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ENGINEERING CONSIDERATIONS OF THE DUOPIGATRON ION SOURCE*

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Summary

In developing an injector system at ORNL with capabilities necessary for high power injection into ORMAK, several engineering problems must be solved. Emphasis is given to the design and fabrication of the system to achieve electrical stability, power dissipation, beam optics, beam quality, high efficiency and reliability.

Introduction

The duoPIGatron ion source has been developed at ORNL for neutral injection heating of the ORMAK plasma. The development and design of the ion source reflects the goals of satisfying the physics requirements of ORMAK while maintaining the efficiency, simplicity, low impurity content, and structural versatility that makes this system applicable to future CTR research. The 7 cm diameter source is capable of delivering 8 A of 25-35 keV hydrogen ions with ≈ 50% gas and power efficiency for 0.1 to 0.2 sec pulses at a 5-10% duty cycle.

Description of Plasma Source

The duoPIGatron shown in Fig. 1 is a test stand version of the sources now being used on ORMAK. The source is divided into three sub-assemblies to make the system more accessible, versatile, and easier to assemble. The top assembly contains the filament, intermediate electrode and anode. The filament is made of 1/16-in. diameter tantalum wire 10-in. long wrapped with one layer of platinum gauze and formed into a bifilar shape. The filament is dipped 3 or 4 times into a BaSr carbonate solution with about one hour of air drying between dips. The filament is outgassed at ≈ 45 A before being installed in the source and is operated at ≈ 35-40 A. The filament is supported by stainless steel posts passing through Kovar fittings which are hard soldered into a copper flange. The 1/16-in. diameter tantalum wire is required to carry the 50-80 A of arc current. The stainless steel posts connected to the arc supply are sleeved with ceramic tubing to prevent discharges to this electrode. The filament assembly also includes the source gas feed system. This consists of a remote controlled, motor driven needle valve and a pulsed gas valve. These are used with only stainless steel tubing and valving to insure low gas impurity.

The intermediate electrode is made of soft iron which is furnace brazed to water cooled copper. The iron shields the plasma formation region of the source from a magnetic field and shapes the magnetic field lines in the PIG discharge region. A water cooled, removable, copper liner is placed inside the intermediate electrode to prevent heating of the iron from the power produced in the filament region.

The intermediate electrode is electrically connected to the anode through a 200-500 Ω resistor and operates at a self biased potential between cathode and anode determined by the plasma. It is insulated from and aligned with the anode with a 2-in. I.D. ceramic ring which is shielded from the discharge by re-entry copper cylinders. The inside diameter of the intermediate electrode is scaled simultaneously with the anode and target cathode to create an efficient optimum plasma for ion extraction. The anode is water cooled copper and easily handles the power from the 50-80 A ≈ 100 V discharge. The anode geometry is scaled along with the cross section of the target cathode to produce the optimum plasma profile.

Description of the Extraction System

The ion extraction region is composed of three multiaperture electrodes that are utilized in an accel-decel arrangement. This electrode configuration permits ion extraction while simultaneously creating a localized electric field to prevent electrons from reaching the ion source from the ion beam drift region. This localized electron trap allows an adequate density to be created by the ions in the beam drift region for space charge neutralization. The three extraction electrodes are 0.060-in. thick, water cooled copper with 0.150-in. apertures located on 0.175-in. centers. The 8 A source has 221 apertures within a 3-in. diameter with a resulting transparency of 54%. The electrodes as shown in Fig. 2 are water cooled with a combination of 1/4-in. copper lines on the periphery and either 1/8-in. or 1/16-in. lines located across the electrode such that no aperture is more than two webbing lengths from a cooling line. The copper water lines are hard soldered to the electrodes before the apertures are drilled using a tape controlled drilling machine. The preparation of these electrodes to facilitate high voltage cleanup is to chemically polish the surface to remove burrs from the apertures, then finally vapor blast the surface to remove oxides just before assembly.

