 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. The coupling is a simple function of the angle between the radial stems and the major stem – the greater the angle, the greater the coupling. In one design that we have considered, the desired coupling, ranging from 29% at 0.75 MeV to 16% at 2.5 MeV, can be achieved by radial stem angles ranging from 51 to 33 degrees.

To facilitate the fabrication of the RFI linac structure under this radial stem approach, we have adopted what we call the "Stacked Cell" approach, shown in Fig. 4, 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 can be held together either by tie-bolts running along the structure or by welding the cells together into a single unit as shown in Fig. 5.

REFERENCES

- [1] D.A. Swenson, "An Rf-Focused Interdigital Linac Structure", 2002 Intern. Linac Conf., Korea, 2002.
- [2] D.A. Swenson, "An Rf-Focused Interdigital Ion Accelerating Structure", CAARI 2002, Denton, TX.
- [3] Krietenstein, Weiland, Ratzinger, Tiede, and Minaev, "Numerical Simulation - ", 1996 Linac Conf. CERN.
- [4] D.A. Swenson, "RF-Focused Drift Tube Linac Structure", 1994 Linac Conf., Tsukuba, Japan, 1994.
- [5] D.A. Swenson, "Applications for the RFD Linac Structure", CAARI 2000, Denton, TX.
- [6] Vector Fields, SOPRANO version 8.700, Oxford, UK



Fig. 4. The "Stacked Cell" Approach.

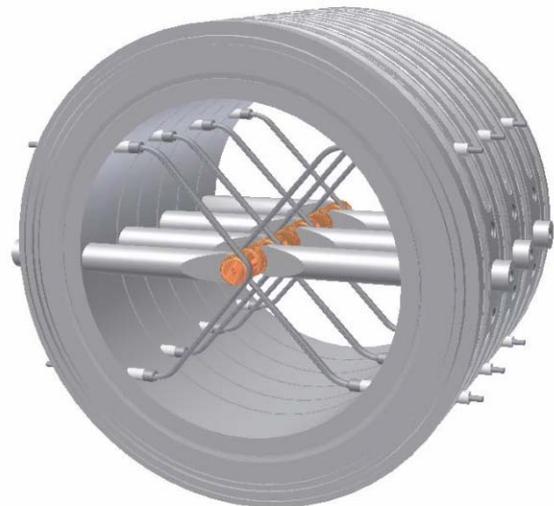


Fig. 5. The RFI Linac Structure.