IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

LOW BETA ACCELERATING SYSTEM FOR HEAVY IONS*

A. Bertsche, J. Brodowski, J. Keane, A. W. Maschke and R. Sanders†

Summary

To investigate the performance that can be achieved for low energy heavy ion particle acceleration, a two megahertz low beta linac is being built. This structure, intended for acceleration of 260 keV xenon or 400 keV mercury, is comprised of a quarter wavelength parallel plate resonator used to support drift tubes forming a $\beta\lambda/2$ structure. The 20 gap accelerator, to be driven by a 30 kilowatt transmitter, will provide 10 milliamperes of mercury ions at the 1.8 MeV energy level. Focussing is achieved by a unique arrangement of electrostatic quadrupoles. A plan view of the accelerating system is shown in Figure 1.

I. Radio Frequency Power Amplifier

The radio frequency power amplifier is a departure from what might be considered conventional for accelerating systems.[1] Instead of designing and prototyping a new system, a 20 year old, 4- to 30-MHz communications transmitter was purchased, rebuilt and modified to operate at 2 MHz. The resulting system required a minimal budget and only four months for completion.

The transmitter was a typical 30 kW unmodulated unit. It consisted of five stages of which the last three operated in a saturated class C mode, and thus, fixed gain. Its output was designed for balanced loads ranging from 300 to 800 ohms.

Certain modifications had to be made before it would be a useable rf system. First, interstage coupling networks had to be altered to tune to 2 MHz. Also, the final tank circuit and output matching networks were discarded and the plates of the final amplifier were coupled directly to a 3000 ohm impedance tap point on the transmission line/resonator as shown in Figure 2. Finally, additional capacitance was added to the high voltage power supply to allow for pulsed operation at nearly the peak power supply voltage with only a small droop. Mercury vapor rectifiers were retained.

Figure 3 shows the transmitter in its final location, connected to the transmission line above.

This rf system has delivered up to 35 kW peak power while driving the transmission line to over 135-kV peak at the open end. This power was only line losses and was obtained by operating at a 1% duty cycle where the transmitter was keyed "on" for 1 millisecond.

II. Quarter Wavelength Resonator

Electrical parameters of the resonator are discussed in detail in a design study and will not be presented here.[2] Mechanical details are given in Section 3. The slab line structure, having a characteristic impedance of 120 ohms, is 90% in air. Near the vacuum tank interface the line is split into two transmission lines allowing two entry points into the vacuum vessel. This substantially reduces the dielectric window feed thru voltage breakdown problem. Inside the vacuum vessel the parallel plate line is continued. Drift tubes are alternately connected to the plates forming a $\beta\lambda/2$ accelerator.

*Work performed under the auspices of the U.S. Department of Energy.

†Brookhaven National Laboratory, Upton, N.Y.

Since the capacitance of the equivalent shunt resonator circuit is high, 1×10^{-9} farads, the stored energy of 2.5 joules at 100 kilovolts operation will ease the beam loading problem.

Construction of the air portion of the line has been completed. A peak voltage of 140 kilovolts between plates has been achieved. The windows showed no sign of voltage breakdown during these tests. Measurement of the partially built resonator yielded a Q between 1800-2000 at a frequency of 2.3 megahertz. This frequency will be reduced to 2 MHz when the drift tubes are added.

This line was successfully driven in a self resonant closed loop mode to assure frequency stability.

III. Rf Transmission Line Construction

The rf transmission line consists of a rectangular outer conductor and two parallel inner conductors. The outer conductor of the transmission line is constructed from .040" thick aluminum sheets and 1" x 1" aluminum corner angles. The outer conductor dimensions are 26" horizontal x 24" vertical. The inner conductor consists of two parallel lines 12" apart constructed from 2" diameter copper tubing and .054" thick copper sheets.

Two 2" diameter x 96" long tubes and two 10" wide x 96" long x .054" thick copper sheets are soft soldered to form one 2-1/8" thick x 12" wide x 96" long section of inner conductor. As assembled section of transmission line is shown in Figure 4.

Each 96" long inner conductor section is mated with coaxial type bullets which fit into inside diameters of 2" diameter copper tubes.

