200-MHZ, 1.5-MEV, DEUTERON RFQ LINAC

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Abstract

A 200-MHz, 1.5-MeV, deuteron RFQ linac system is under construction at Linac Systems. The linac structure employs the four-bar, radial-strut design, where the four bars are supported by a series of radial struts emanating from the wall of a cylindrical cavity with four-pole symmetry. This structure looks and performs very much like the four-vane RFQ structure. This design is about twice the efficiency of the conventional four-bar RFQ design. Another important advantage of this design is that the dipole mode is higher in frequency than the quadrupole mode, thus eliminating any problems with the mixing of the dipole mode with the quadrupole mode. Injection of deuterons into the linac will be at 40 keV from a microwave ECR ion source. The linac structure is 2.72 meters long. The peak beam current out of the linac will be 20 mA. A pulse duty factor of 5% will yield an average beam current of 1 mA. The rf power requirement is 58 kW to excite the structure, plus 30 kW to accelerate the beam, for a total of 88 kW. This linac system is scheduled for completion in the spring of 2007.

INTRODUCTION

A 200-MHz, 1.5-MeV deuteron RFQ linac system is under construction at Linac Systems, consisting of a microwave ECR ion source, an Einzel-lens-based LEBT, a four-bar RFQ linac, an rf power system, and associated vacuum, cooling, and control systems. The total cost of the 1.5-MeV system will be less than $500k. The parameters for this system are presented in Table I. The plan (not yet funded) is to extend the energy of this system to 5 MeV with the addition of an Rf Focused Interdigital (RFI) linac section.

Table 1: List of Parameters

Beam Particle	Deuteron
Ion Source Energy	40 keV
RFQ Output energy	1.5 MeV
Rf Frequency	200 MHz
Beam Current (peak)	20 mA
Beam Duty Factor	5%
Beam Current (average)	1 mA
Length (RFQ)	1.72 m
Length (with Ion Source & LEBT)	2.72 m
Length (accelerator Stand)	2.90 m

ION SOURCE / LEBT

The ion source for this project is a microwave electron-cyclotron resonance (ECR) ion source. The design is a direct descendant of the LEDA ion source [1] and a recent IUCF ion source [2]. The ion source consists of a cylindrical plasma chamber (140-mm diameter by 140-mm long), surrounded by an electromagnetic solenoid to shape the plasma, fitted with an aperture at one end to allow for beam extraction. The mechanical design of the ion source and the low energy beam transport (LEBT) system is shown in Fig. 1.

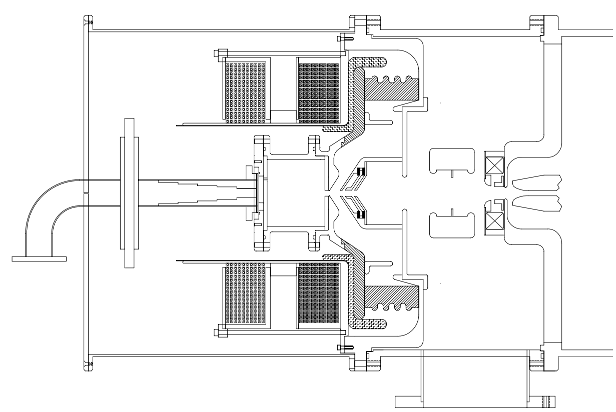

Figure 1: Ion Source/LEBT Configuration.

Microwave power and a controlled flow of deuterium gas are fed into the plasma chamber. The microwave power ionizes the deuterium gas, forming a plasma, while the magnetic field of the solenoid controls the shape of the plasma. Electric fields near the extraction aperture pull deuterons out of the plasma and accelerate them to an energy of 40 keV. The shape and spacing of the plasma and extraction electrodes are custom designed for a 30-mA deuteron beam.

