K$^+$ DIODE FOR THE LLNL HEAVY ION RECIRCULATOR ACCELERATOR EXPERIMENT*

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ABSTRACT

An 80keV K+ diode source that will deliver up to 9mA of beam current has been developed for the LLNL Small Recirculator experiment [1]. The diode consists of a hot plate alumino-silicate (Zeolite) source, a graphite Pierce electrode, and an exit extraction electrode. The K+ source emitting surface is planar, and one inch in diameter. A fine (70 line/inch) high transparency (90%) mesh is placed in the exit beam extraction electrode. The exit mesh reduces the sensitivity of the diode optics to possible variations in the diode gap and exit aperture shape, without a growth in the beam emittance. Numerical EGUN simulations were used for the diode physics design. The simulations showed that the diode can deliver a uniform 9mA K+ beam with a normalized emittance of about 0.05 mm-mr, resulting mainly from the source temperature at 1000°C. The beam at the diode exit is aperture to a diameter of 11mm to meet the recirculator experiment requirements of a 2mA beam with 0.01 mm-mr normalized emittance. The 80kV source acceleration potential is provided by a thyratron switched, 4µS long 8-section PFN which drives a 1:10 step-up pulse transformer. We shall report on the source performance including measurements of the beam total current, current density profile, phase space profile, angular divergence, and transverse emittance.

I. THE INJECTOR SYSTEM

A. Introduction and Requirements

A small-scale recirculator experiment is being built at the Lawrence Livermore National Laboratory to study the feasibility of recirculating induction accelerators for future heavy ion fusion applications. The injector system for this scale model experiment is required to deliver a K$^+$ ion beam with a normalized emittance of less than 0.1 mm-mr at an energy of 80 KeV. The injector is to provide a 4µs wide beam pulse at a current of 2mA, operating at a pulse repetition rate of 10 Hz.

B. Injector Design

The injector system shown in Fig 1 consists of an hot plate contact ionization source which emits a K$^+$ ion beam into a diode configuration. The source is mounted on a Pierce shaped graphite plate anode connected to a 80kV pulser. The beam, focused along the diode passes through a fine mesh into the injector electrostatic quadrupole (ESQ) matching section.

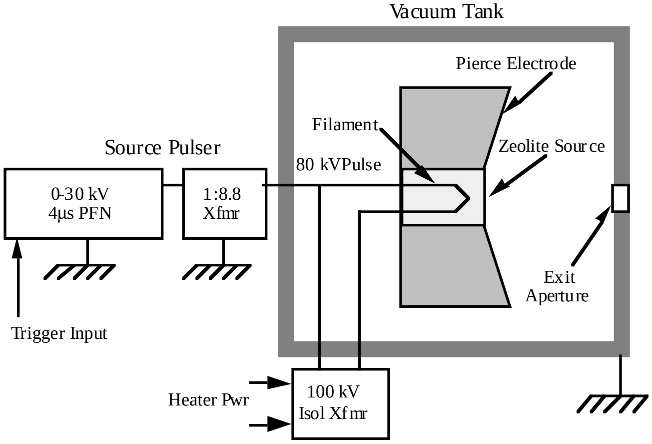

Fig. 1. Block diagram of K+ ion injector system.

Beam parameters needed for characterizing and matching the injector can be monitored at the source and the injector exits. Time resolved total beam current is measured using Faraday cups [2], beam envelope, phase space (transverse rms emittance) and current density profiles can be measured using slit-slit cup scanners [2] and beam longitudinal energy using an electrostatic coaxial bend energy analyzer [2].

C. Source Design

The source uses a standard 1" diameter flat Spectra-Mat source cup. The cup has a porous tungsten surface which is coated with a layer of alumio silicate. To emit ions (above emission limit) the source coated surface is heated to about 980°C. The source heater power (about 150W) is delivered through a high voltage isolation transformer to allow connection of the source emitting surface to an 80kV pulse anode voltage. The source intrinsic normalized emittance ε_n of 0.02 mm-mr (due to source surface temperature) is given by

$$\varepsilon_n = 2a\left(\frac{kT_f}{m_i c^2}\right)^{1/2}$$

were m_i=40 is the ion mass, a=6mm is the beam radius, c=3e8m/s, and T_f=1273 °K is the source surface temperature. The diode geometry was designed using

EGUN code calculations [3]. Fig 2 shows the resulted diode geometry and the ion beam trajectories in the diode.

