AN RF FOCUSED INTERDIGITAL LINAC STRUCTURE*

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Abstract

An Rf Focused Interdigital (RFI) linac structure will be described. It represents an effective combination of the Wideroe (or interdigital) linac structure, used for many low frequency, heavy ion applications, and the rf electric quadrupole focusing used in the RFQ and RFD linac structures. 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. However, because of the differences in the rf field configuration along the axis, the scheme for introducing rf focusing into the interdigital linac structure is quite different from that adopted for the RFD linac structure. The RFI 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).

1 INTRODUCTION

A way to introduce rf focusing into low frequency, rf linac structures has been discovered. This rf-focused structure promises to have exceptional properties for the efficient acceleration of protons, light ions, and heavy ions. We have chosen to call this new linac structure the Rf-Focused Interdigital (RFI) linac structure. The RFI linac structure represents an effective combination of the interdigital (Wideröe[1] or Sloan Lawrence[2]) linac structure, used for many low frequency, heavy-ion applications, and the rf electric quadrupole focusing used in Linac Systems' Rf-Focused Drift tube (RFD) linac structure[4-7]. However, because of the differences in the rf field configurations, the scheme for introducing rf focusing into the interdigital linac structure is quite different from that adopted for the RFD linac structure, which is based on the conventional drift tube (Alvarez) linac structure.

The drift tubes of an interdigital linac structure alternate in potential along the axis of the linac. Consequently, the electric fields between the 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 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 most drift tube linac structures, the drift tubes are supported on, and cooled through, drift tube stems extending from the wall of the cavity. 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 of their polarity. This same practice has been adopted for the RFI linac structure. One possible configuration for RFI linac structures is shown in Fig. 1.

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, as shown in Fig. 2, 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. For example, when the accelerated particles are half way between the

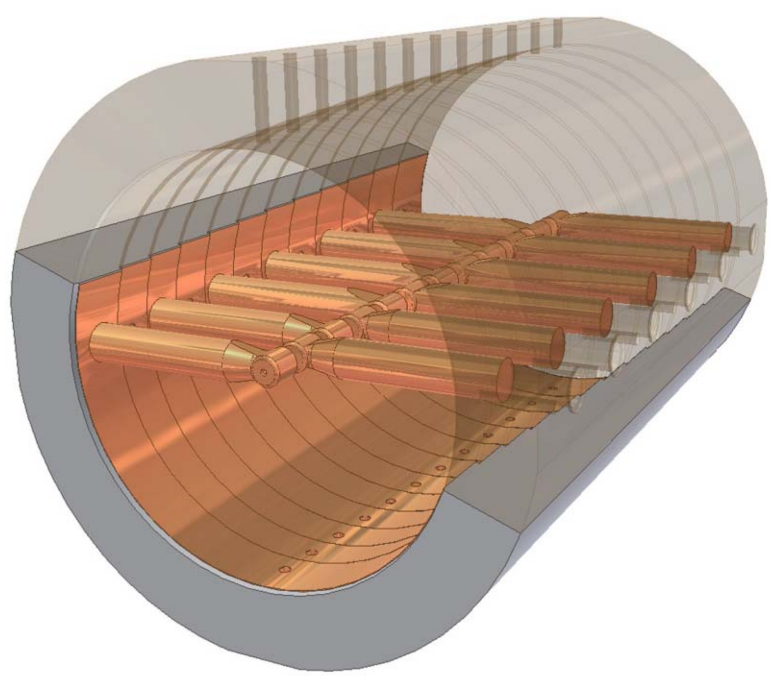

Fig. 1. An Interdigital Configuration for the RFI Linac.

