ION PULSE PROPAGATION THROUGH A PREVIOUSLY UNFILLED ELECTROSTATIC APERTURE LENS ACCELERATING COLUMN

H. L. Rutkowski, S. Eylon, D. S. Keeney
Lawrence Berkeley Laboratory

Y. J. Chen, D. W. Hewett, J. Barnard
Lawrence Livermore National Laboratory

ABSTRACT:

Heavy Ion Fusion experiments require very high current beams with excellent beam quality during a short pulse. Scaled experiments planned at LBL require very short pulses (µsec) compared to what one expects in an HIF driver (20-30 µs). A 1MV acceleration column composed of aperture lenses has been constructed at LBL in order to study the propagation effects on such ion pulses. The column is initially empty of space charge but with the full acceleration potential applied. A short current pulse is then injected into the column with a planar diode "current valve." Effects on the pulse propagation due to rise time, pulse duration, and beam size have been studied. Experiments on transported beam current and emittance have been conducted using a carbon arc plasma source (2" and .5" diameter) and a 1" diameter alumino-silicate potassium ion source. Computer simulations using a 2.5D time dependent code are compared with the experimental data.

INTRODUCTION

In the case of using induction linacs for heavy ion fusion one wishes to build an injector that can accommodate a short pulse 20-30 µs long and at very high current of typically amperes per beam while preserving a high quality electrical pulse. This means that one must have some sort of gating mechanism to inject the pulse into the accelerating column which has already been brought up to voltage, but which contains no charged particles. The column-beam system must come to equilibrium after beam starts to enter the column. Significant distortions in the pulse will cause problems in the succeeding linac transport system.

We have studied pulsed injection into a 1MV electrostatic aperture lens column using carbon arc ion sources and K^+ alumino-silicate sources. The pulse lengths in this case are 1-2 µs because the injector is intended for a scaled experiment which cannot accommodate the longer pulse of a driver because of the cost limit on Metglas available for the machine. The column was originally designed to accelerate a 2 inch diameter 500 mA C^+ ion beam.

EXPERIMENTAL SYSTEM

The injector accelerating column is shown in Fig. 1. It is an electrostatic aperture lens column that operates at a full design voltage of 944 kV. the carbon arc ion source is shown on the left. After the column is brought to full voltage with an approximately critically damped pulse (30 µs risetime) the beam is gated into the column with a "current valve" diode. The valve diode is a planar 9mm gap that can be operated up to 15 kV. There is a 90% transmitting nickel mesh at the exit into the accelerating column. The arc plasma is kept from entering the valve before hand by use of an electrostatic plasma switch.(1) Two versions of this source were used, 2 inch and 0.5 inch diameter, the smaller beam being produced by aperturing the plasma switch. The pulse length and current are varied by changing the pulse forming network that drives the planar current valve diode. The beam was diagnosed in several ways. The most reliable method was the use of a calibrated ferrite core current transformer placed on the back-side of the second ground plate behind the electron trap. Downstream from this transformer a 5 inch diameter aperture, deep (12"), Faraday cup was placed as a beam dump and electron trap. The 5 inch deep collector cup was modified by placing a graphite disk on the rear surface to reduce production of secondary electrons by the beam. The cup suppresser ring (also 5 inches deep) in front of the collector cup and the collector cup could be biased up to 10kV positive to trap secondary electrons. Failure to use this beam dump results in backstreaming secondary electrons passing through the current transformer giving anomolously high current readings. This effect occurs even if the beam is allowed to hit the vacuum chamber wall which is approximately two feet from the column exit. Use of the current transformer allows one to measure total beam current at high levels without intercepting the beam. Using capacitive coupling, collected current can also be measured from the beam dump and from the electron trap electrode. Calculations with the EGUN (2) code were used to verify that the beam would be completely deposited in the beam dump collector only and that secondary electrons would be completely trapped in the dump. Therefore all anomolous beam behavior would have to be due to departures from ideal beam optics. Later on, emittance measurements were carried out using a double slit emittance scanner capable of .2 mrad angular resolution.

