Box 7: Tandem Terminal Ion Source

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Introduction

Some astrophysics experiments require ion beams at low energies to simulate the reactions that take place in stars. The accompanying low count rates from the small reaction cross sections can be improved with higher beam currents. The beam power requirements are not beyond the capabilities of an FN tandem but do require operation in an unusually low-voltage, high-current regime. A radio frequency (RF) discharge source assembly has been designed and developed for use in the terminal of the model FN tandem electrostatic accelerator at the University of Washington to produce high-intensity, low-energy beams of $^{1}H^{+}$, $^{2}H^{+}$, $^{3}He^{+}$ and $^{4}He^{+}$. A similar source arrangement was used in the FN tandem at Florida State University to accelerate $^{15}N^{+}$ ions.

The RF Discharge Source

The assembly, illustrated in Fig. B7.1, consists of a commercially manufactured RF discharge source [1], a porcelain insulator containing an extractor electrode and einzel lens, a double-focusing permanent dipole magnet or a spherical electrostatic deflector, vertical and horizontal electrostatic steerers, and a gas bottle manifold with associated isolation and metering valves. The RF source was specified to deliver 400 µA of $^{1}H^{+}$ from a 2 mm diameter aluminum canal while producing a gas load of 0.2–0.4 Pa l/s. Since the tandem does not have any terminal pumping, we were concerned that a large gas load would result in collisions with the low-energy particles and reduce transmission. In order to reduce the gas load, a 1 mm diameter canal was specified. The gas load from an RF discharge source varies approximately as d^3/l, where d is the canal diameter and l is the canal length [2,3]. Reduced beam current was expected using the smaller canal because source output varies as $(d/l)^2$ and as $1/\sqrt{m}$, where m is the mass in AMU [4]. In a high-intensity proton experiment, we tested the source with a high gas flow and determined that the gas load from the source operating with a 2 mm canal could be managed by our pumping system.

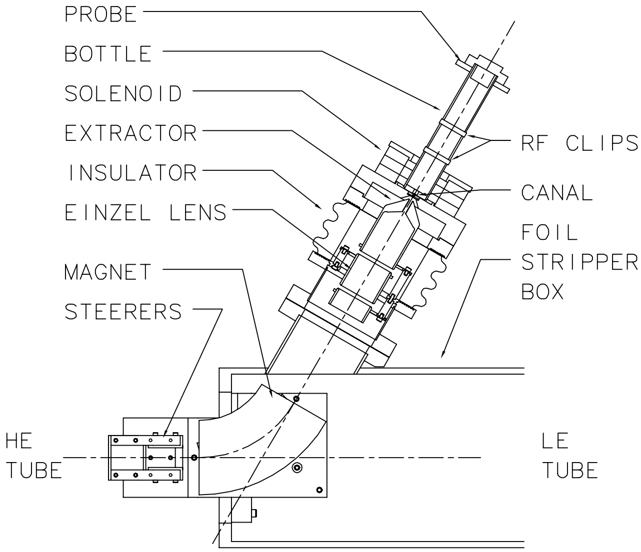

Fig. B7.1. Terminal ion source and associated optics

The Double-Focusing Magnet

Removing heat from and delivering current to an electromagnet operating inside a vacuum chamber is a difficult and complex problem. To avoid this problem, we designed and built a pair of permanent-magnet assemblies. One of the assemblies transports $^1H^+$ or $^2H^+$ and the other transports $^3He^+$ or $^4He^+$. Each dipole magnet has a 60° bending angle and a 14 cm bending radius, R. The poles are made from 8C ferrite material with the pole faces cut at 17° to the beam axes to produce double foci at $3.46R$, or about 50 cm, from the pole faces [5]. The frames are made from soft steel and bolted together. The poles are glued onto the top and bottom frame pieces. The assemblies are magnetized to produce a transverse B-field of 0.15 to 0.25 T. Thin (1.5 to 3.0 mm) steel pole caps which overlap the ceramic pole pieces by 1 to 5 mm on each side along the beam trajectory are required to tune the field to the magnitude appropriate for each individual ion species and to make the fringe fields at the pole faces more uniform. The magnet is mounted on an aluminum platform inside the foil-stripper box.

