ION SOURCES FOR HIGH CURRENT TANDEM ACCELERATORS

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Abstract

An expanded plasma ion source is described which generates high current negative ion beams of hydrogen (~ 1mA) and helium (~ 3 μA). Also presented is preliminary data for a diode ion source where useful currents of many ion species, including O^-, Al^-, Cl^-, Cu^-, Bi^-, $(UF_n)^-$, have been obtained. A description of a negative ion injector specifically designed for the injection of high currents into tandem accelerators is outlined.

Introduction

The ion source of a tandem is external to the accelerator's pressure vessel, and may be situated at ground potential[1] or at an elevated voltage[2] for operation in a d. c. or pulsed mode. Negative ions may be formed by either the attachment of electrons to fast primary positive ions in gas or solid targets[3], or by radiative and dissociative processes[4], before the ions have been accelerated to high velocity. Although both types of processes have been used for the production of negative particles, the latter processes appear to offer the greater promise for the production of high currents[5]. Such sources are commonly known as direct extraction sources. Since certain negative ions such as He^- have only been observed in collision attachment ion sources, both types of sources are necessary for accelerator injection.

Matching of the Ion Beam to the Accelerator

A beam of particles will be transmitted without loss through an accelerator provided

$$\epsilon < a$$

where ϵ is the beam emittance from the source and a is the beam acceptance of the accelerator.

For a typical tandem accelerator the acceptance measured at the object plane of the accelerator, varies between 0.04 and 0.11 rdn. cm. depending upon the terminal potential. Experiments with H^- beams of several hundred microamperes intensity, described by Brooks et al[6], showed that at these current levels source emittances less than 0.04 rdn. cm. can be obtained, and that this emittance is primarily due to the positive ion beam.

The Expanded Plasma Ion Source

As a first step in the production of high intensity negative ion beams (~ 1 mA) it was necessary to develop an ion source with a positive ion current output exceeding 100 mA having a low emittance. The emittance of an ion beam depends directly upon the temperature of the emitting plasma and the radius from which the beam is extracted[7]. For these reasons it was necessary to establish an optimum size for the plasma surface from which the ions are extracted, as an increase in this radius tends to reduce the temperature of the plasma.

The space charge limited current I,[8] extracted from a plasma boundary of area A, with an extraction gap d, and extraction potential V, is given by

$$I = f(A, d) \left(\frac{e}{m}\right)^{1/2} V^{3/2} \qquad (1)$$

For any particular extraction system employed it has been shown that f (A, d) is a dimensionless geometric quantity with the property

$$f(A, d) = f\left(\frac{A}{k^2}, \frac{d}{k}\right) \qquad (2)$$

To change the beam diameter for a given beam current, the extraction configuration may, therefore, be scaled linearly. The beam divergence under space charge limited conditions, is unaffected by the changes in the linear dimensions of the beam.

Experimental Measurements

For these experiments the ion source geometries shown in Fig. 3 were used. The ion source is elevated to a positive potential with the extraction electrode maintained at a negative voltage, to increase the electric field in the region where the space charge forces are greatest. Electrons,

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which are produced from the ionization of the residual gas beyond the extraction field, neutralize the positive ion beam in the drift region. The neutralization is virtually complete outside of the extraction region. The total positive ion beam transmitted through the attachment canal of the original source, Brooks et al[6], as a function of energy was measured and is shown in Fig. 2 (a). It was observed that the beam intensity, as measured by a calorimeter, was unaffected by the presence of gas in the attachment canal; thus, results obtained without gas in the canal were assumed to be applicable when the source was used to generate negative ions. The geometry of the extraction region was then scaled by a factor of one-half, the plasma diameter being reduced from 5 cm to 2. 5 cm. as shown in Fig. 2 (b). A test at 30 keV with this geometry gave the same transmitted current as the original configuration, shown by the current point (b) of Fig. 3 and the beam diameter was reduced by a factor of two. A separate measurement of the beam divergence confirmed that it was identical to the unscaled source. For the beam current range shown in Fig. 3, the beam current to return current ratio of the source power supply was > 90% for all geometries indicating negligible beam interception on the extraction electrodes and small electron currents.

After the initial experiments with positive ions using the one-half scale source, the diameter and length of the canal were increased in the manner of Fig. 2 (c). The extended canal and the gas baffle shown between the source chamber and negative ion drift region were fitted to the beam profile. The current transmitted through the system after these changes is the curve (c) of Fig. 3. It can be seen that at 30 keV the transmitted current was increased by 50%. During these tests it was observed that high frequency beam modulation or "hash" drastically increased the emittance of the beam, as well as reducing the transmitted currents. Under proper operating conditions, however, the modulation depth was $\leq$ 5%.

An analyzing magnet was located after the gas baffle, and the negative ions produced in the attachment canal were focused into Faraday cage, shown in Fig. 4. The attachment gas selected was hydrogen because it gives the highest yield and lowest scattering of H^- ions above 20 keV and a satisfactory yield of He^- at 50 keV, the highest practical voltages for the external supplies and bushing.