The ion source, which operates at an elevated electrical potential (40 kV), is entirely encased within the grounded shell of the accelerator. Although the solenoid is in close proximity to the ion source, an insulating bushing between the solenoid and the ion source allows the solenoid and its power supply to be at ground potential. The microwave power source, which resembles a conventional microwave oven power source, is at ground potential. An insulated break in the microwave waveguide allows the microwave power to be delivered to the ion source at its elevated potential. The only other connections that cross the high-voltage boundary are the hydrogen gas supply and a bit of deionized water for cooling purposes. Because of its power efficiency, this source can be operated in a continuous-wave (cw) mode. However, for this application, the microwave power will be pulsed, which results in a pulsed deuteron beam. This ion source promises convenient, reliable, efficient, maintenance-free, operation at the required deuteron beam current and duty factor for a modest cost.

The LEBT is based on a single Einzel lens, which focuses the beam from the ion source extraction electrodes into the RFQ linac structure. The Einzel lens voltage will be about 38.4 kV. It will be mounted on a manually operated XYZ stage to facilitate steering and matching the beam into the RFQ. The total length of the LEBT is 250 mm. A PBGUNS [3] simulation of the beam profile from the plasma surface, through the extraction electrodes and Einzel region to the RFQ entrance is shown in Fig. 2. The beam current in this simulation is 30 mA with 85% of the beam as d+ ions and 15% of the beam as d2+ ions.

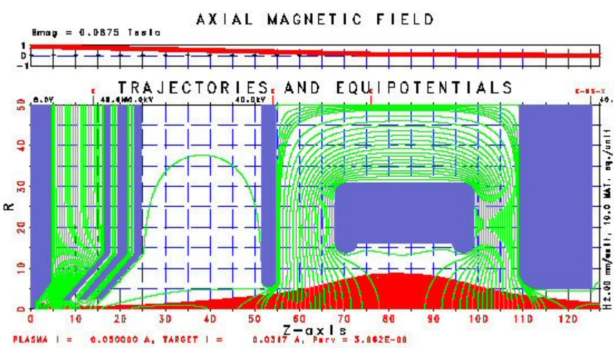

Figure 2: Beam Profile from Ion Source through LEBT.

RFQ LINAC

The RFQ linac is designed for an output energy of 1.50 MeV, a length of 1.72 m, and an rf frequency of 200 MHz. Because of this relatively low frequency, the linac is designed as a Radial Strut, Four-Bar RFQ structure. This structure looks and performs very much like the Four-Vane RFQ structure. In this design, the four bars are supported by radial struts emanating from the walls of the cavity with four-pole symmetry, as shown in Fig. 3.

An advantage of this design over the four-vane configuration is that the dipole mode has a higher frequency than the quadrupole mode, thus eliminating any problems with the mixing of the dipole mode with the quadrupole mode. An advantage of this design over other four-bar configurations is that it has a higher rf efficiency than the four-bar configurations without quadrupolar symmetry. It is about twice the efficiency of the conventional, four-bar RFQ design.

The rf cavity mode spectra for this 200-MHz structure is shown in Fig. 4. Here the quadrupole mode is seen to be at 199.462 MHz, while the dipole mode is at 212.160 MHz, indicating a mode spacing of 12.7 MHz with a 45-db trough between the two modes. The quadrupole mode is the lowest frequency mode in the entire mode spectrum.

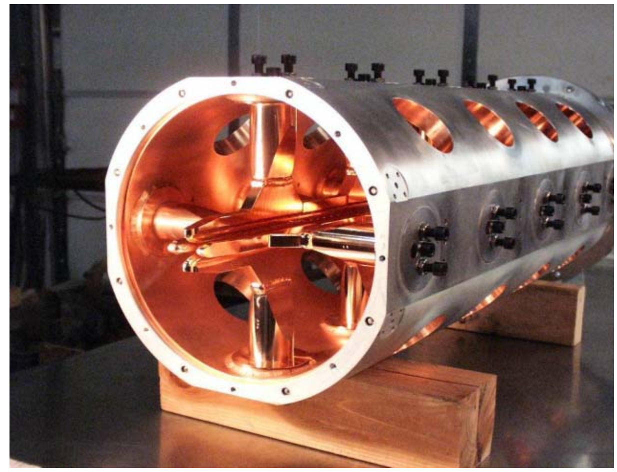

Figure 3: Radial-Strut, Four-Bar RFQ.

