NEGATIVE ION BEAM ACCELERATION AND TRANSPORT EXPERIMENTS

Cooper, W.S.

1985-11-01

LBL-19578 c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

Presented at the 11th Symposium on Fusion Engineering, Austin, TX, November 18-22, 1985

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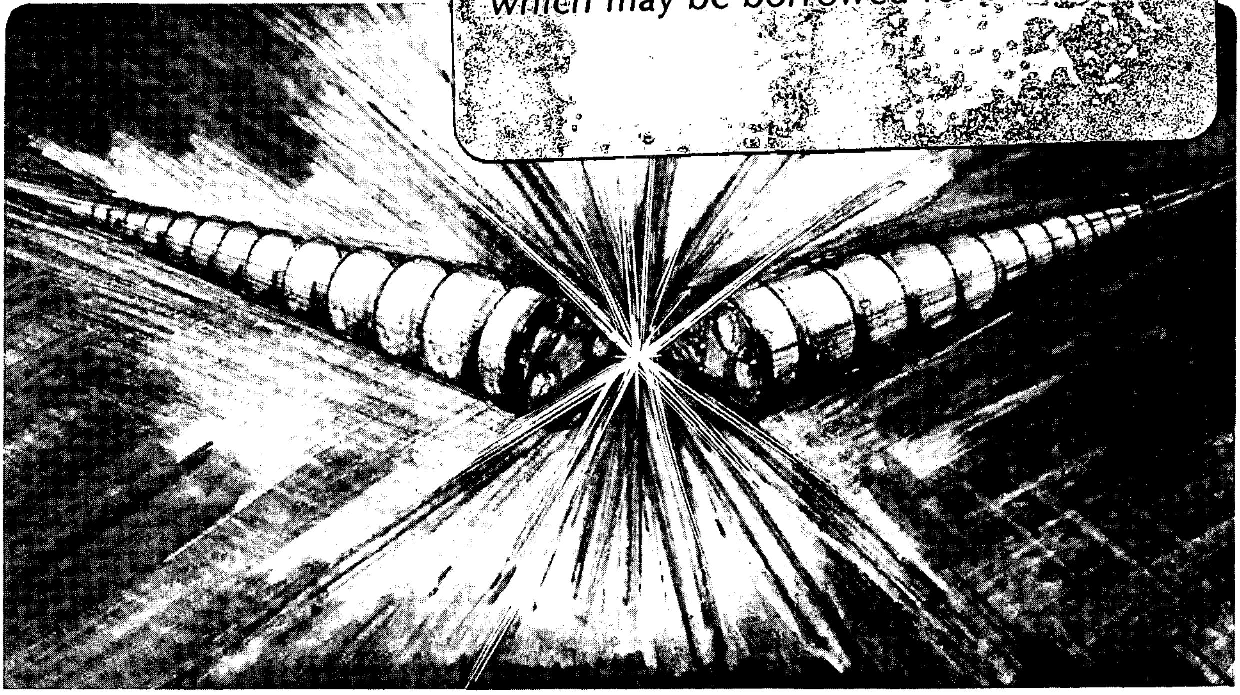
November 1985



LBL-19578 c.2

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-19578

NEGATIVE ION BEAM ACCELERATION AND TRANSPORT EXPERIMENTS*

W. S. Cooper, O. A. Anderson, J. Kwan, and W. F. Steele
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Introduction

Conventional neutral beam systems require line-of-sight access to the plasma in a confinement experiment. If the target is a reacting plasma, the neutrons produced by the fusion reactions are free to stream into the neutral beam system, inducing radioactivity and possibly damaging beamline components. To counteract this problem, we have started a series of experiments designed to develop a means of transporting a negative ion beam through several bends (negative ions are used rather than positive ions because they can be converted to neutral atoms with higher efficiency). This technique could be used to transport the ion beam through a maze in the neutron shielding before conversion of the beam to neutrals, thus providing neutron shielding for critical components of the beamline such as the ion source and accelerator. Neutronics calculations done for a hypothetical mirror reactor indicate that adequate shielding can be provided by this method.[1] This technique can also be used to advantage to transport a preaccelerated beam, before final acceleration, through a differential pumping section, to minimize the H^- loss by pumping away the background H_2 gas as quickly as possible.