The transmission line is suspended from horizontal "I" beams and supported with vertical channels (all made of aluminum). The inner conductors are hung from "I" beams with porcelain antenna holders. The "I" beam and channel suspension system is totally independent of the buildings existing structure. It was chosen because of the transmission line's weight (2500 lbs). The last 8 feet of the transmission line are transformed into two independent transmission lines with a 5" diameter inner conductor and a 13" x 13" square outer conductor. Each line is fed into the accelerating tank through a vacuum feedthrough on each of the two tank ports.

The vacuum feedthrough is a short tapered circular coaxial line with 1" thick x 13" diameter rexolite window and appropriately located "O" rings placed on the inside and outside conductors.

With 100 kV rf induced voltage and transmission line, transition and vacuum feedthrough showed no signs of voltage breakdown.

IV. Linac - Principle of Operation

The acceleration system (Wideröe structure) consists of twenty drift tubes equally divided between two drift tube tables mounted one above the other (Figure 5). The drift tubes are mounted so as to alternate from lower to upper table and provide a constant and uniform 2 cm gap between drift tubes. The two tables, with their integral drift tubes, are each powered to 50 kV but with opposite polarities. This places 100 kV across each gap thus providing the desired accelerating

0018-9499/79/0600-3742$00.75 © 1979 IEEE

field. To compensate for the increased velocity of the particles and to match the particles to the acceleration gaps, the drift tubes grow progressively longer along the length of the tank. The increase in length is achieved by lengthening the electrodes which make up the electrostatic quadrupole found in each drift tube. The progressive lengthening of the quadrupole also enhances its focussing capability. Since each electrostatic quadrupole tracks the input to its drift tube (50 kV), its focussing is achieved by adding a biasing voltage of ± 10 kV.

V. Linac - Tank Assembly Construction

The tank assembly (Figure 5) consists of a tank, two drift tube tables, twenty drift tubes with electrostatic quadrupoles, bus, bus connectors, and an assortment of ceramic insulators.

The tank was obtained from another group free of charge and is of stainless steel with an 89 cm (35 inch) inside diameter and 5.33 meter (17 foot 6 inch) length. Existing ports are being utilized for power input and instrumentation feed through.

The drift tube tables are fabricated from stock aluminum channel welded into a configuration which provides a rigid support, minimum machining, and ease of assembly. The tables are mounted to the tank through ceramic insulators.

Each drift tube (Figure 6) consists of two copper plates with three sides rounded to reduce the electrical stress developed by the 100 kV potential across the acceleration gap. A stock size copper tube is soldered to the internal side of each plate to improve the field shape at the bore and also to provide some shielding to the electrostatic quadrupole and its ceramic insulators. The electrostatic quadrupole consists of four copper electrodes of stock bar size. The ends of each electrode are machined to receive a stock cable termination which in turn is soldered to the drift tube end plate. The drift tube assembly is secured to the drift tube table by four threaded rods. The quadrupole is powered through bus wire fed through a clearance hole in the table and tied into insulated bus bar.

As can be seen, the tank assembly is made up of readily available stock size materials, which in turn require a minimum of machining. The hardware, including the ceramic insulators, consists of common "off the shelf" items. This all lends itself to rapid and inexpensive fabrication.

VI. Focusing

The key to getting high current performance in a linear accelerator is large acceptance in transverse phase space. This is achieved by increased bore size, which implies low frequency, and strong quadrupoles. At velocities below $\sim$.03c, electrostatic focusing becomes competitive with magnetic focusing. At B = .002 electrostatic focusing is very much better. A cost savings of about a factor of 100 results from the use of electrostatic rather than magnetic focusing.

References

1. Sanders, R. T., A Low-Cost Rf System for a 2-Megahertz Heavy Ion Accelerator, BNL 50960, Jan. 1979.
2. Keane, J. T., Design of Quarter Wavelength Resonator for 2-Megahertz Heavy Ion Accelerator, BNL 50872, July 1978.

Acknowledgements

The authors are indebted to a large number of people at BNL. Special recognition is due J. Boruch, R. Glasmann, E. Meier and K. Riker.