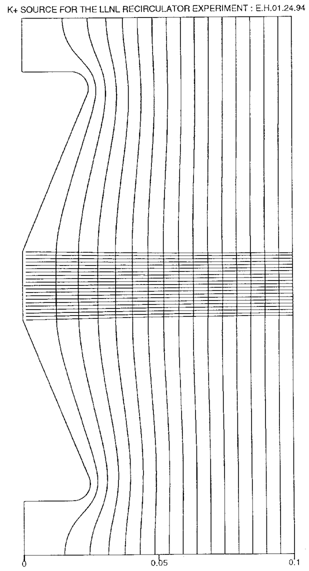

Fig. 2 EGUN evaluation of source ion trajectories.

The diode current is limited to 2mA using a 1cm diameter aperture in the diode exit plate (ground potential). To improve the diode beam optics a fine mesh is placed on the diode exit aperture. The mesh parameters (70 line/inch, transparency of 90%) were determined in early experiments [4] showing no degradation in the beam emittance when passing through the mesh.

D. Source Pulser

The source is pulsed on with a +80 kV - 4µs electrical pulse. The 4µs pulse is generated from a triggered pulse forming network (PFN) connected to a 1:8.8 high voltage step-up transformer. Fig. 3 shows the pulser circuit, and Fig 4 shows the pulse waveform. The pulser is capable of continuous operation at a repetition rate of 10 Hz.

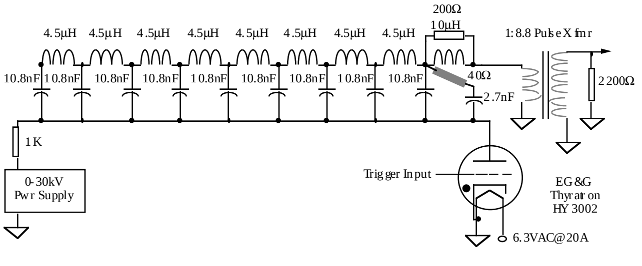

Fig. 3 Schematic diagram of injector pulser PFN.

Approximately 150 watts of filament power is required to heat the ion source to operating Since the ion source is pulsed to +80kV, the filament circuit must be electrically isolated from ground potential, and a 200kV isolation transformer is used for this purpose. Both the isolation transformer and the 1:8.8 step-up transformer are located in a tank containing Dyala oil for electrical insulation.

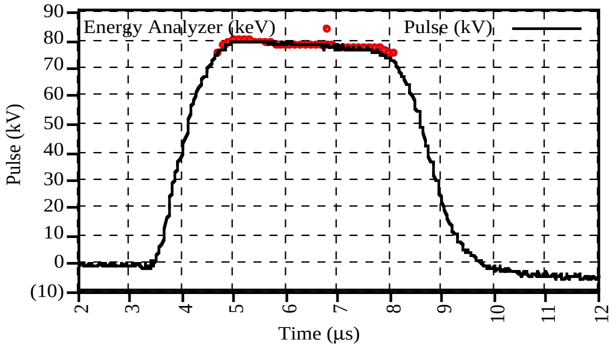

Fig 4. Ion source pulser waveform and measured beam energy.

II. INJECTOR SOURCE AND BEAM CHARACTERIZATION RESULTS

The source surface temperature was measured using a hot wire pyrometer. Fig 5 presents the source temperature T_f dependence on heater power W_h, showing that a P_h of 200W is needed to obtain a working T_f of 970°C.

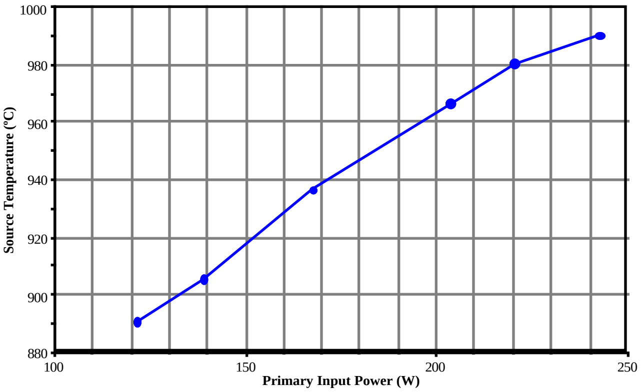

Fig. 5. Source temperature vs input power.