Ion Source, Accelerator, and Matching/Pumping System

The negative hydrogen ion (H^-) beam is produced by a surface-conversion ion source[2] and is accelerated by a conventional single-slot accelerator. The beam is in the form of a sheet, with a nominal cross section of 25 by a few centimeters. The design current is 1 A, at an energy up to 80 keV. The corresponding current density is approximately 13 mA/cm^2.

Following acceleration to 80 keV, the beam enters the Matching/Pumping (M/P) section, which uses the Transverse Field Focussing (TFF) concept.[3] Static electric fields transverse to the beam deflect the beam and provide the focussing forces necessary to counteract the beam space charge forces. The TFF M/P section[4] consists of two sets of carefully shaped, curved electrodes, and is intended to transport the beam through two linked 70 degree bends. In the regions near the edges of the beam, the electrodes are shaped so as to provide a potential well in the long direction of the sheet beam, to prevent the beam from spilling out. Local pumping, provided by cryopumps, is used to minimize negative ion loss due to stripping of the electron by collisions with background gas. These cryopumps, now nearly completed, will be employed in the next stage of the experiment. Weak magnetic fields, from permanent magnets built into the electrodes, remove any electrons that might have been accelerated along with the H^- beam. An additional function of the TFF M/P section is to change the cross section of the beam to better match an additional TFF accelerator, now under construction.

A diagram of the source, 80 keV accelerator, and TFF M/P section is shown in Fig. 1; Fig. 2 shows a photograph of the TFF M/P section electrodes.

Ion Source and Accelerator Performance

The ion source and accelerator have produced a 1-A, 80 keV beam of H^- ions with a pulse length of 30 seconds[5]. A number of measurements has been made to characterize the beam produced by the source and accelerator, prior to its entering the transport section. These measurements are summarized in Table 1.

Table 1. Typical ion source and accelerator data.

Beam current	1 A
Beam energy	80 keV
Electron content	12%
Uniformity along slot	± 20%
Normalized emittance perpendicular to slot	0.45π mrad•cm
Beam divergence (1/e) parallel to slot	± 17 mrad

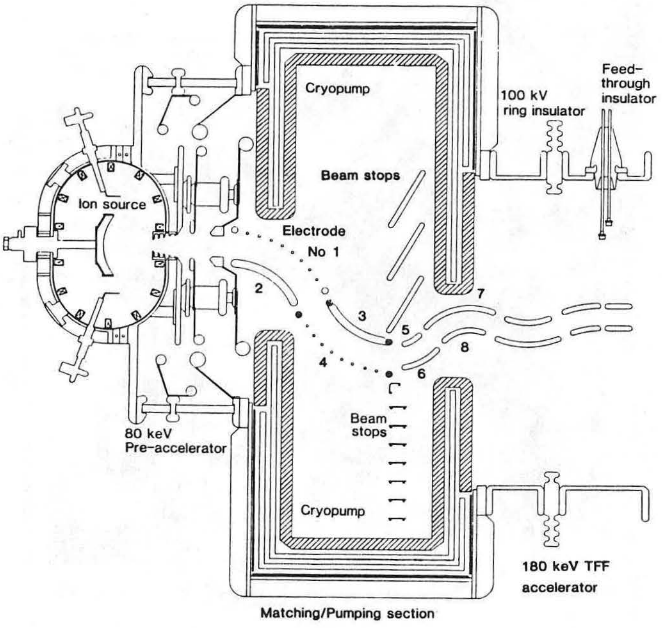


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Fig. 1. Plan view of the 180 keV TFF system. Electrodes 1 through 4 comprise the TFF M/P section.