The main structural element of the RFQ is a heavy wall aluminum tube, which serves as the RFQ cavity wall. Precision flats machined into the outer wall of the cavity wall serve as a mechanical reference for the alignment of the RFQ bars. The RFQ bars are made from aluminum stock, extruded with a longitudinal hole for cooling purposes. Each bar is supported by eight struts.

Four separate cooling channels are machined into the RFQ cavity wall. The four bars and their struts have eight separate cooling channels. Temperature-controlled water will be pumped through these channels to cool and control the temperature of the structure, which in turn controls the resonant frequency of the structure. A counter flow arrangement is employed so that the average temperature at all locations along the structure will be similar.

The RFQ linac structure will be mounted inside a vacuum tank that provides the high-vacuum conditions required by the beam and rf power. The RFQ vacuum tank will be pumped by two 400 l/s turbomolecular vacuum pump and will typically operate at a vacuum pressure in the range of 5×10^{-7} Torr.

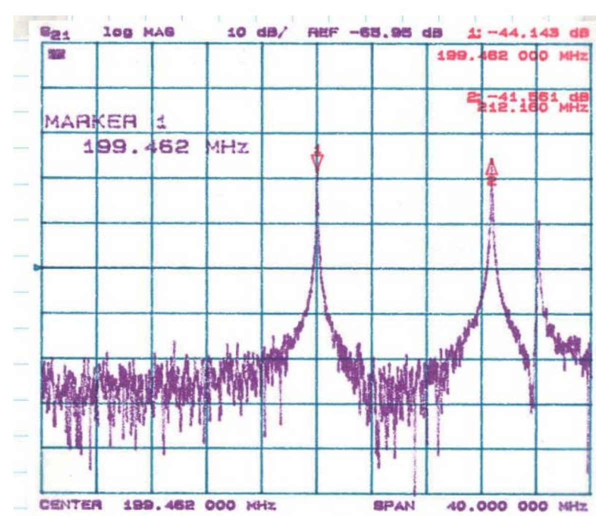

Figure 4: RFQ Mode Spectra.

The beam dynamics codes RFQSCOPE and PARMTEQ were used to converge on a detailed design for the RFQ linac. With an r_o radius of 3.6 mm and an electric surface field gradient of 26.5 MV/m (1.8 Kilpatrick), the structure will have 147 cells in a length of 1.72 m. The beam capture efficiency will be 92.4%.

The PARMTEQ output is shown in Figs. 5 & 6. Figure 5 shows the radial and energy profiles of the beam through the RFQ linac section. Figure 6 shows the three phase space projections of the beam at the input and output of the RFQ linac.

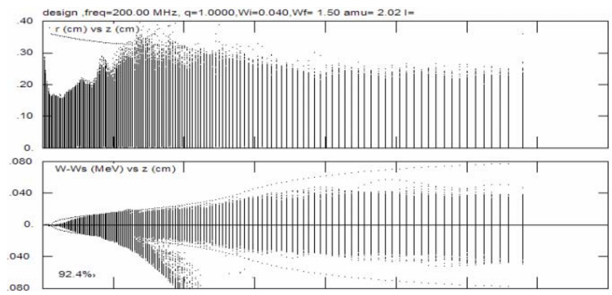

Figure 5: Radial and Energy Profiles through RFQ.

