FIRST RESULTS ON BNL H− MEQALAC

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INTRODUCTION

The MEQALAC (Multiple-Beam Electrostatic Quadrupole Array Linear Accelerator) concept and its first experimental test have been described previously(1). The test verified that a MEQALAC can transport and accelerate multiple, high brightness beamlets starting at very low initial β(5×10^{-4} in the test). The six-dimensional phase space density per beam, $(\bar{I}/fez)/(\varepsilon_{NL}\ \varepsilon^2_{NL})$ (ref. 2) was $3.3\times10^{29}/m^3$-rad^3. This paper will describe initial results of a second MEQALAC test which explored higher frequency operation with smaller bore size. The current density was higher by up to a factor of seven. This MEQALAC was a four beam H− accelerator(3). Conceivably, it could lead to a replacement for relatively bulky and expensive Cockcroft-Walton pre-injectors.

ACCELERATOR CONSTRUCTION

A BNL Mark III magnetron(4) with a grooved cathode supplied the H− ions. Beam was extracted with a double gap geometry. The first gap, at 2 mm, held off 15 kV DC and the second gap, at $2^{1/2}$ mm, held off 25 kV DC.

Figure 1 shows the four channel accelerator. It consists of a transport section in front (LEBT), followed by the linac section sitting on top of its resonator. The ground shield in front protects the LEBT insulators from DC corona coming from the source. In operaton, this shield was pushed flat against the ground extractor on the source. The main purpose of the LEBT was to simulate the effect of the bunching length required by the eventual addition of a buncher (see Fig. 6). The linac section consists of ten accelerating gaps with a quadrupole inside each drift space. Figure 2a shows some dimensions at the transition from the LEBT into the linac, and Figure 3 shows the resonator design(5). The BNC connectors to the drive and pick-up loops can be seen on the side of the resonator in Figure 1.

LEBT and linac quad construction have been described before(3). Two alignment rods running along the entire structure through holes in the insulators and in the two big ground planes at each end of the linac align these quads with respect to each other and with respect to the beam holes in the linac rf structure. Parts of these rods can be glimpsed in the linac section in Figure 1. The ground plane at the front of the LEBT is screwed to these rods. Each linac quad unit is sandwiched by retainer rings which fix their position on the rods. Retainer rings are also placed on the rods on each side of the two big linac ground planes to keep the rods from slipping.

The linac was designed to accelerate H− from 40 kV to 125 kV assuming 12.7 kV peak rf voltage. The transit time factor was taken as

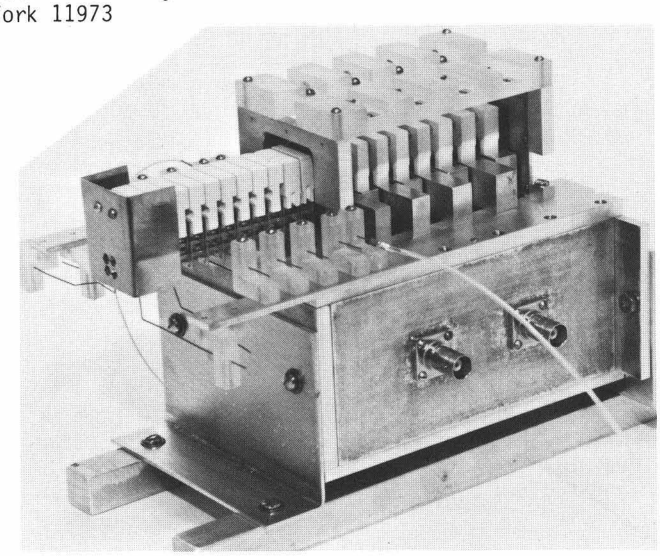

Fig. 1. Four beam H− MEQALAC. 12 quad LEBT in front followed by the linac with 10 accelerating gaps. A buncher could be included by using the LEBT shown in Fig. 6.

$$T = \frac{\sin \pi g/L}{\pi g/L} \cdot \frac{I_0\,(2\pi r/L)}{I_0\,(2\pi aL)}$$

where
g = accelerating gap = 1 mm
a = channel radius = 1.5 mm
L = $\beta\lambda/2$.

Table 1 summarizes the design.

TABLE 1. 4 Beam H− MEQALAC Parameters

Transport Section	
cell length, L_{cell}	13.8 mm
quad radius, r_q	1.5 mm ±10%
# of cells	6
r_q/L_{cell}	0.11
(quad length)/L_{cell}	0.4
Linac	
input $\beta\lambda/2$	6.9 mm
output $\beta\lambda/2$	11.8 mm
quad radius	1.5 mm ±5%
# of accel. gaps	10
gap width	1 mm
frequency	200 MHz

RESULT

For the first test of this MEQALAC, done in mid-February, 1981, a $1^{1/4}$" ID x 1" long tube was placed near the exit of the linac. When biased to >40 kV, only accelerated particles in the four beamlets could punch through. About 100 μA was observed.

