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EXPERIMENTS ON THE ACCELERATION AND TRANSPORT OF MULTI-KILOAMPERE ION BEAMS

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Abstract

The Pulselac C accelerator is being constructed to study the properties of space-charge-neutralized ion beams and to demonstrate the feasibility of controlling high ion fluxes. A gas-injection plasma gun has been developed which can supply over 50 A/cm^2 of N^+ or other intermediate mass ions. This source supplies ion flux for the magnetically insulated extraction gap. The source and extractor produce a 100 kV, 5 kA annular ion beam which propagates into a diagnostic region. Diagnostics, including a Thompson parabola mass spectrometer, a magnetic spectrometer, magnetically insulated detectors, and biased charge collectors, have proven the purity and uniformity of the beam and have given preliminary information on its propagation characteristics. Further experiments on the injector will include focusing using a toroidal lens and studies of beam aiming from the extractor gap. Two inductive post-acceleration stages, presently under construction, will increase the beam energy by 500 keV.

Accelerator Features

A preliminary configuration of the Pulselac C accelerator with one inductive stage is shown in Fig. 1. The plasma gun and extractor are presently in operation. Two post-acceleration stages and a toroidal field lens are being assembled. The plasma gun consists of a pulsed gas valve and deflection nozzle which produce a gas layer near a glass surface. A fast capacitor bank is discharged into a spiral coil beneath the glass surface. The gas is ionized and accelerated forward by radial magnetic fields to generate ion fluxes equivalent to 50 A/cm^2 or greater. The source has several advantages over other sources such as flashboards. The ion species can be selected by changing the injected gas, the plasma is relatively pure, and the system can be fired thousands of times without damage. It currently is operating at a repetition rate of 1 ppm.

The plasma from the source drifts 10 cm to an azimuthally slotted field excluding plate which acts as the anode of the extractor gap. The plasma gun assembly and field excluder are pulsed to 100 kV by a 4:1 isolation transformer. Power is brought to the plasma gun through the transformer secondary. The injector gap is magnetically insulated by

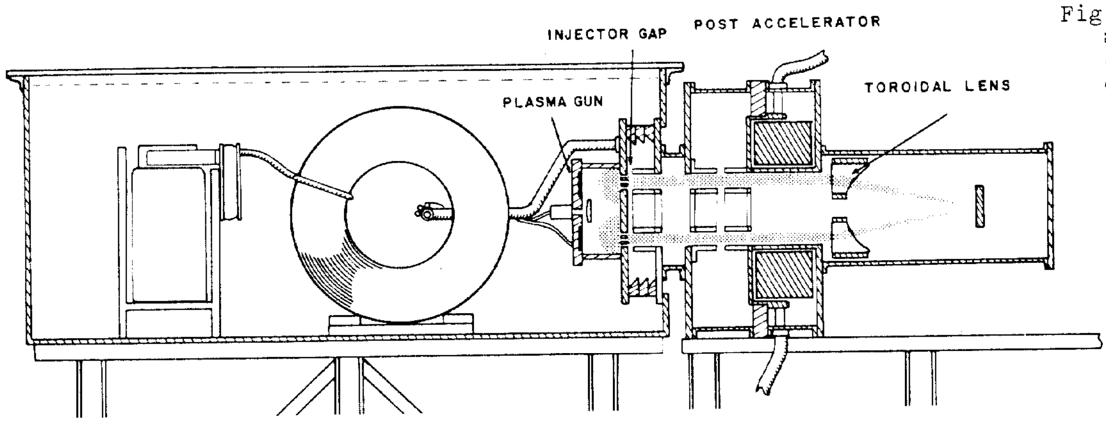

Fig. 1. Pulselac C accelerator with one inductive cavity.