Beam parameters were measured at the diode exit and injector matching section exit were measured and compared with the physics design calculation. Fig. 6 shows the beam total current wave form measured using a Faraday cup at the injector exit. One can see a fast rise about 0.1 µs in the measured current wave form compared with 1µs in the diode pulser voltage wave form. The slow rise in the diode voltage generates slow ions in the beam head leading to a time compressed rise in the beam current. This observation is consistent with beam transient simulations along the injector using the HINJ [5] code.

Improving (shortening) the diode pulser rise time will improve the shape of the beam head.

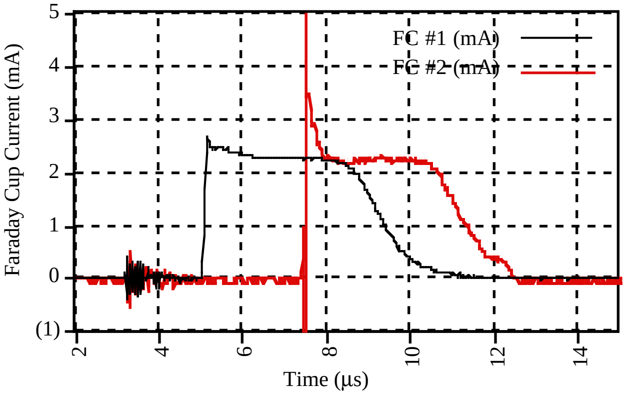

Fig 6. Ion beam current measured at the diode exit and at the end of the beam matching section.

Fig. 4 also shows the measured beam longitudinal mean energy wave form, using an electrostatic 90 deg. bend at the matching section out put. The measured beam energy was found to be consistent with the measured diode pulser wave form Fig 4. The beam transverse dynamics i.e. the beam transverse phase space density profile in x,x' (horizontal direction) and y,y' (vertical direction) were measured using the slit slit-cup beam scanners. Beam phase space measurements at the source exit, Fig 7, showed a beam radius (circular symmetry) of 6mm consistent with the diode exit aperture diameter of 12mm and a divergence of 3mr. This measurement together with Faraday cup beam current measurements at the diode exit were found to be in agreement with the diode design EGUN simulations. The measured 80kV beam un normalized rms transverse emittance was 4 mm-mr leading to a normalized emittance of 0.03 mm-mr, consistent with the above calculated beam normalized emittance of 0.02 mm-mr (beam radius of 6mm) due to the source surface temperature.

These measurement results (at the diode exit) were used as the beam input parameters to the MATCH code beam matching calculation. Following the MATCH code calculations, the quadrupoles voltages were set for matching conditions. The matched beam phase space profile in the vertical direction at the matching section exit was measured. The measurement was repeated with the quadrupoles voltage polarities switched to allow the measurement of the beam phase space in the horizontal direction. The measured beam parameters were consistent with the MATCH code calculation. The MATCH code being a 2D code does not incorporate the curved shape of the quadrupole ends. To improve the calculation accuracy one can use available 3D beam simulation or an effective quadrupole length that can be obtained either experimentally or by using 3D simulations.

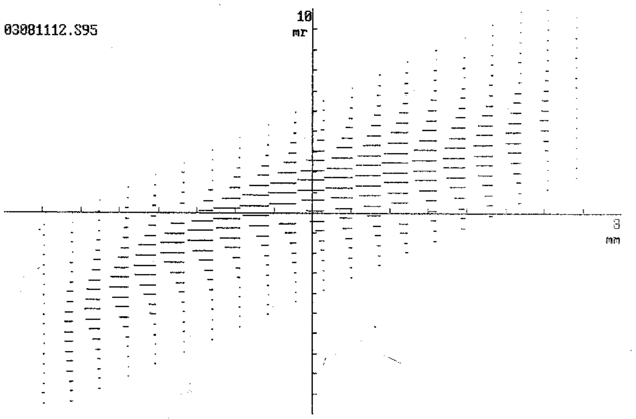

Fig 7 Unnormalized emittance scan of beam at diode exit.

III CONCLUSIONS

The performance of the injector has met our requirements in terms of beam current, emittance and energy level. Further work on the pulser to improve the risetime and voltage flat-top will be needed for operation with the recirculator.

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IV. REFERENCES

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