The high intensity negative ion source which has been described was incorporated into an injector and tested with the Research Tandem,[9] High Voltage Engineering Corporation. The arrangement of injector components is shown schematically in Fig. 4 where it can be seen that high speed differential pumping is used to remove the gas from the ion source and exchange canal; a low conductance baffle is used to isolate the source region and the rest of the system.

The Diode Ion Source

Recently, several workers have reported a high production of negative ions when these are extracted directly from the source plasma without the intermediate stage of charge attachment from a positive ion beam.[5] The most important advantages of this technique are high intensities, low beam emittance and small energy inhomogeneity. The mechanisms used in the formation of these ions are, possibly, dissociative processes induced by the electrons in the discharge.

A diode ion source has been developed at HVEC using an intense low energy electron beam for the generation of negative ions by dissociative capture in a gas target followed by direct extraction of a negative potential. A two-stage extraction system with magnetic suppression reduced the electron loading currents to negligible values. The preliminary experiments showed that for the ion species tested, Fig. 5, useful current levels were obtained for tandem operation, with up to 600 μA of H^-. Helium was run in the source but no negative helium ions observed.

The emittance of the ion beam from the diode source, described in the last section, has not been measured. Experience with similar sources indicates that for comparable currents the emittance decreases by an order of magnitude below that of beams from a collision attachment source.

Table I. Typical operating parameters of the negative ion source system.

		H_2	He
Positive ion energy	keV	30	50
Positive ion current	mA	80	60
Negative ion current	μA	700	3. 0
Target thickness, H_2	μcm	180	100*
Emittance of H_1^- beam rad cm $MeV^{1/2}$		.0065	---
Energy spread of ion source	eV	50	---
Total energy spread	eV	82	---
Source gas flow	μl/s	15	---
Attachment gas flow	μl/s	50	35
Neutral beam current equiv.	mA	56	---
Noise level in beam	%	< 5	< 5
Target chamber pressure	10^{-5}torr	2. 8	2. 0

Table I. (continued)

Drift region pressure	10^{-5} torr	.5	.5
Source arc current	A	5	7
arc voltage	V	120	150
Source pressure, arc off	μ	400	600

*Below equilibrium target conditions.

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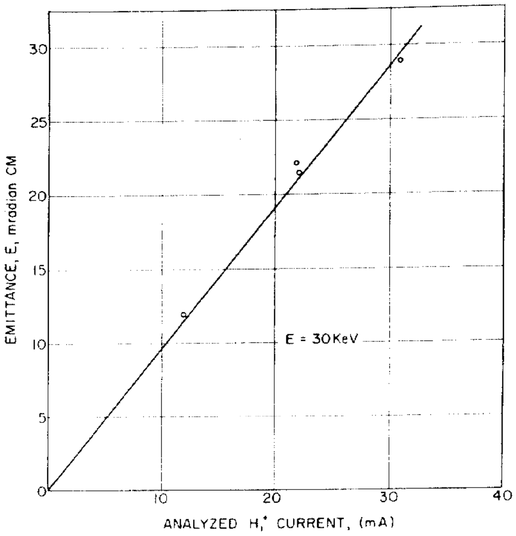

Fig. 1. Beam emittance at 30 keV as a function of analyzed proton current.

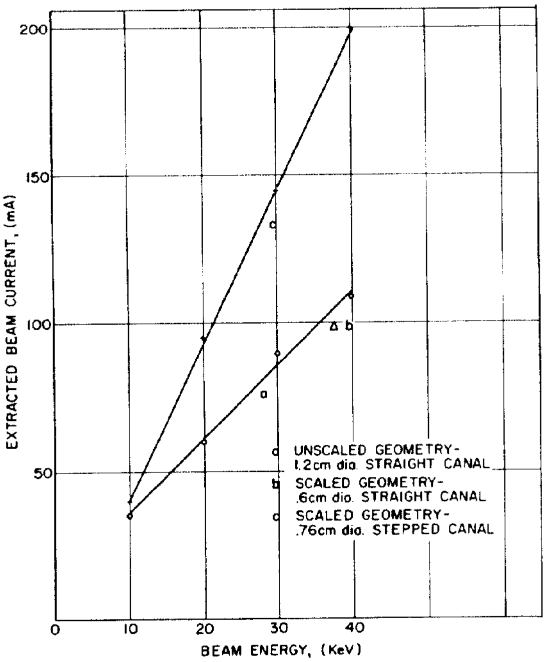

Fig. 2. The total ion beam transmitted through various attachment canal geometries as a function of beam energy.

