

A NEW LOW ENERGY HEAVY ION ACCELERATOR\*

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Abstract

A heavy ion accelerator and beam transport system have been designed and constructed for studies of the interaction of radiation with matter. The air-insulated electrostatic accelerator was made to our specifications by Radiation Dynamics, Inc., with a beam energy continuously variable from 2-200 Kev. A modified duoplasmatron ion source provides ions of hydrogen, nitrogen, oxygen and noble gases at beam currents as high as 5 ma. The accelerating potential is provided by an oil insulated power supply regulated to  $\pm 0.01\%$ . The beam transport system consists of a water-cooled insulated slit, magnetic spectrometer for beam definition of energy, charge state and isotopic composition, and a target chamber. A second magnetic spectrometer is available for further particle energy definition or for momentum analysis of the ion beam after interaction with a target. An extensive series of experiments for evaluating the accelerator performance are described, and results are reported for typical beam current density profiles, emittance areas, and maximum current densities attainable for different ions at various beam energies.

Introduction

The experimental program in our laboratory on the interaction of radiation with matter requires a low energy heavy ion accelerator. In particular, we are concerned with the range of particle energies where effects due to atomic displacements are comparable to electronic excitations. These energies fall in the range of the so-called ionization threshold energies which, for heavy ions are of the order of A Kev, where A is the atomic weight of the ions. All inert gas ions are to be used in the

initial stages of this work. Therefore, the accelerator was specified to provide continuously variable beam energies ranging from about 1 Kev to 200 Kev. Since no commercial unit met these specifications, we contracted Radiation Dynamics, Inc., to design and build an accelerator to fill our requirements.

Description of Accelerator Facility

The major component of the accelerator system is a DN-200 Dynagen air insulated uniform gradient accelerator manufactured by Radiation Dynamics, Inc. The accelerating potential is obtained from a high voltage power supply BA1-200-7.5 manufactured by Universal Voltronics, Inc.

The accelerator has a maximum energy rating of 200 Kev and it can produce ion beams from the following gases: H<sub>2</sub>, D<sub>2</sub>, He, N<sub>2</sub>, O<sub>2</sub>, Ne, A, Kr, and Xe.

The typical current from the accelerator with hydrogen gas in the ion source varies with energy as indicated in the following table:

Beam Energy	Total Beam Current
150-200 Kev	5 ma
70-150 "	4 "
50- 70 "	3 "
30- 50 "	2 "
10- 30 "	0.2 "

For heavier ions the total beam current decreases with increasing atomic mass. By reversing the polarity of the high voltage power supplies, electrons may be extracted directly from the ion source.

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As shown in Fig. 1 the "Dynagen" consists of a liquid Freon cooled Dynamag duoplasmatron ion source<sup>1</sup> with associated power supplies, accelerator tube and an oil diffusion vacuum system. The ion source is attached to the end of the accelerator tube near the terminal. Mounted inside the spun aluminum dome are the power supplies for the ion source filament, magnet, arc, extractor, and lens. These power supplies obtain their power from a 2 KVA, 400 cps, 120/208 volt alternator located in the upper part of the terminal dome. The alternator is driven by a 1 inch Delrin shaft running from the grounded end of the accelerator frame where it is coupled to a 3 H.P. motor. This simple method isolates the terminal power supplies from the power line.

Two acrylic resin plates form an insulated cantilever support for the high potential terminal. The steel frame of the Dynagen supports the vacuum equipment at the grounded end of the accelerator tube.

The accelerator tube consists of 15 stages at 1.5" intervals. Each stage consists of a stainless steel plate separated from its neighbors by cylindrical glass spacers 1.4" long, 6" O.D. and 5" I.D. The elements of the accelerator tube are bonded together with an epoxy resin formulated for this purpose. A series of six rings surround the accelerator tube to minimize undesirable field gradients.

The accelerating potential is provided by a continuously adjustable high voltage power supply in an oil filled tank. The maximum output is 200 KV with not more than 0.01% ripple in the operating range up to 7.5 ma. The voltage of the power line feeding the power supply is regulated to 0.01% by a Sorensen 2501 line regulator. Therefore, at small beam currents the power supply is line and load regulated, while for high beam currents the power supply is not load regulated.