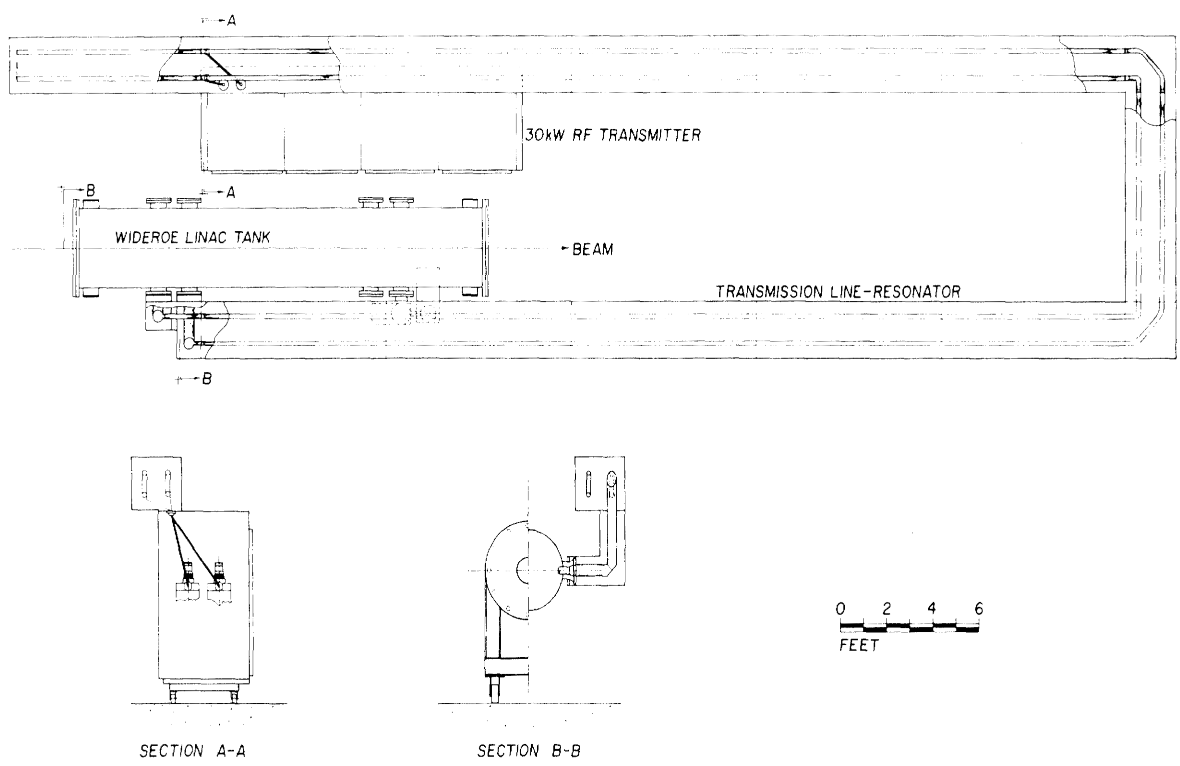

Figure 1. Plan View of 2 MHz Accelerating System

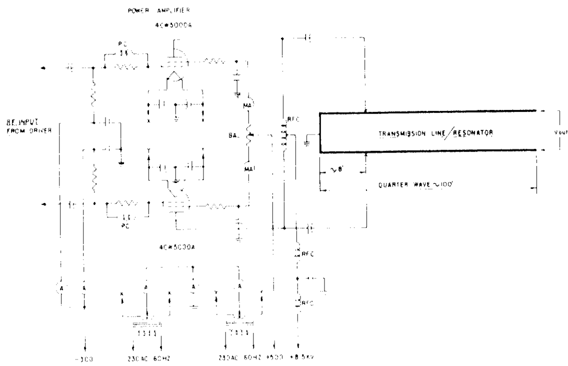

Figure 2. Transmitter Final Amplifier and Resonator

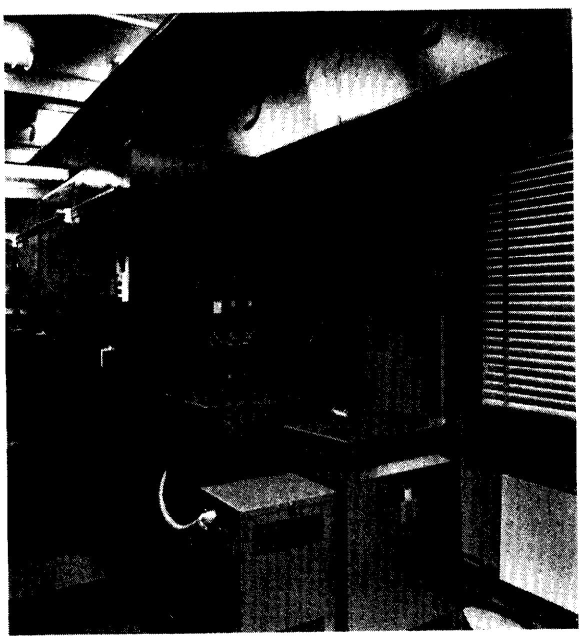