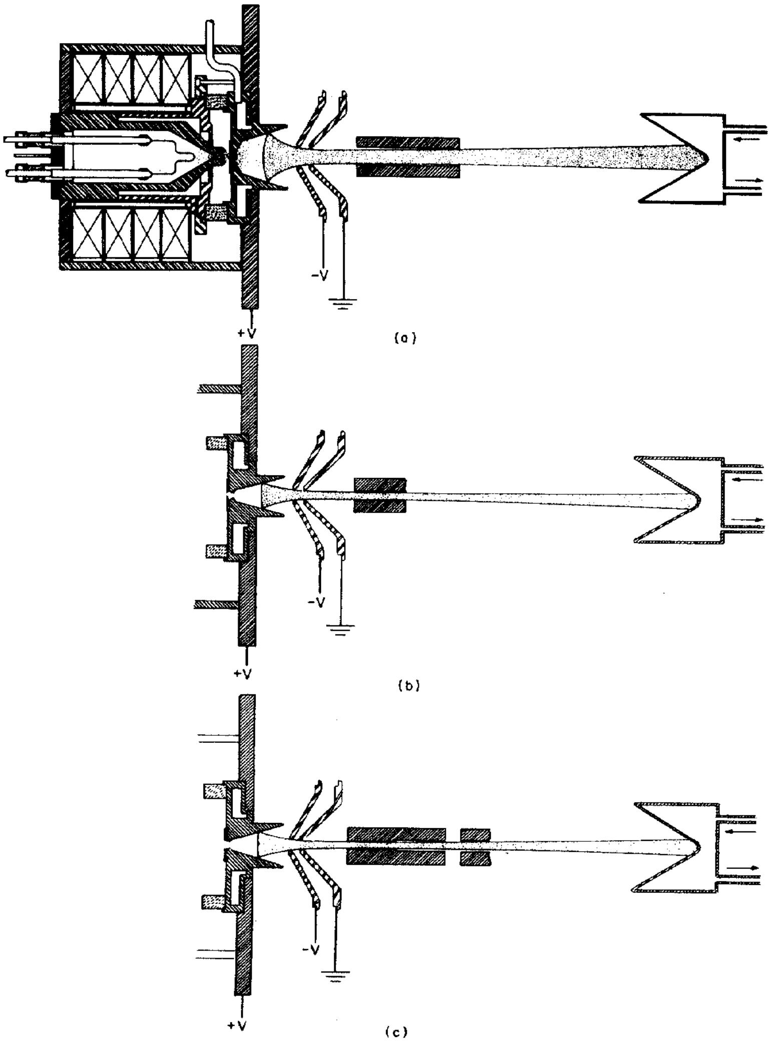

Fig. 3. (a) Unscaled negative ion system geometry. (b) One-half scale geometry. (c) One-half scale stepped canal geometry.

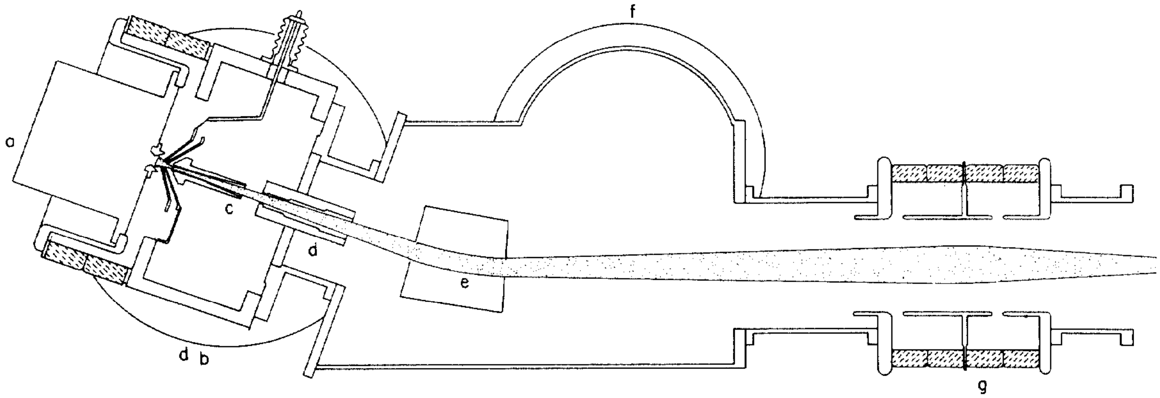

Fig. 4. A high current tandem negative ion injector schematic. (a) Duoplasmatron ion source. (b) 20" oil diffusion pump. (c) Gas attachment canal. (d) Gas baffle. (e) 20° analyzing magnet. (f) 14" oil diffusion pump. (g) Unipotential lens.

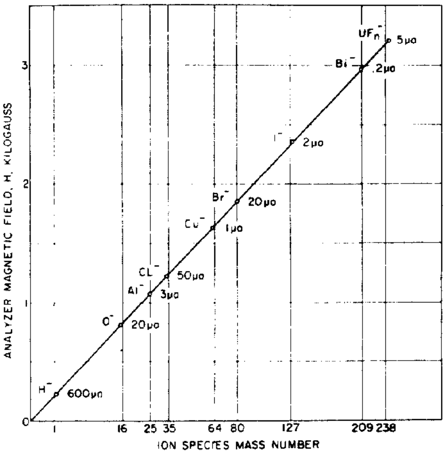

Fig. 5. Analyzed negative ion species and currents of the direct extraction diode source.