The vacuum equipment consists of a 6" NRC oil diffusion pump with a liquid nitrogen cold trap and a Welch 1397B mechanical pump. The pumping speed of the system is rated at approximately 800 lit/sec. at  $10^{-4}$  torr. An air-actuated 6" gate valve separates the pumping system from the accelerator.

### Beam Transport System

The beam transport system encompasses all the equipment which the ion beam traverses after emerging from the accelerator. It consists of beam slits, waveguide tubes, magnetic spectrometers, target chambers, detectors, and the associated vacuum pumping systems. Our beam transport system, shown in Fig. 2, is designed for maximum flexibility of rearranging, substituting and inserting components to meet the requirements of different experiments.

The connections between the accelerator and the entrance slit box and between the slit boxes and the magnetic spectrometer tubes, are short straight sections of WR-187 bronze waveguide tube with inside dimensions of 0.872" high by 1.872" in the horizontal plane. They terminate either in flanges of choke type, UG-148B/U with a Viton "O" ring, or in flat cover flanges UG-149A/U. The tubes are plated with silver and a rhodium flash. The magnetic spectrometer tubes are 90° bends of the same waveguide material with a 20" mean radius of curvature.

The spectrometer magnets are identical to those described by F. A. White<sup>2</sup>. Each magnet provides magnetic fields up to 10 kilogauss at a maximum input of 300 volts and 2 amperes. Singly charged ions of mass up to 60 and energies up to 200 Kev can be analyzed by these 20" radius magnets. The overall dimensions of each magnet are about 32" x 26" in the horizontal plane and 43" high. Their weight including coils is about 3.5 tons. A translating mechanism permits adjustment of the position of the magnet over a distance of a few inches along the 45° line bisecting the quadrant.

In general, the first spectrometer (see Fig. 2) defines the composition, energy and charge state of the ion beam impinging on the target. The second magnetic spectrometer analyzes the particle energy and charge after the beam passes through the target. If the target is replaced by a slit, both magnets can operate as a two-stage magnetic spectrometer.

### Performance of Accelerator

An extensive series of experiments were performed on the accelerator in

order to evaluate and to determine the characteristic of the ion beam of the machine before entering the transport system. To this end we measured typical beam current density profiles, maximum beam current density versus energy, and the emittance area of the accelerator.

The experimental arrangement consisted of a pair of crossed, insulated, water cooled and moveable beam slits forty inches from the base of the acceleration tube. By sweeping the small opening formed by the crossed slits, over the entire beam width, the current density distribution was determined by measuring the transmitted current with a properly biased faraday cup. As an example, Fig. 3 shows the beam current density distributions in terms of contour lines of constant current density for an argon beam at 150 Kev. The area enclosed by the dashed rectangle was investigated, points lying outside of the rectangle were extrapolated from the data. The contour lines are fairly uniformly spaced indicating a symmetrical ion beam. In a few cases however, we observed significant asymmetries in the beam current density distributions. Furthermore, during these experiments it was noted that initially the ion beam was exhibiting rapid fluctuations in beam spot position. However, this condition disappears after about two hours of operation at high beam currents.

Next we measured the maximum current that can be transmitted through a 1 x 1 cm opening as the beam energy was varied. The experimental arrangement is the same as described previously with both slits opened one centimeter. Figure 4 shows the results obtained for helium and argon beams. We note that helium yields higher current densities. This can be attributed to the differences in the space charge expansion of the two ion beams. In fact the ion optical theory developed by Moak<sup>3</sup>, if applied to this situation, essentially accounts for the difference in current densities. From these two curves one can estimate the current density available for other gases over the whole energy range.

For measuring the beam emittance area the first slit was located 40" from the base of the accelerator tube. The second slit was located 78" from the accelerator tube and was in the same plane as the first slit. The first slit defined a slice of the ion beam and the second slit was moved relative to the beam axis to determine the spatial distribution. The result of a typical measurement is shown in Fig. 5 for a 1 ma helium beam at 150 Kev energy. The total area of the emittance diagram, which is independent of accelerator focussing conditions, yielded a value of 0.821 milliradian-inches. On scaling this value to lower energies, we find that this area is nearly equal to the emittance area of the ion source. Furthermore, this value is smaller than the acceptance area of our beam transport system.