The second sub-assembly of the system contains the target cathode which is the first of the three electrodes. This electrode is connected to the anode through a 500 Ω resistor and operates typically slightly positive with respect to the intermediate electrode. This electrode is easily removed from the source assembly either as an individual unit or as an entire sub-assembly from the epoxy insulator. The electrode is aligned with the other two electrodes by either three or four radial adjustment screws located around the perimeter. Once the electrode is aligned both optically and with a series of alignment pins, it is securely clamped in place to prevent any movement. The target cathode is machined and drilled as a plane-surface but then is formed on a mandrel to a concave surface with a radius of curvature that is determined from the radial density profile of the ion source plasma. This curvature is in the direction to reduce the central spacing between the target cathode and the accel-electrode to adjust the electric field in proportion to the density gradient. This allows all of the source apertures to operate near the maximum extractable space charge limited current where the current is maximum and the ion optics are best. The target cathode is electrically connected to the positive terminal of the high voltage acceleration supply.

The third sub-assembly of the source is composed of the accel and decel electrodes and the high voltage insulation. The insulator is an epoxy made from a

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mixture of 40 parts by weight of Versamid 140 hardener to 100 parts of Shell Epon 815 resin. This epoxy has good vacuum properties and can be machined to the necessary tolerances. The 1-1/2-in. wide surface located between the target cathode assembly and the accel electrode has ≈ 1/8-in. wide and 1/8-in. deep convolutions machined into the epoxy both to increase the insulation path along the surface and to shadow some of the surface from conductive materials sputtered from the electrodes by ions in the extraction region. The epoxy has stainless steel rings imbedded in it to prevent long term deformation of the epoxy by the "O" ring that can eventually lead to small vacuum leaks. We have never had an electrical failure of these epoxy insulators up to voltages of 80 kV. There were surface leakage breakdowns along the epoxy surface between the target cathode and accel electrode before the convolutions were added. These breakdown paths could be removed by re-machining the surface and the insulator could then be used again. A long surface insulating path is created on the atmospheric side of the epoxy by adding an epoxy cylinder as shown in Fig. 3. This type of cylinder also allows the injector to be used in a re-entry arrangement into the ORMAK device.

The accel electrode is mounted to a copper plate through which the water cooling lines pass. Alignment is assured by close tolerance machining between the copper and epoxy. "O" rings make the vacuum seal to the epoxy. The accel electrode is machined and drilled as a flat surface and then formed to a radius of curvature corresponding to the desired beam focal length. This shapes the electric field in the beam extraction region to focus the ions from the apertures located at the largest radius to a chosen focal point. This particle focusing will be even more important for future sources with larger cross sections. The accel electrode is typically operated at ≈ -1 to -1.5 kV and has a drain of ≈ 0.4 A with 8 A of extracted ions. This 0.4 A includes the ions impinging on this electrode and the resulting secondary electrons current which is several times the ion current.

The decel electrode which is operated at ground potential is also mounted by its water lines to a stainless steel plate which is insulated from the accel electrode by a second epoxy plate. The water lines allow enough flexibility so that the decel electrode can be attached to and aligned with the accel electrode with three 1/2-in. shielded ceramic insulators. The decel electrode is formed with the same radius of curvature as the accel electrode with a spacing of 0.080-0.125-in. between them.

Figure 4 shows the hydrogen current to a 9 cm diameter target spaced 1 meter from the source, plotted versus the total hydrogen beam extracted from a 7 cm diameter duoPIGatron source at 25 keV. The center curve is the calorimetrically measured current at the target. In the lower curve the numbers have been converted to kilojoules. The upper curve is the H^0 equivalent applying measured ion species fractions and gas cell pressures.

Conclusions

In summary, this plasma formation and ion extraction system of the duoPIGatron ion source is a very simple, efficient system and these sources have been used for 100's of thousands of 0.1 sec pulses with no deterioration in performance. All of our present indications are that we can continue to scale these sources from the present 7 cm diameter, 8 A systems to the future 15-20 cm diameter, 30-50 A systems. Based on present plasma and ion optical studies, we are optimistic not only that one can scale the source to the required current level but that one can simultaneously improve the efficiency and beam optics. Improved cooling techniques now being studied should allow the source to be operated for time periods of seconds. We presently operate the source up to ≈ 35 kV and therefore next generation injection heating requirements of 40-50 kV are a relatively small extrapolation.