COMPUTER MODELING

The column was originally designed using the EGUN code for a steady state, 2 inch, 0.5A C^+ beam at full 944kV design voltage. The 0.5 inch carbon source

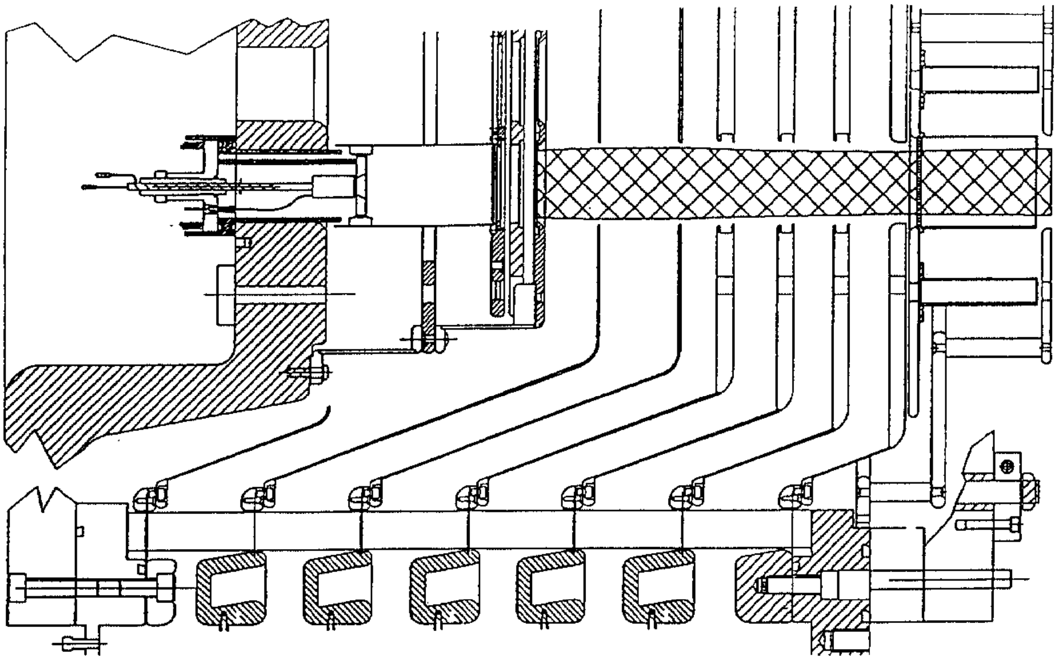

Fig. 1 Accelerating column with carbon arc source installed on left followed by plasma drift region, plasma switch, and current valve diode. Crosshatched area is the calculated beam envelope for a 2" source and starts at current valve exit. Electron trap is the cylindrical electrode before exit ground plate

measurements were modeled in the same way. Beam clearance in the large aperture case was a few millimeters at closest approach, but the ideal beam propagated all the way to the exit without touching electrodes in calculations. The small aperture beam had minimum beam clearances of 18mm. A time dependent simulation using the GYMNOS code was performed for both the small carbon source and a 1 inch diameter K+ alumino-silicate source. Both simulations ran until the 1 μs (nominal) injected current pulse left the column at 2 μs after start. The beam was not seen to hit the electrodes and predicted current levels agreed substantially with EGUN predictions.

EXPERIMENTAL RESULTS

At the beginning of injector tests the carbon arc source was used without the current valve by putting the plasma switch grid at the location of the current valve exit grid. Long pulses were extracted at reduced current because of the geometry change. the extracted currents agreed reasonably with computer predictions. However, when the current valve was installed the propagated pulses were not well behaved even though preliminary tests on a test stand showed that good pulse shapes were coming out of a duplicate valve diode. The thought was that the rise time was playing a role in the behavior of the beam and the rise time was slowed. Some negative spikes were visible on the pulse rise even after it was gradually increased to 1.5 μs.

Tests were then performed using 2.5 μs wide pulses with a 250 ns rise time. The current was measured with the current transformer combined with the beam dump to trap secondary electrons. 500 mA currents at full column voltage were measured which is the expected Child-Longmuir current from the valve diode. However, a negative notch appeared at approximately 0.5 μs into the pulse. The current after the notch was flat. Reducing the pulse width to 1.5 μs resulted in negative current signals from the current transformer. In other words, electrons were exiting the column in sufficient quantities to more than cancel the ion signal. The current signal from the electron trap had the same shape as the negative signal from the beam, but was a positive signal. This indicated that the beam was hitting the electron trap, generating secondaries which then flowed with the beam out of the column. The beam dump showed very similar negative signals compared to the current transformer. Under these conditions the central portion of the pulse was negative and there was a weak positive signal at the beginning and the end of the pulse.