On the whole therefore the accelerator meets our requirements for the satisfactory performance of the integrated facility. However, there are still some shortcomings. Specifically, we have to cope with the ion optical aberration we have observed in some cases and with the spatial instability of the ion beam during short term runs.

#### Acknowledgements

This accelerator facility was conceived by and is being constructed under the direction of Professor Werner Brandt. We are grateful for his constant help, guidance and encouragement. Professor F. A. White kindly provided us with the design of his magnetic spectrometers. Professor E. Grisewood advised us on radiation safety. We discussed with Dr. M. Cleland several of our problems of instrument operation.

#### References

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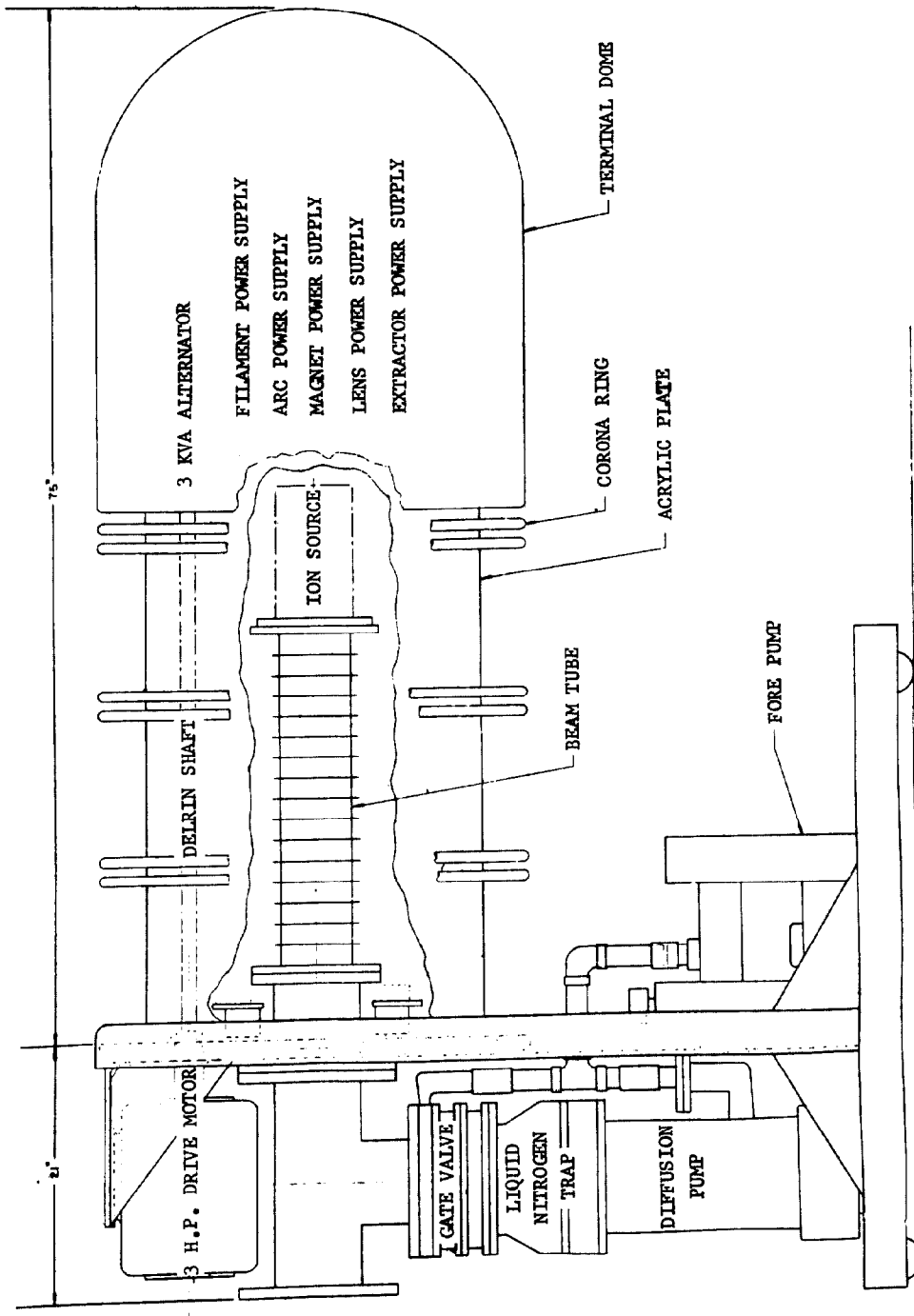


Fig. 1. Side view of accelerator.