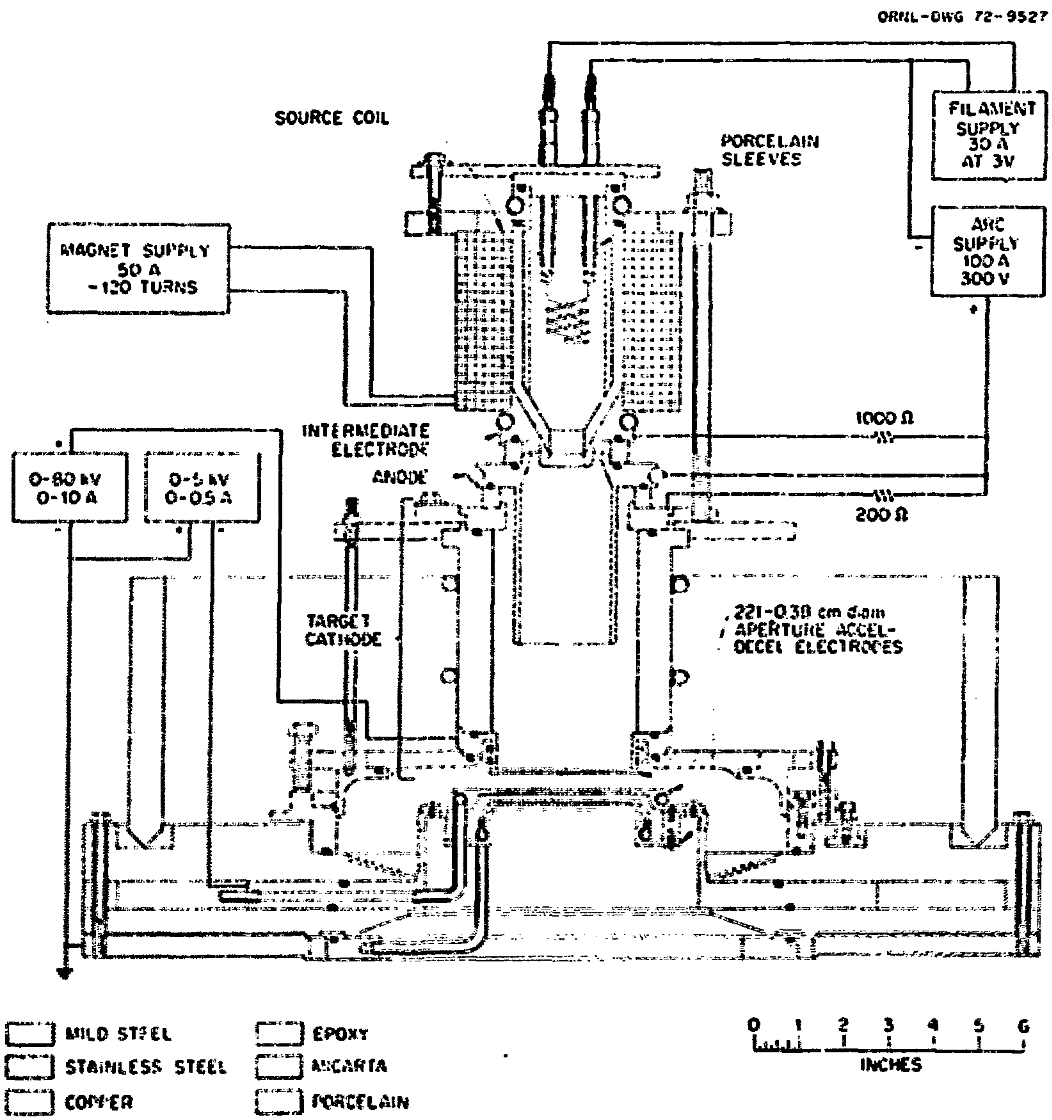
Figure Captions

Fig. 1. Test Stand Version of the DuoPIGatron Type Ion Injection System Used on ORMAK.