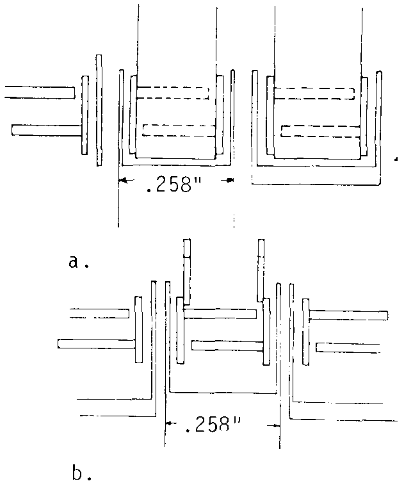

Fig. 2a. Geometry and dimensions of a. the LEBT to Linac transition and b. the buncher region of the new LEBT of Fig. 6. Figures drawn to scale in longitudinal direction only.

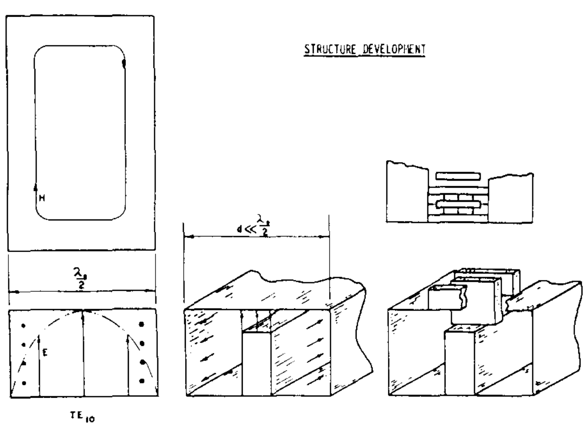

Fig. 3. The resonator is basically a resonant section of ridged waveguide. Inductance per unit length decreases in inverse proportion to β particle velocity). Therefore, capacitance per unit length is made to increase by increasing the tab overlap area (not explicitly shown). Tabs (not shown) added to each end of the ridge reduced the voltage variation in the gaps from 15% to 5% by adjusting their capacitance to ground. E and H represent electric and magnetic fields.

A crossed-field mass analyzer verified that it was all H^-, and then, by electrostatically deflecting a slice of the beam, the energy spectrum was measured. Figure 4a. shows the result. The high energy peak was still too low in energy. It was felt that rf was being capacitively coupled into the drift space via the quad plates, so the transit time factor was actually lower than that given at the end of the introduction. By improving metal-to-metal contacts in the tank, and by eliminating tracking at the drive loop (the connector was changed from BNC to type N), the tank Q was improved, so the rf voltage could be pushed up to 18 kV.

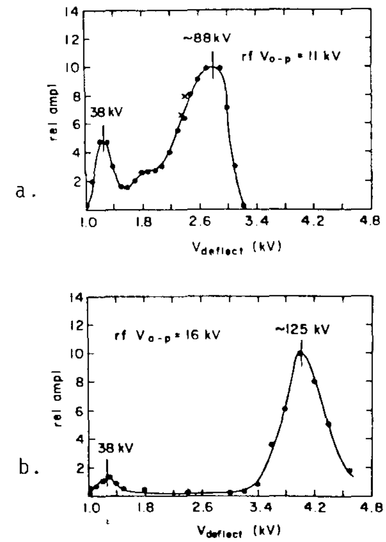

Fig. 4a. Energy spectrum with low rf.
b. Energy spectrum with correct rf, which was about 25% higher then expected. Abscissa is deflector voltage, proportional to beam energy as shown.

At these higher rf levels, electrons were observed streaming out of the linac. Their energy spectrum was taken, and was found to tail off at an energy corresponding to the peak rf voltage as expected, thereby providing an interesting check on the rf calibration. The magnitude of this electron current was comparable to the accelerated H^- current, but a 200 gauss permanent magnet easily swept them away.

The plot of the amplitude of the 120 kV portion of the energy spectrum versus rf level, Figure 5, shows that about 16.5 kV peak rf voltage was actually needed to reach design energy. The accelerated current increased to 400 μA for an input of about 4 mA. Relevant operating conditions are given in Table 2.

In the experiments, sparkdowns made data collection difficult for source voltages greater than about 37 kV or for LEBT quad voltages above ±3 kV. A spark in the source region caused LEBT to spark even if the LEBT quad voltages were under ±3 kV, and vice versa. Both areas were sources of DC corona. Furthermore, the corona increased as operating hours accumulated on the source, perhaps due to deposition of Cs from the source or sputtered Mo from the cathode. Enough power was involved to result in serious thermal loading in some cases. The corona current returned to its original level after cleaning the metal surfaces involved with Alkonox and an alcohol rinse. Pulsing the source and LEBT voltages essentially eliminated the sparking problem. LEBT was pulsed from ground, and the source and intermediate electrode were pulsed from DC values of 25 kV and 10 kV respectively, where almost no corona was ever observed. The linac was not used in these tests.