Figure 3. Transmitter and Resonator

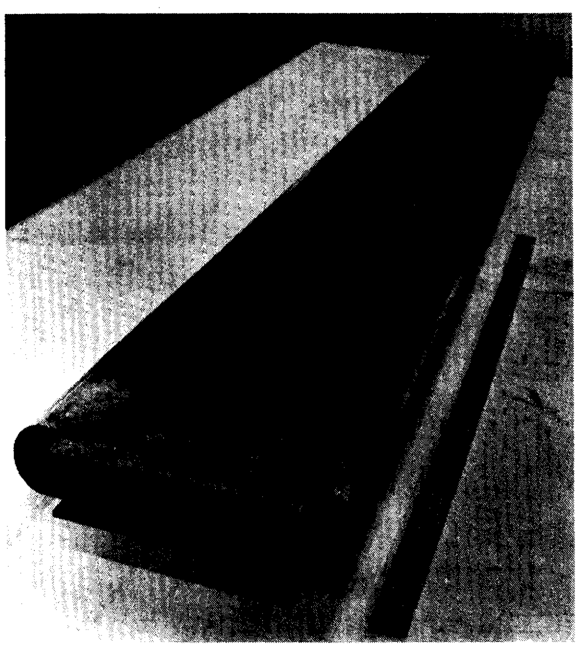

Figure 4. Assembled Slab Line Section

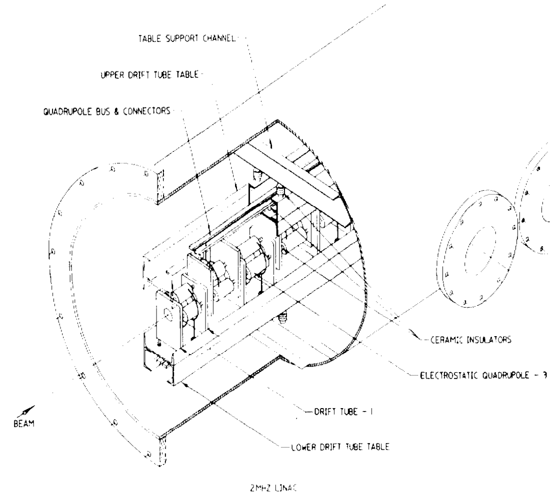

Figure 5. 2 MHz Tank Assembly

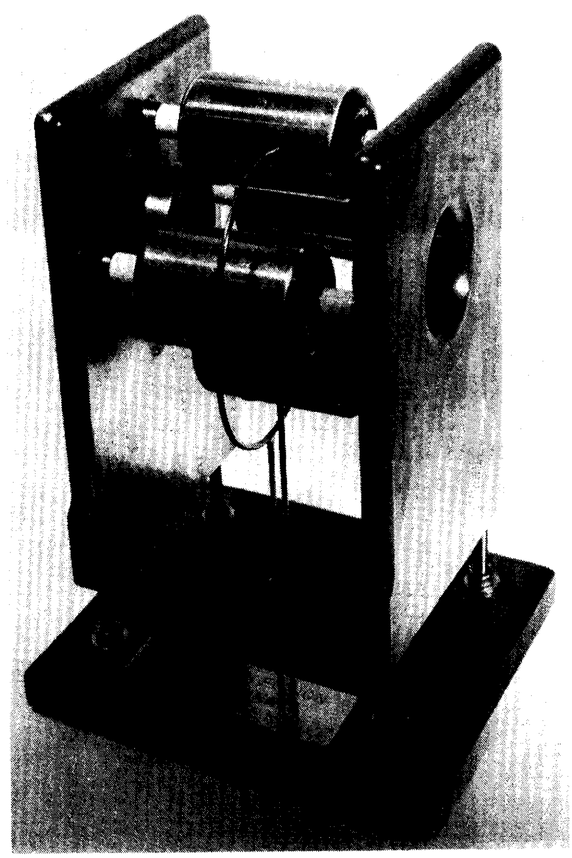

Figure 6. Drift Tube No. 1