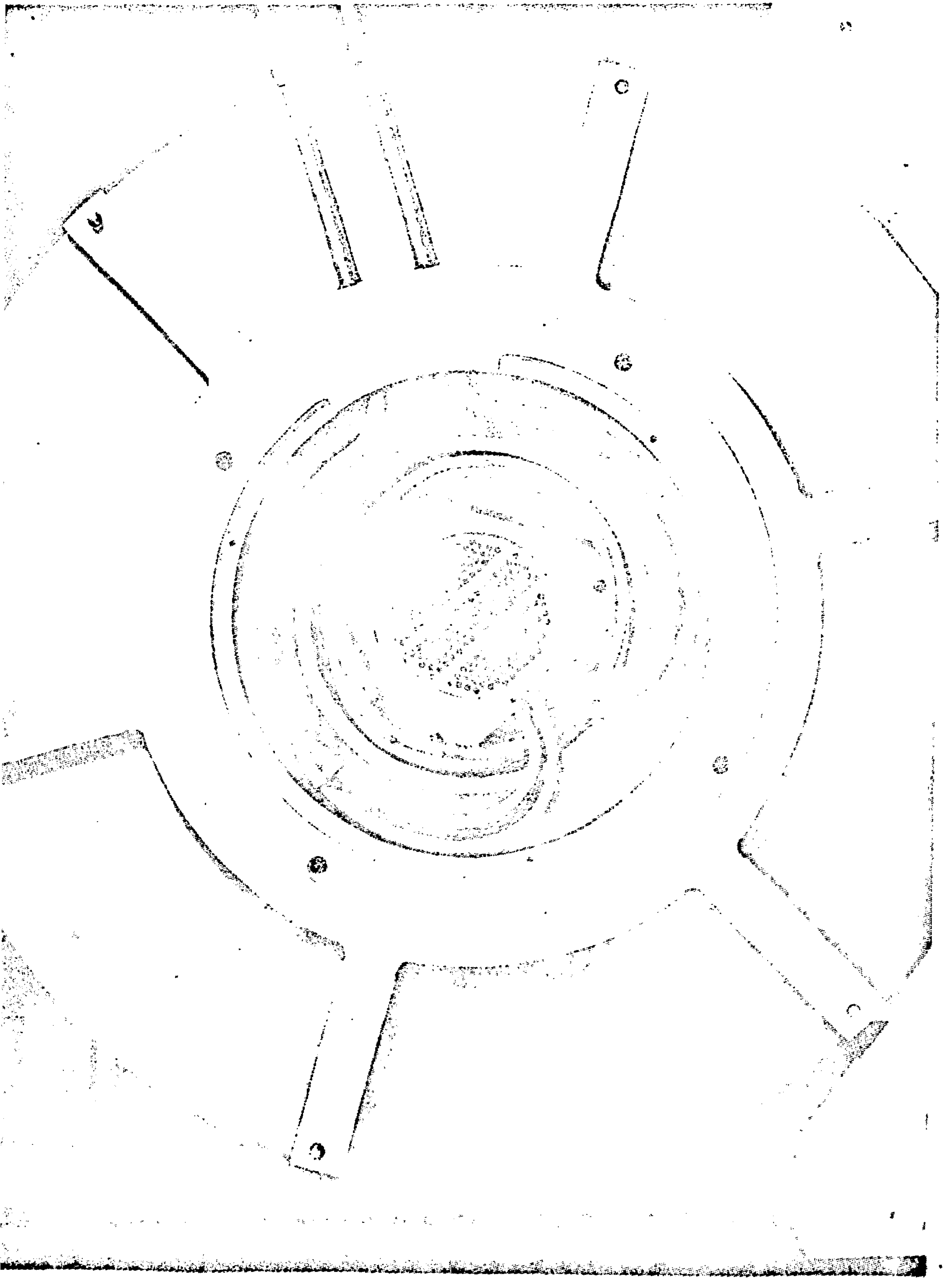
Fig. 2. Multiaperture Decel Electrode of Water Cooled Copper Used With 8 Ampere DuoPIGatron Source.