The Spherical Electrostatic Deflector

A double-focussing, spherical electrostatic deflector may alternatively be used to deflect the beam onto the accelerator axis. The advantage of such a system is that it is mass-independent and may be used with a gas manifold to rapidly switch between the ion species available. The disadvantage is that the optics are not as well matched in the geometry available, and beam transport suffers somewhat. Two additional high-voltage supplies are required to operate the electrostatic deflector. The system was modeled using an electrostatic software package [6], and it was found that the optimum transport would occur with the deflector electrodes operated in an unbalanced mode with the inner, negative electrode at about 1.5 times the voltage of the outer, positive electrode. The bending radius R of the deflector is again 14 cm and the deflector produces foci located $2R$, or about 28 cm, from the electrode edges [7].

Beam Transport and Optics

Vertical and horizontal steering plates are mounted on the platform downstream from the deflection system. The plates are 5.7 cm wide, 4.5 cm long and spaced 2.6 cm apart, with the horizontal pair preceding the vertical pair by 3 mm. Bipolar power supplies producing ± 350 V drive the steering plates. The supplies are 4-stage multipliers running off of the 400 Hz terminal power. For simplicity, these supplies accept the same AC input lines as the normal terminal steerers.

Within the source, one of two available einzel lens assemblies is used depending on the deflection system. A 2.5 cm diameter, short lens is used with the electrostatic deflector to produce an object point in front of the deflector and an image point inside the beam tube 28 cm from the deflector. A 5 cm diameter, long lens is used with the dipole magnet to produce a virtual object 12 cm behind the actual source and an image point inside the beam tube 50 cm from the magnet.

Accelerator Tube Gradient

The entrance voltage gradient of the spiral-inclined-field tube produces lens action that is too strong for the low-energy (17 keV) beam, and the transverse electric-field components are large enough to sweep the beam into the side of the tube. The tube and the spiral inclined planes were carefully modeled using a computer program to determine how the entrance gradient could be modified to successfully transport the beam. A set of resistor values was determined by iteratively applying the code and observing the calculated variation of the displacement of the beam from the tube axis. We reduce the gradient in approximately the first quarter of our high-energy accelerator tube (the first half of accelerator tube #3) during source operation to eliminate these problems. Twenty-two resistor assemblies having 20% of the nominal column resistor value are installed at the tube entrance. These are followed by 3 assemblies with 50% value, 10 assemblies with 60% value and 14 assemblies with 70% value.

The aperture size of the spiral tube is small enough to restrict beam transport at energies below about 2 MeV. For lower-energy beams, down to 150 keV or even less, we install a KN accelerator tube in our beam tube #3 position which has noninclined planes and a much larger aperture. The noninclined-field tube planes allow secondary electrons to easily stream to the terminal. As a result this tube produces x-rays at terminal voltages above 4.5 MV that are intense enough to make the accelerator unusable.

Ion Beams and Experiments Run

The source proton current was expected to be about 100 μA with a gas load of 0.03 Pa l/s. The source produces 70 μA of protons with a measured gas load of 0.1 Pa l/s and a focused FWHM of 1.3 mm. The measured beam emittance is 1.1π mm mrad $\sqrt{\text{MeV}}$. At the 5.5 MV terminal voltage required by one of the experiments, 90% of the beam is transported through the spiral-inclined-field tubes. Over the terminal voltage range of 0.15 to 7.5 MV, over 50% of the beam can be transported using one of the configurations described. A brief summary of the experiments run and ion beams produced using this source is given in Table B7.1.

Table B7.1. Table of ion species and terminal-ion-source experiments

Ion	Energy Range (keV)	Experiment	Beam Current (μA)
$^1H^+$	160–1400	$^7Be(p, \gamma)$	10–40
$^2H^+$	770–1400	$^7Li(d, p)$	15–20
$^3He^+$	5000–6000	$^6Li(^3He, n)$	28
$^4He^+$	1370	$^7Be(\alpha, \gamma)$	15

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