A HIGH EFFICIENCY ION OPTICAL SYSTEM FOR TANDEM ACCELERATORS

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Abstract

The ion optical problems of injecting ions into a tandem are reviewed and it is shown that signigicant improvements in transmission efficiency are to be expected if the diameter of the terminal stripping canal is increased and if the electrostatic field at the entrance to the accelerator is terminated in a controlled manner. Results with an experimental tandem accelerator are reported.

Introduction

Negative ions injected into a tandem are accelerated to the terminal, where stripping occurs, with subsequent acceleration of positive ions. The charge changing target in the accelerator terminal, usually a gas canal, is in practice the element which limits the acceptance of the accelerator. Because of the necessity of pumping stripper gas from the terminal region and yet maintaining a relatively high vacuum in the acceleration tubes, the maximum canal diameter is usually less than 7 mm. To avoid loss, the beam emittance[1] must be less than the acceptance of the canal. Since the focal properties of the acceleration tube are calculable, it is useful to refer the acceptance of the terminal canal to the object plane of the acceleration tube. These acceptance values in the object plane are given by the expression,

$$a \left(\frac{eV_t + E_i}{E_i} \right)^{1/2} \quad \text{or } a\,Q^{1/2}$$

where: a = acceptance of canal

V_t = terminal voltage

E_i = injected ion energy

In principal it is necessary only to position the appropriate lenses between the source and tube object plane to match the beam to the accelerator.

Matching Methods

The two methods of injection which have been employed are know as, Constant Q injection[2, 3] and Fixed Energy injection[4].

The Constant Q injection technique requires positioning the optical elements of the injection in such a manner that a good acceptance match is achieved at the lowest desired terminal voltage. Once accomplished, the accelerator transmission can be held constant throughout the terminal voltage range by raising the input beam energy correspondingly with the terminal voltage. The optical properties of an electrostatic system are dependent only on the ratio of energies and not the absolute values of the potentials.

In practice this system has the serious disadvantage that all the ion source components (vacuum chamber, analyzing magnets, etc.) must be operated at high voltage over a rather large range. With input beam energy requirements reaching several hundred keV, the injector obviously becomes elaborate and quite inaccessible during operation.

Fixed Energy injection, on the other hand, requires that lenses along the input beam path are adjusted to match the changing acceptance value at the object plane of the accelerator in the manner shown in Fig. 1. The figure illustrates the problems associated with fixed energy injection. Fig. 2 (a) is an experimental curve obtained with such a system, on an HVEC tandem accelerator showing transmission as a function of terminal voltage. At the high energy end of this curve the fall off is due to the effect of spherical aberrations in the injection lenses. The inclined field tube[5, 6] now used on tandem accelerators has very nearly the same acceptance as the standard tube.

Accelerator Improvements

Water Vapor Stripper

Fig. 3 is a conceptual drawing of a water vapor stripper canal as tested in the terminal of the HVEC tandem research accelerator. The device consists of a temperature controlled boiler from which the vapor is allowed to stream into the canal through a variable leak. The stripping canal was 2.5 cm diameter by 50 cm long with LN_2 condensing traps at either end. The long canal target has an advantage over the sub-sonic jet system re-

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ported earlier by Roos et al[7] in that the target thickness necessary for charge equilibrium requires a water vapor mass flow about a factor of 100 lower, with a corresponding increase in operational life. A water transfer of ~ 5 cc/hr. for a target thickness of 700 μcm has been proven and the vapor losses were found to be less than 0. 1%. In operation, pressures along the acceleration tubes were easily maintained in the low 10^{-6} torr range; in fact, pressures within the terminal vacuum chamber typically are as low as those near the vacuum pumps at the tank base. Fig. 4 illustrates a comparison of the terminal acceptance values for gas and water vapor canals showing an increase of a factor of six in acceptance.

Gridded Acceleration Tube

At the acceleration tube entrance the fringing field shape, inherent in the free space solution of Laplace's equation, forms the predominant lens for focusing ions to the terminal. The strength of this lens is, of course, dependent upon terminal voltage and its entrance requirements introduce the injector problems referred to in Fig. 1. However, if the entrance field is terminated in a controlled manner by a conducting grid of high transparency (88%) for charged particles, this lens is virtually eliminated, and the ions undergo acceleration only upon entering the tube. Fig. 5 (a) schematically illustrates the control of radial field components at the tube entrance. Since the tube entrance lens is now ineffective some other lens along the injector path must now focus the ions to the terminal and this has been accomplished with a variable bi-potential lens formed prior to the grid. The lens strength may now be varied independently of terminal voltage, as in Fig. 5 (b).

The use of such a grid may introduce problems; first, whether it will withstand the bombardment of negative and positive ions which are present in the accelerator; secondly, there is the problem of the small facet lenses introduced by each aperture in the mesh of the grid. Experience at HVEC suggests that for the currents employed in the tandems and for the light isotopes the lifetime of the grid should be very large. The second effect, due to local field distortions near to the grid wires, cannot be neglected, however, and these effects cannot be compensated by the use of an external optical element as there is no correlation between the radial position of the ion and the angle through which it is deflected.