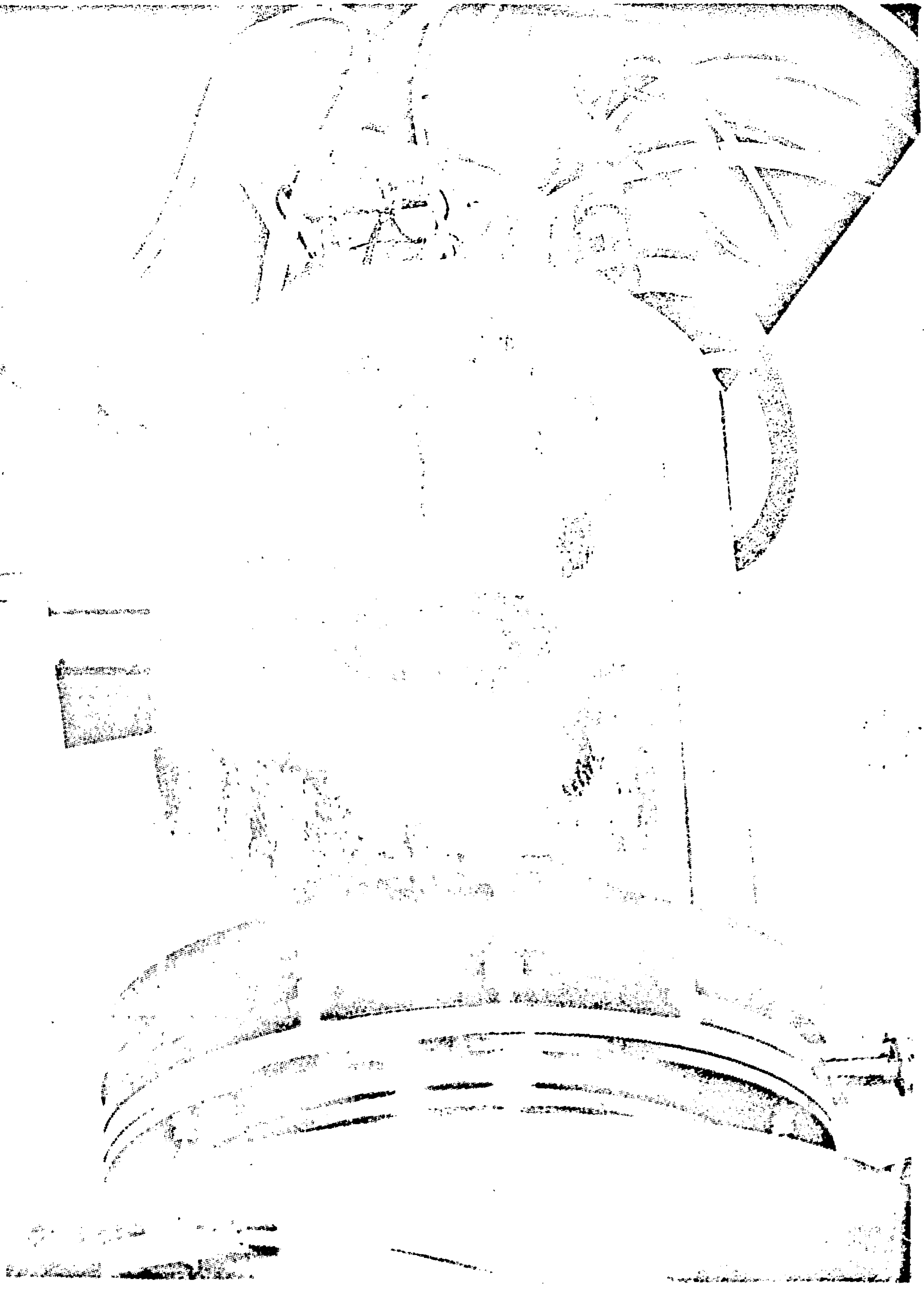
Fig. 3. Injector Used on ORMAK Showing Epoxy Cylinder Allowing Re-Entry Arrangement into the ORMAK Device.