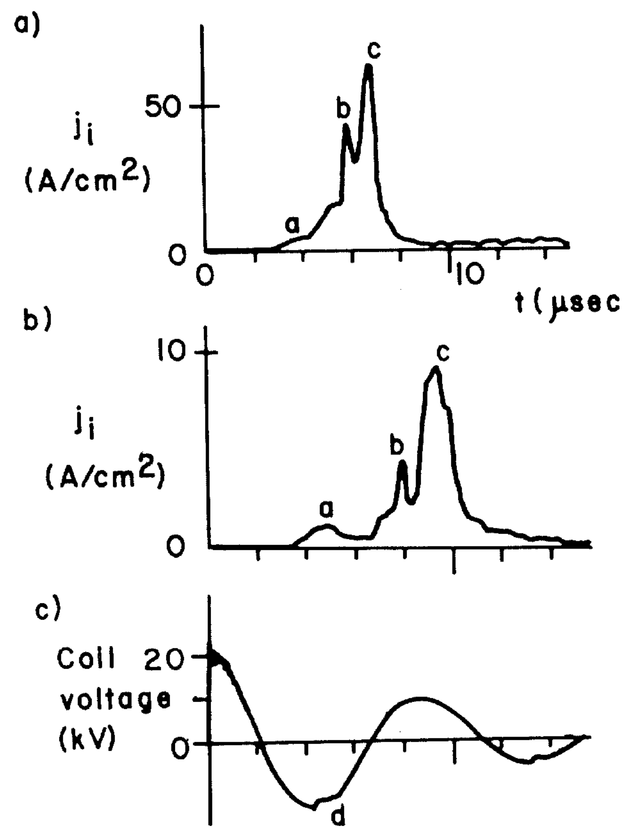

Fig. 2. Plasma gun characteristics. a) Ion flux 15 cm from coil. b) Ion flux at 35 cm. c) Coil voltage. Features of traces - a: UV radiation, b: proton precursor, c: high energy nitrogen ions. d: inductive coupling to plasma.

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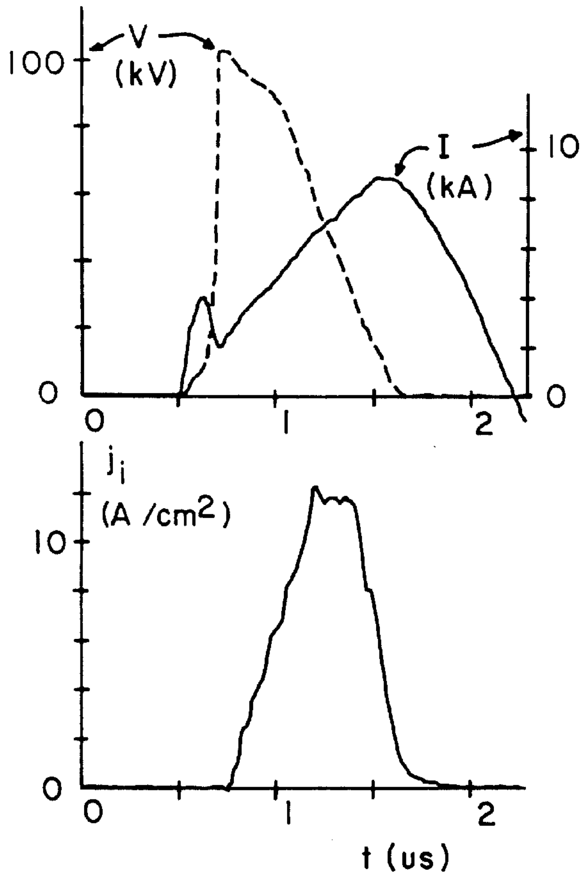

Fig. 3. Voltage, current and downstream ion current density from extractor.

coils opposite the field excluder. Voltage and current traces for the extractor are shown in Fig. 3. The gap behavior can be divided into three phases. Since the plasma arrives at the gap before the main voltage is applied, there is a clearing phase with low voltage and rising current. This ends with an abrupt drop in current and rise in voltage. In this second phase, the current is determined by the incoming flux of ions. During this time, the voltage remains relatively flat. After about 0.5 μs, the current begins to rise and the downstream ion flux decreases. This is the final phase when the extractor gap has significant electron leakage. The leakage is caused by the movement of electrons along field lines connecting anode to cathode. In post-acceleration gaps this does not occur. The field geometry is produced by two sets of coils and there are no connecting lines. When electron leakage dominates in the extractor, the voltage eventually drops to zero.