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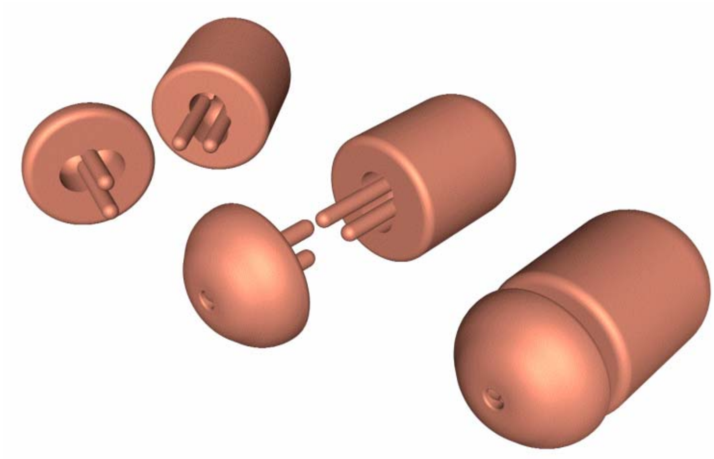

Fig. 2. RFI Drift Tube, Exploded and Assembled.

accelerating actions of the RFD structure (ie, within the drift tube), the electric fields are near maximum strength in the opposite direction and are suitable for focusing the beam. 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 forward (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 acceleration). Hence, the drift tubes of the RFI linac structure are asymmetrical, consisting of a minor piece and a major piece as shown in Figs. 2 and 3.

The acceleration gaps (between the drift tubes) and the focusing gaps (inside 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-piece drift tubes are supported on two-bladed stems, with each blade supporting one electrode of the two-piece drift tube. The major piece of each drift tube is supported on a major blade while the minor piece is supported on a minor blade located upstream of the major blade

The two-bladed stems form inductive dividers, coupled to the magnetic fields surrounding the stems, that 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.

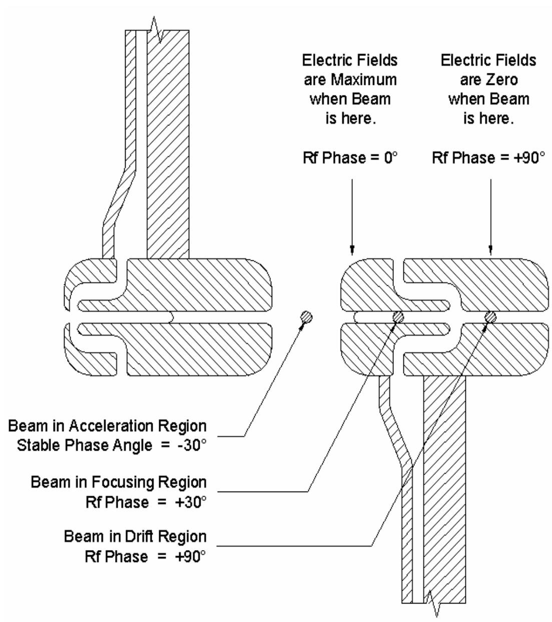

Fig. 3. Asymmetrical Drift Tubes.

2 ACCELERATING AND FOCUSING FIELDS

The beam bunches arrive at the centers of the gaps between the drift tubes at times when the electric fields are optimum for acceleration. At this phase, the electric fields in the gaps are in the proper direction for acceleration of beam and are approaching their maximum magnitude. Typically, the acceleration phase is designed to be 30° in advance of the peak magnitude in order to provide a longitudinal focusing action on the beam to keep it bunched. Associated with this choice of acceleration phase is a weak transverse defocusing action that must be overcome by additional transverse focusing incorporated into the linac structure.

The beam bunches arrive at the centers of the rf quadrupole focusing region one sixth of an rf cycle later when the electric fields have passed through their peak magnitude and are beginning to decrease. At this phase, the fields within the drift tubes will provide rf quadrupole focusing to keep the beam within the drift tube aperture.

As the beam bunches move from drift tube to drift tube (one half rf cycle), the direction of the transverse focusing fields reverse, resulting in an alternation of focusing and defocusing actions in both transverse planes.

3 BEAM DYNAMICS

The beam dynamics performance of the RFI linac structure was investigated with the aid of TRACE-3D, a well-known, linear beam dynamics computer program. The effects of the rf acceleration and focusing fields in the RFI linac structure on low intensity beams of charged particles passing through the structure have been analyzed. These calculations establish the capabilities of the RFI linac structure for acceleration of low intensity beams of protons, deuterons, and heavier ions.