In an attempt to find better beam propagation the carbon source was masked to 0.5 inches aperture. this should have resulted in a 28 mA C^+ beam propagating for the 11.6 kV current valve voltage applied. With the much larger beam clearance provided in this case

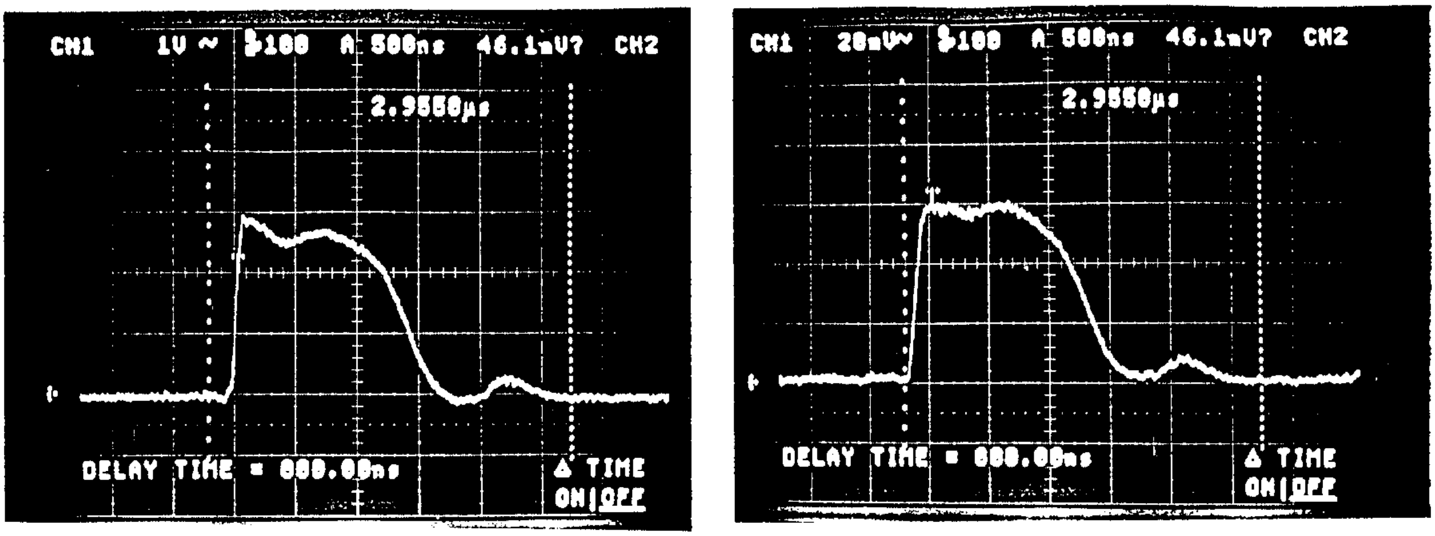

Fig. 2 Current measurements at column exit, (left) beam dump, (right) current transformer, for 1 inch potassium alumino-silicate source, 800kV column voltage, peak current 59 mA in each case.

positive signals were seen, but they were quite erratic in magnitude. The beam dump measurements gave a current of 24 mA ± 4mA at full operating voltage on the column. The current transformer signals were much higher, about twice the expected current and with very large error bars. Both the EGUN simulations and the GYMNOS simulations showed the beam propagating down the column without hitting electrodes.

The one inch alumino-silicate source was installed. After calibrating the temperature of the source as a function of input power, beam was propagated down the column. The current signals from the column became much more reproducible and there was almost exact agreement between the current transformer and the computer simulations. The beam dump current was low, but this was later shown to be a result of a defective capacitor in a coupling box which attenuated the beam signal while maintaining voltage on the beam dump collector cup. The beam propagated was 82 mA, K^+ at 904 kV column voltage with a 1.5 μs (0 to 0) pulse width.

After the initial current measurement with the hot potassium source, the column had to be used at reduced voltage because of breakdown problems not related to the source. Operating at 800 kV column voltage, beams were propagated using different grids in the current valve. Substituting a 200 x 200, 50% transmitting stainless steel mesh gave 79 mA beams with normalized emittance of 2.6×10^{-7} π m-rad. Removing the grid altogether gave a current of 20 mA and a normalized emittance of 5×10^{-8} π m-rad. This second case had a very narrow beam of 2.4 mm diameter. These results were in agreement with GYMNOS simulations.

CONCLUSIONS

These experimental results indicate that in propagating the large diameter carbon beam from the plasma source, the beam hit at least the electron trap at the column exit. This was probably caused by an unstable ion emission surface at the plasma switch. Substituting the solid surface hot source improved propagation and agreement with simulations to such an extent that the emission surface stability must be the prime suspect in causing poor beam propagation. The hot source is now being used as the main approach to building an injector for these scaled experiments.

REFERENCES

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