Following the extractor, additional beam acceleration will be accomplished using coventional linear induction accelerator technology. This is combined with neutralized transport using magnetically insulated gaps and electron sources in the drift regions. A toroidal magnetic field lens will be used after the final acceleration stage to focus the beam to the axis.

Diagnostics

In initial operation of the extractor, several diagnostics have been used to

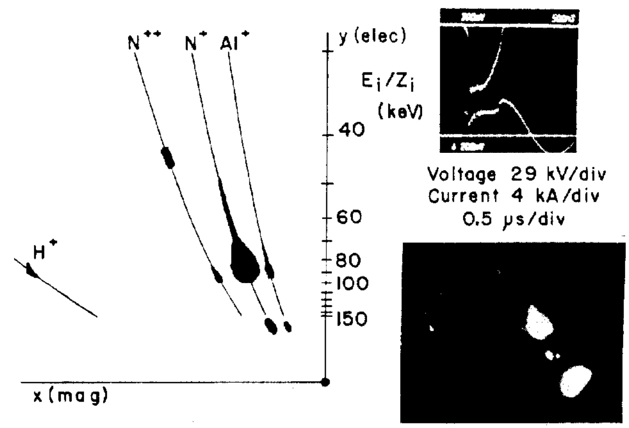

Fig. 4. Output of Thompson parabola mass spectrometer with corresponding voltage and current traces for nitrogen gas injection.

determine the beam characteristics. A trace from a magnetically insulated detector is shown in Fig. 3. The probe measurement agrees well with that predicted from the extractor current during the second phase. This indicates low electron leakage. Output from the Thompson parabola mass spectrometer is shown in Fig. 4. This diagnostic indicates ion species present but gives little information on their relative abundance. Using output from a time-resolved magnetic spectrometer (such as that shown in Fig. 5), it has been determined that with nitrogen injection the relative fractions of N^{++} and Al^+ are small compared to N^+. This has been confirmed by time-of-flight analysis. An example is shown in Fig. 5-2.

A magnetically insulated probe has been developed to measure the high ion current densities extracted. As shown in Fig. 6, the beam passes through a small aperture (0.5 - 1.0 mm) into a transverse magnetic field. A narrow conducting tube around the beam shorts out polarization fields allowing electrons to be stripped from the beam. The ions then emerge into a drift region where they expand and are collected in a second tube. An array of these detectors has been constructed to measure beam radial profiles. An example is

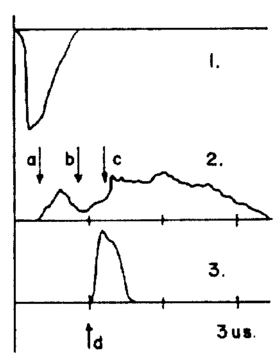

Fig. 5. Time-resolved mass-determination diagnostics. 1) Injector voltage profile. 2) Time-of-flight detector at 1.3 m. 3) Magnetic spectrometer output in 80-90 kV channel for N^+. Arrival times are a: p^+, b: N^{++}, c: N^+, d: N^+.

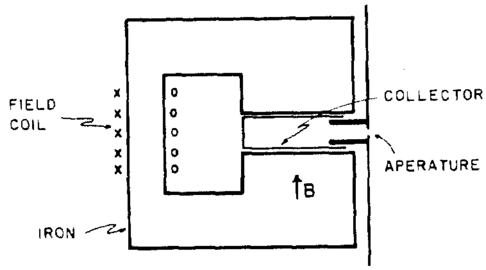

Fig. 6. Magnetically insulated probe for high ion current density measurements.

shown in Fig. 7. The beam has a rather broad profile early in time, but there is an indication of focusing toward the drift tube center as the current increases. The probe array will be used to make measurements of beam aiming and divergence from the extractor gap.