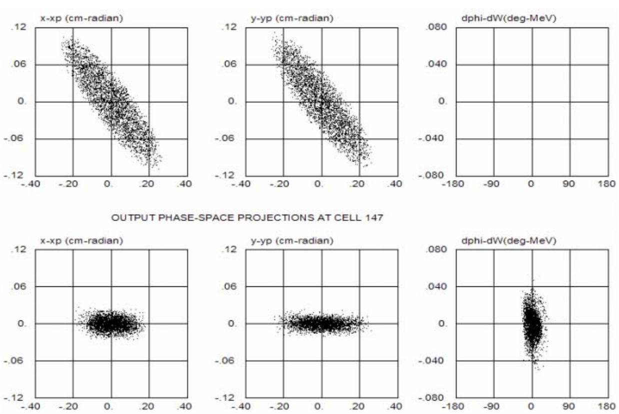

Figure 6: Phase Space Projections In and Out of RFQ.

The scalloped surface of the RFQ bars will be machined using a CNC milling machine with a ball end mill. The ball end mill will move longitudinally along the structure, bobbing up and down to create the scallops, while moving closer to the midplane of the bar with each pass. Figure 7 show the surface of an existing RFQ bar, as machined (without any polishing).

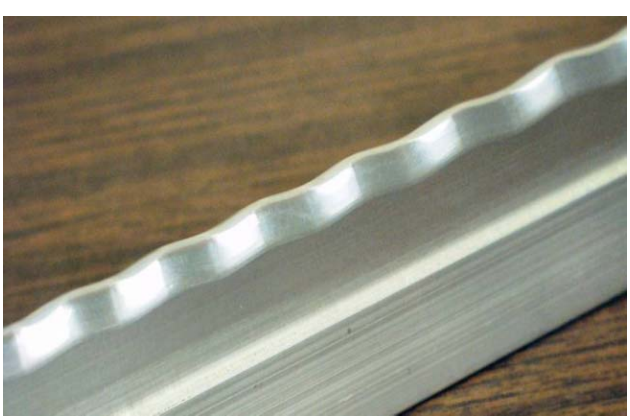

Figure 7: Surface of an existing RFQ Bar as machined.

RF POWER SYSTEM

The Rf Power System is a 200 MHz rf system, designed to provide 104 kW of peak rf power at a 5% duty factor. The rf power amplifier is based on a parallel planar triode concept, developed by JP Accelerator Works, Inc. (JPAW), and demonstrated at rf frequencies up to 600 MHz and peak rf powers up to 240 kW. The design will utilize an axial array of 4 Russian GS-35B tubes around the output coax. These tubes are rugged planar triodes with a 6.3 cm^2 cathode, requiring 36 W of heater power. Each tube is capable of 30 kW peak power output at the 5% duty factor up to 1 GHz.

The rf power system consists a low level rf system (LLRF), a solid state amplifier (SSA), two one-tube intermediate power amplifiers (IPAs), and a final power amplifier (FPA). The LLRF contains an rf oscillator, frequency control, rf pulse switch, amplitude feedback control and VSWR fault protection circuitry. The oscillator will be a microprocessor controlled direct digital synthesis (DDS) circuit. The pulse width is adjustable from 10 μs to 100 μs and the repetition rate from 10 to 500 Hz. The SSA and IPAs increases the power level from the LLRF to 12 kW for driving the FPA.

The 4 FPA power tubes will be arranged in a circle around a standard EIA 3-1/8" coax. Each tube has its own cathode bias and heater power circuit. The cathode bias circuit adjusts the bias on each tube to maintain a programmed level of cathode current.

The directional coupler provides rf samples proportional to the forward and reflected wave amplitudes in the output coax. The reflected amplitude signal is used by the LLRF for fault protection due to high VSWR. The forward amplitude signal is used in the frequency control circuit to lock the rf system to the accelerator resonant frequency. A pickup loop in the cavity provides a signal that is used in the frequency control loop and in the amplitude control feedback circuit.

The DC power supply will involve a 10-kV, 3Φ, 20-kW transformer, a 3Φ solid state rectifier, an SCR controller, and a crow-bar protection circuit.

ACKNOWLEDGEMENTS

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