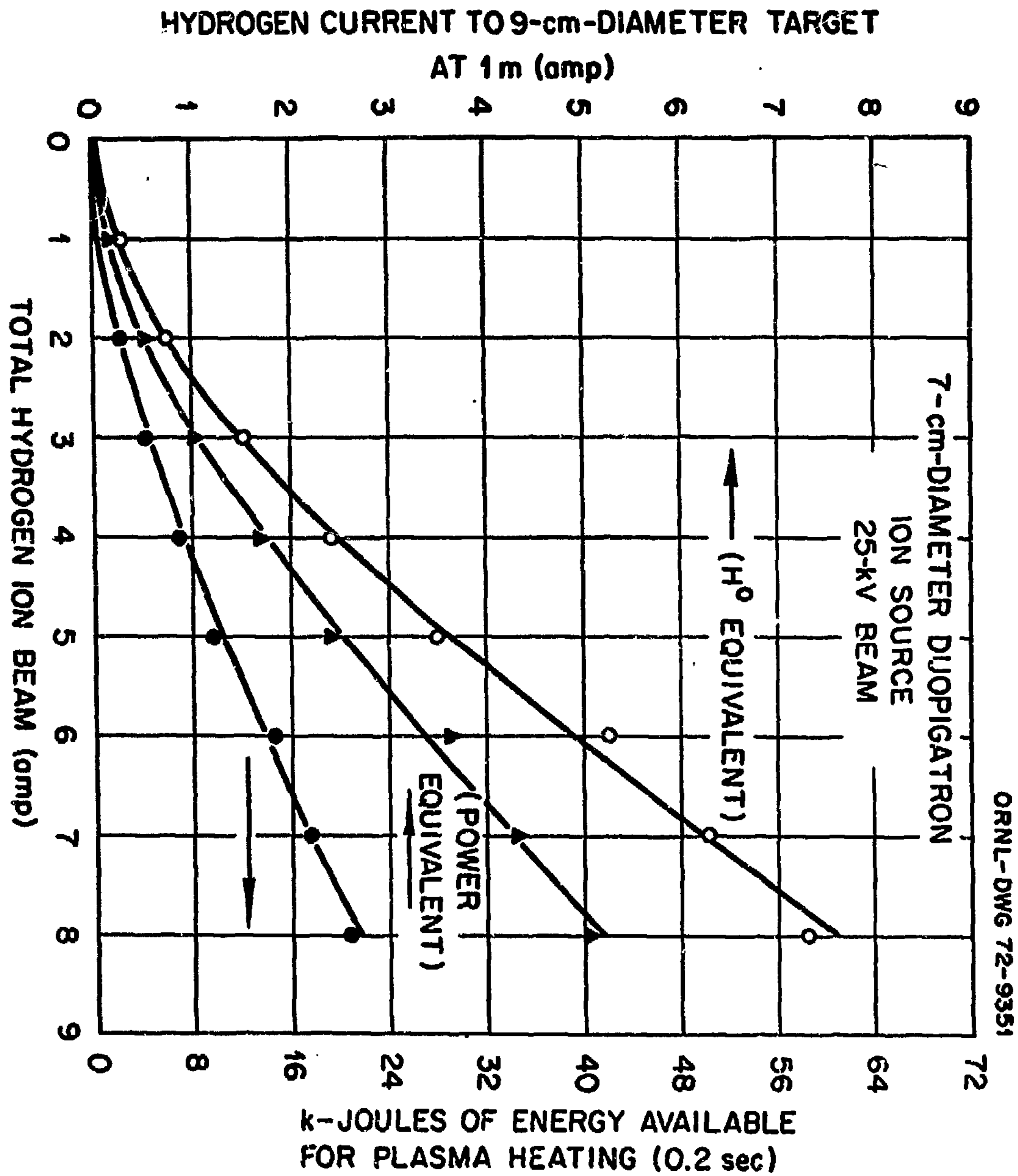
Fig. 4. Equivalent 25-keV Ion Beam Current and Energy Usable for Neutral-Injection Heating of ORMAK vs the Total Extracted 25-kV Ion Beam Current.



DUOPIGATRON ION SOURCE






HYDROGEN CURRENT TO 9-cm-DIAMETER TARGET
AT 1 m (amp)
0 1 2 3 4 5 6 7 8 9
TOTAL HYDROGEN ION BEAM (amp)
0 1 2 3 4 5 6 7 8 9
k-JOULES OF ENERGY AVAILABLE
FOR PLASMA HEATING (0.2 sec)
0 8 16 24 32 40 48 56 64 72
7-cm-DIAMETER DUOPIGATRON
ION SOURCE
25-kV BEAM
(H^0 EQUIVALENT)
(POWER
EQUIVALENT)
ORNL-DWG 72-9351