Post-Acceleration Stages

A schematic diagram of the post-acceleration stages under construction is shown in Fig. 8. The insulating field for the acceleration gap is produced by two sets of magnet coils. The gap is inductively isolated by ferrite cores immersed in oil. The voltage to drive the gaps is supplied from a 12.5 Ω, 60 ns, 250 kV Blumlein line connected to the cavity by high voltage coaxial cables. Electron sources will be located in the drift regions adjacent to gap. These will supply free electrons for beam neutralization. Studies on the system will center on electron neutralization, focusing effects in the gaps, interactions of the beams with the cavities, and the effect of post-acceleration on the beam emittance.

Conclusion

The Pulselac C experiment is providing information on the generation and propagation of high current ion beams. The plasma source and extractor are operating in a repetitive mode with currents exceeding 5 kA. Diagnostics with a Thompson parabola mass spectrometer, magnetic spectrometer, and time-of-flight detectors indicate that the beam is relatively pure. The ion flux agrees with the total injector current over most of the power pulse. New diagnostics have been developed to determine the propagation characteristics of the beams. Post-acceleration modules will soon be on-line. These modules will be used to test neutralization, transport, and focusing of the beam in the acceleration gaps and drift regions. Focusing experiments are planned with a toroidal magnetic field lens.

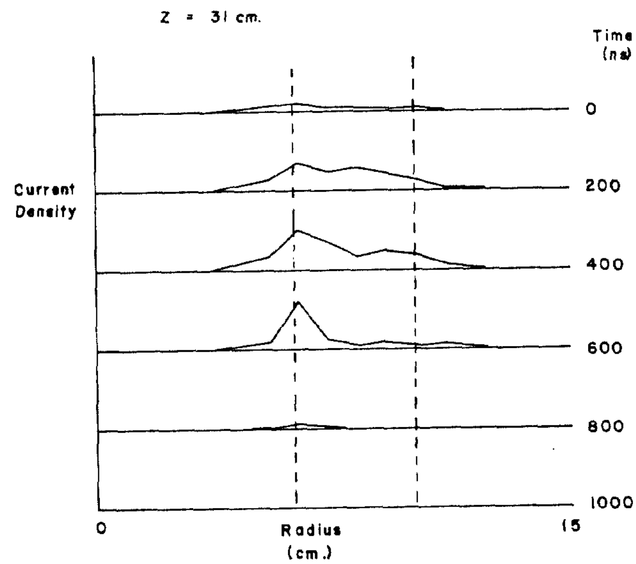

Fig. 7. Radial beam profiles at various times in the extractor pulse at a location 31 cm from the gap. (Dashed lines represent inner and outer dimensions of the extractor gap.)

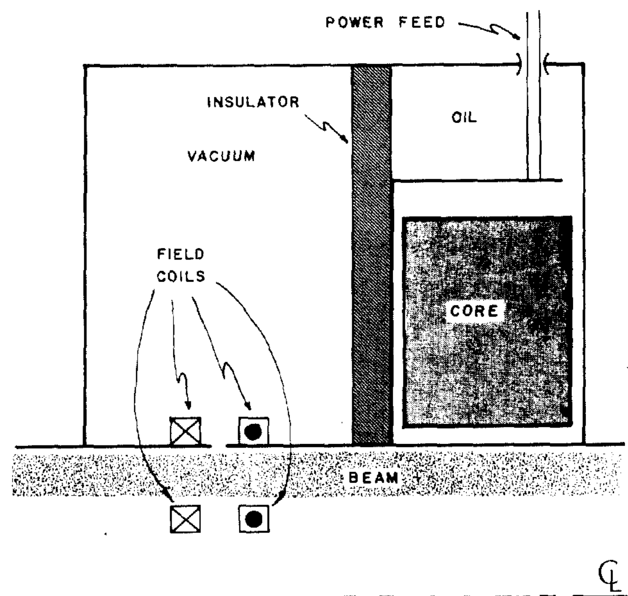

Fig. 8. Block diagram of an inductive post-acceleration module. (Electron sources are not shown.)