At higher intensities, the repulsive electric forces between the charged particle of the beam have a defocusing effect on the beam, tending to reduce the net focusing action provided by the RFI acceleration and focusing fields. The beam current at which this effect jeopardizes the useful performance of the linac structure is referred to as the "space charge limit". The most restrictive space charge limit occurs at the very beginning of the linac where the beam energy is the lowest. The space charge limit of the RFI linac structure was investigated, using the TRACE-3D program, for all combinations of two operating frequencies (100 and 200

MHz) and three injection energies (0.5, 1.0, and 2.0 MeV). In all of these cases, the space charge limits were in excess of 60 mA. At 200 MHz, the space charge limits were in excess of 100 mA. These calculations establish the capabilities of the RFI linac structure for acceleration of high intensity beams of protons, deuterons, and heavier ions.

A PARMILA-like beam dynamics code, PARMIR (Phase And Radial Motion In RFDs), was written to facilitate the study of the beam dynamics in the RFD linac structure. Some modifications were made to this program to support beam dynamics studies of the RFI linac structure. PARMIR now simulates multi-particle beam dynamics in drift tube and interdigital linacs that employ rf focusing inside the drift tubes.

4 RF EFFICIENCY

Preliminary calculations suggest that the effective shunt impedance, ZT^2, for the RFI linac structure is very efficient. Figure 4 shows that the rf efficiency of the RFI linac is 5-to-10 time that of the conventional drift tube linac and 10-to-40 times that of the RFQ linac in the energy range 1 to 5 MeV. This represents a significant improvement over the prior art.

5 COLD MODEL

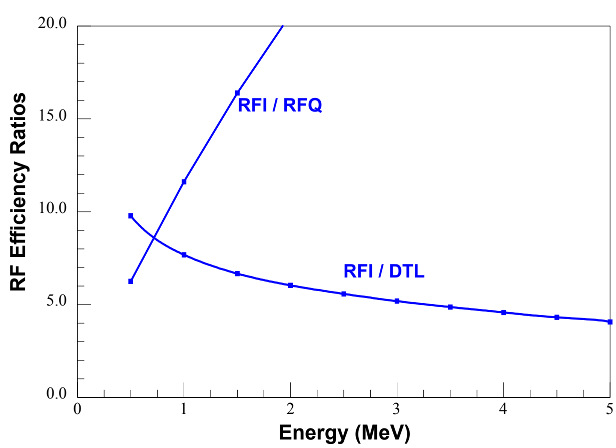

Fig. 4. Ratio of RFI Efficiencies to Other Structures.

Whereas, much can be learned from cavity field calculations, much can also be learned from the measurement of rf field distributions and cavity modes in a cold model. Here, the term "cold model" refers to a relatively simple mechanical model of the structure, without the complications of vacuum seals and/or cooling channels.

A cold model of the RFI linac structure, shown in Fig. 5, is in fabrication. Initially, this model will be used to study the proposed interdigital linac structure, without the complication of the two-piece drift tubes and the two-bladed stems. The "bead perturbation" technique will be used to measure the axial field distribution as a function of stem diameters and end wall tuning. Next, a few RFI-type drift tubes and stems will be fabricated and tested in this model.

The 0.5-m-long cold model is designed to resonate at 200 MHz and will have 12 drift tubes spanning the proton energy range from 0.5 to 2 MeV. Rf calculations suggest that the inner diameter of the tank must vary from 240 to 300 mm over that energy range.

This cold model is close to the geometry of a 2.5 MeV proton linac that Linac Systems is developing as an accelerator-based epithermal neutron source for the boron neutron capture therapy (BNCT) medical application.

6 ACKNOWLEGEMENTS

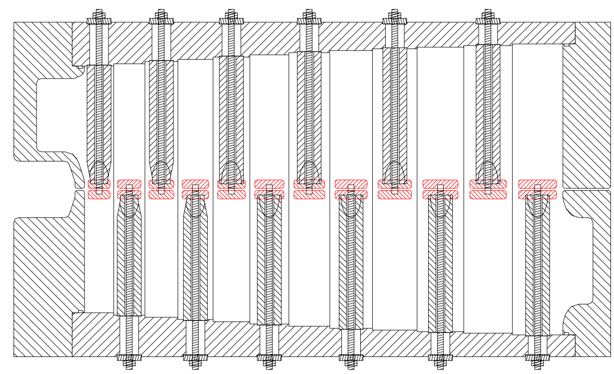

Fig. 5. RFI Cold Model in Fabrication.

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