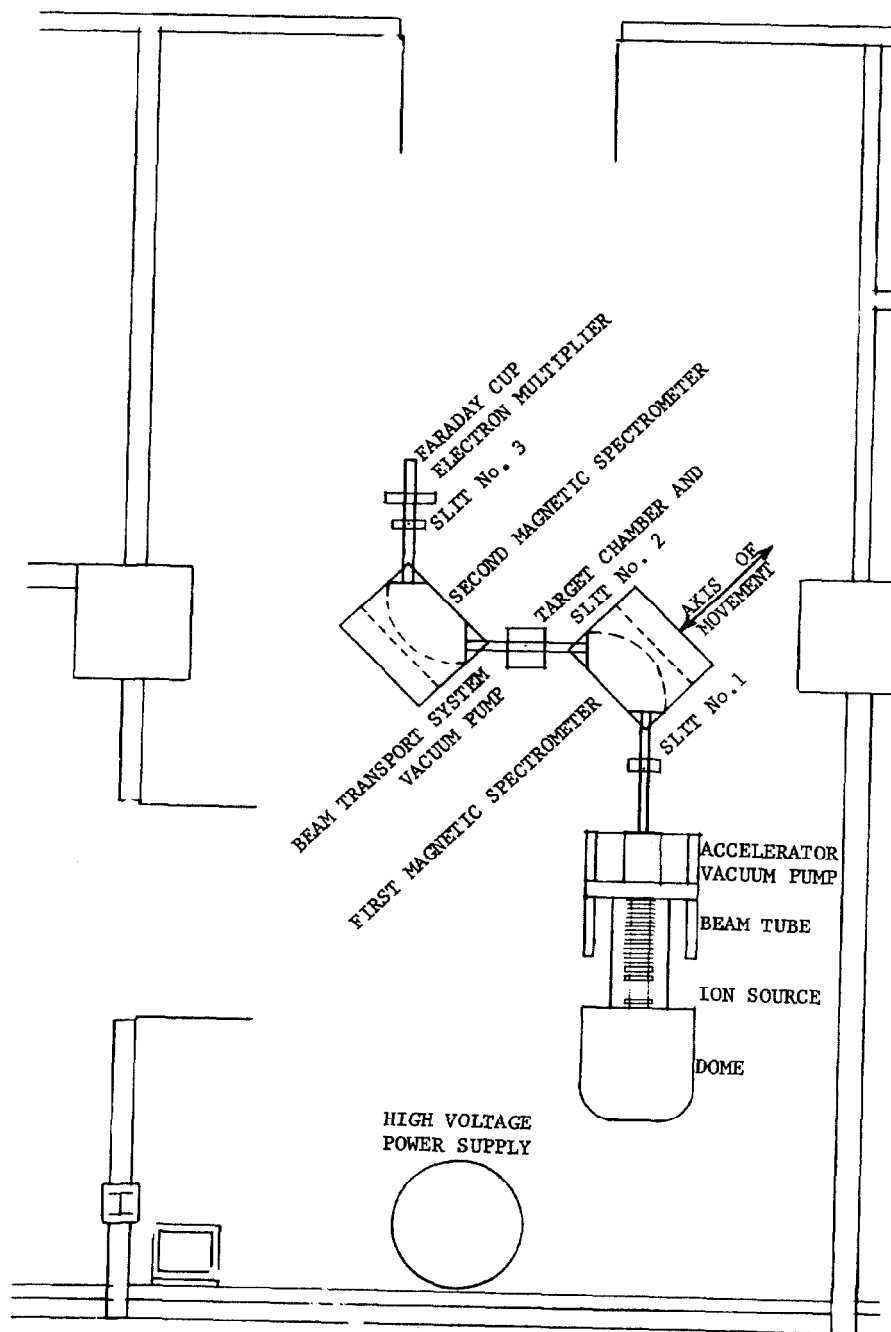


Fig. 2. Accelerator with beam transport system.