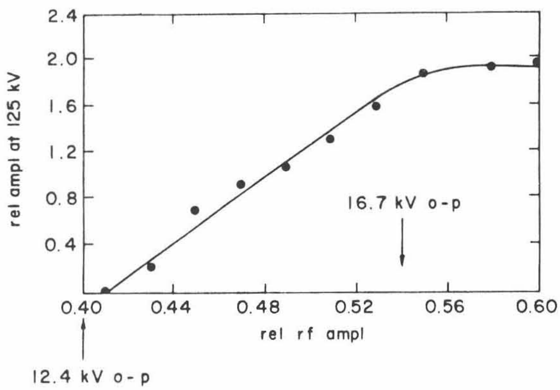

Fig. 5. Accelerated current, relative units, versus gap voltage in relative units. Absolute gap voltages are marked in two places.

TABLE 2. 4 Beam H− MEQALAC, Initial Results (no buncher)

Input energy	40 kV
Output energy	peaked at ~ 120 kV
Total output current	0.4 mA
Current out/ current in	~ 10%
Rf power	6 kW
Rf pulse width	50-100 μs
Peak rf voltage/gap	~ 16 kV
Quad voltage, transport section	limited to ±3 kV DC by sparking
Quad voltage, linac	± 4 kV, pulsed
Ave. vac. pressure	(2-4) x 10^{-5} Torr, pulsed gas
Rep rate	2 pps

CONCLUSION

Accelerated beam was observed at design energy, but the current was low compared to that required from the BNL 750 keV Cockcroft-Walton pre-injector. The LEBT capture efficiency, 25%-30%, could not have been improved too much without a lower source emittance. The linac efficiency, ~10%, should have been around three times better. One reason it was low was that the beam emerging from LEBT was probably not optimally matched into the linac. A new LEBT (Figure 6) with independent quads was made, but never tested with the linac. Another reason may have been rf and DC aperture defocussing effects. An experimental indication of DC aperture defocussing turned up in tests of the new LEBT without the linac. Namely, the voltage on the quad in the buncher was consistently low, and the subsequent quad voltages were high, as if a disruption occurred at the buncher where DC ground planes are inserted (see Figure 2b).

With the new LEBT, 1.5 mA per channel was obtained. Combined with its greater flexibility for matching, 2 mA total accelerated current should be achievable with the buncher on. A further factor of 5 and a second linac tank would be needed to compare with the present BNL Cockcroft-Walton. The second tank would be about two feet long, operate at 50 kV peak rf voltage, and require about 30 kW. However, there are no plans now to continue work on this project.

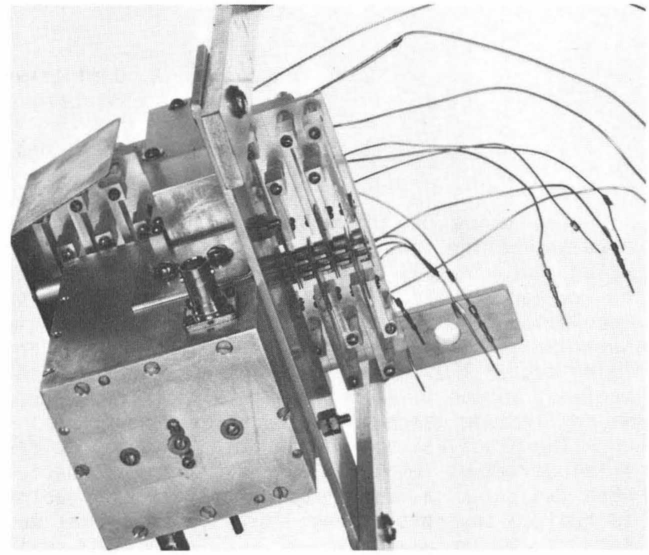

Fig. 6. New LEBT design with double gap buncher included. Drive and pick-up loops are visible on the resonator box. The accelerating gap, separated by βλ/2, protrude into the LEBT as sketched in Fig. 2b.

REFERENCES

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4. K. Prelec, Proc. of the Symposium on the Prod. and Neutr. of H− Ions and Beams, p. 111 (BNL 50727). See also Th. Sluyters and C. Lam, ibid., p. 211.

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Discussion

The MEQALAC quads are not excited by rf, but by dc voltage supplies.

We believe the xenon accelerator operated at the space-charge limit of the channels because the source could provide five times the channel limit current, so most of this was lost. In the new accelerator, the injector provides about one-fourth of the space-charge limited current, but at an emittance about three times the channel acceptance. The matching is also not accurate, and again much of the input beam is lost.

We changed the resonator design (used for the xenon machine) for the new device because a different frequency was used. From gap to gap, the H− MEQALAC is a βλ/2 Wideröe structure.