The potential distribution at the grid wires has been measured in an electrolytic tank and shows that the angular deflections can be estimated with sufficient accuracy, assuming that the facet lenses have a focal length equal to that given by the Davisson formula for a single aperture lens, i. e.

$$f = \frac{4V}{E_2 - E_1}$$

where V = incident ion energy

E_2 = field strength beyond grid aperture

E_1 = field strength prior to grid

Carrying this approach through for an acceleration distance to the terminal of four meters, a tube gradient of ~ 32 kV/in and an initial beam energy of 50 keV, the increase in beam diameter at the terminal using a mesh of pitch 40 is in the order of 2. 5 mm ~. 1 in. With the availability of a large diameter (~ 1 in.) terminal canal this effect does not significantly change the transmission characteristics. Fig. 2 (b) shows that improvement obtained when the gridded entrance lens was added to the accelerator which prior to the addition gave the curve shown in Fig. 2 (a).

Experimental Results

In the HVEC research tandem the gridded entrance lens and the large aperture water vapor stripper were both installed in the accelerator. They were used with the injector described by Bastide et al[8]. Analyzed proton currents of up to 350 μA were observed over the energy range 0. 4 - 2. 2 MeV. This was obtained with an injected current of 400 μA of H^-, giving a transmission efficiency of 87%.

Although more negative ion current was available for injection, the accelerator became unstable above 400 μA due to the belt charge limitations of the electrostatic generator. The charging current was about 1 mA for this injection condition. Below this limit the accelerator was easy to operate and in particular the injection conditions were found to be quite relaxed.

Preliminary results injecting helium negative ions have shown transmission efficiencies of 50 - 70%. At 1 mV, He^{++} currents of 0. 8 μA have been achieved; the cross-section σ_{-10} indicates stripping losses in the drift region of the injector of ~ 30%.

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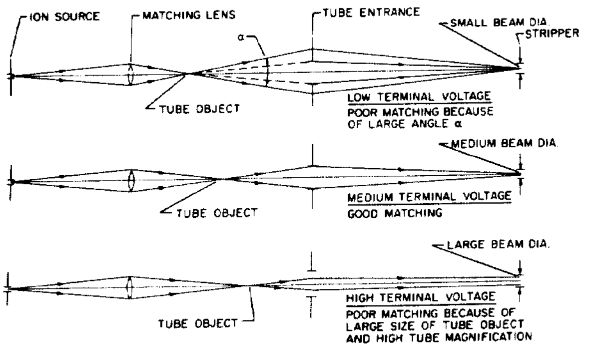

Fig. 1. Optical problems associated with fixed energy injection.

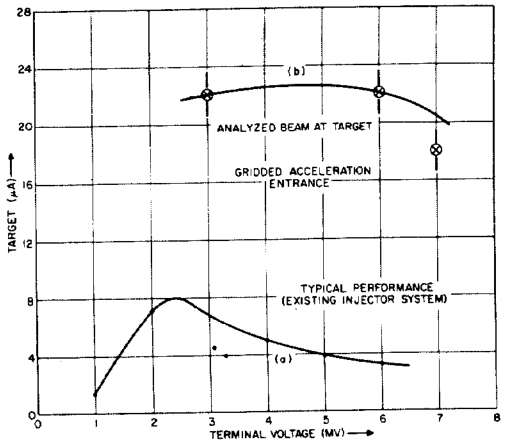

Fig. 2. Comparison of transmission for open and gridded acceleration tubes.

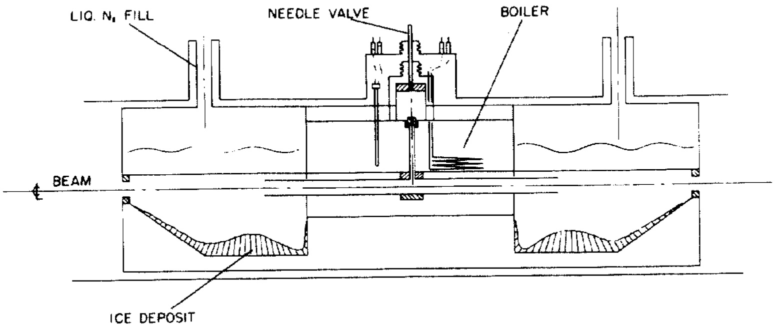

Fig. 3. Terminal water vapor canal and condensing traps.

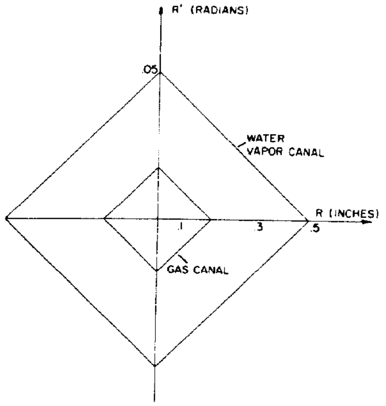

Fig. 4. Acceptance comparison of gas and water vapor canals.

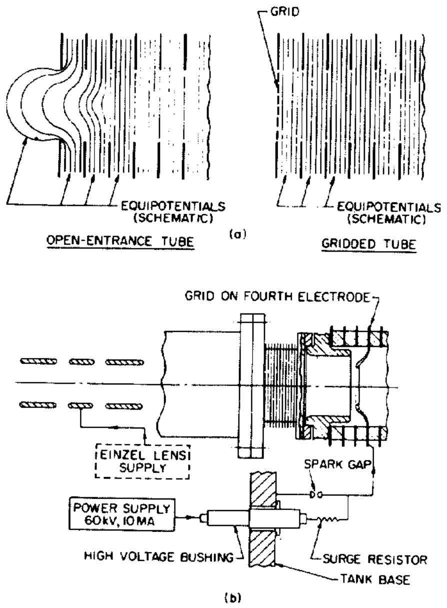

Fig. 5. Control of electrostatic field at tube entrance. (a) Control of fringing field. (b) Technique of emittance lens control.