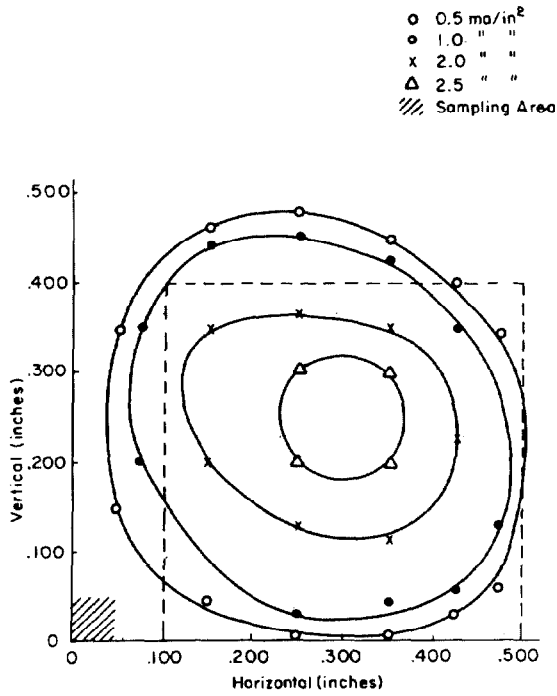


Fig. 3. A typical beam current density profile for a 150 keV argon beam. The area enclosed in the dashed rectangle was investigated. The origin is for reference only and has no physical significance.

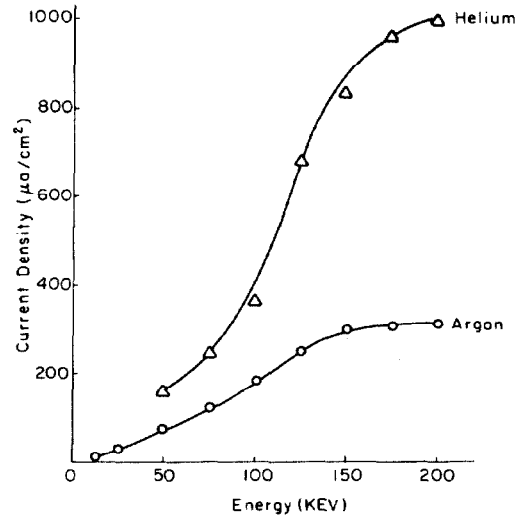


Fig. 4. The maximum beam current versus energy on a 1 x 1 cm target 40 inches from the accelerator tube for helium and argon ions.

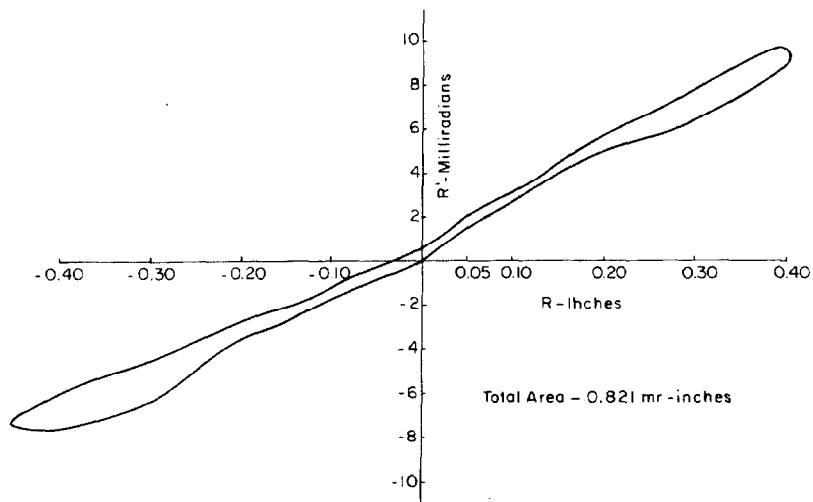


Fig. 5. A typical emittance area for a 1 mA 150 keV helium ion beam.