The emittances quoted are normalized, and refer to the beam within a contour containing 90% of the beam. A typical emittance diagram taken in the transverse direction (short direction of the beam) for a beam energy of 57 keV is shown in Fig. 3. The aberrations seen are due to the very high perveance of the accelerator and nonuniformity of current density; measured and calculated emittances are in good agreement.[5]

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*This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

TFF Matching/Pumping Section Performance

To date we have operated the TFF transport system with H$^-$ beam currents up to 400 mA and energies up to 57 keV. An emittance diagram of a 57 keV beam taken in the transverse direction at the midpoint of the beam is shown in Fig. 4. The normalized emittance of this beam is about 33% higher than that of a similar beam measured at the exit of the preaccelerator before installation of the TFF M/P section (compare with Fig. 3). We are investigating the cause of this apparent emittance growth. Computer simulations show no emittance growth; it is likely that the apparent increase is caused by ripples in the output of the high voltage power supply (which at the time was not regulated), which causes the beam to "flutter" in both angle and position, leading to a time-averaged measurement of the emittance that exceeds the true emittance.

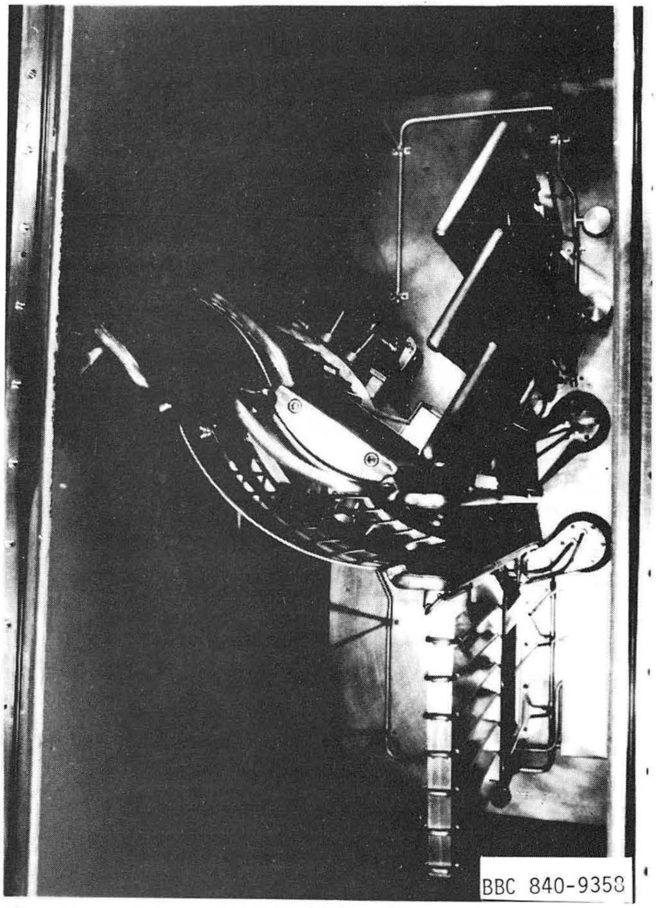

Fig. 2. Top view of the TFF M/P electrodes installed in the vacuum housing.

Faraday cup measurements taken 40.6 cm downstream to detect negative ions and electrons indicate that the electron content of the beam is insignificant; the electron trap built into the transport section works as expected. The beam also steers as expected from ion optics calculations when the potentials on the TFF electrodes are varied. The total H$^-$ current exiting the TFF M/P section, as determined by integration of the current density over the cross section of the beam, agrees well with the power supply current after correction for electron content in the initial beam. The measurements made on a 40 keV beam indicate a loss of about 14±7% of the H$^-$ beam. Monte Carlo gas flow calculations[6] had predicted a loss of 17%.

At this stage of the experiment, the currents drawn to the TFF electrodes are substantial; the variation of these currents with gas flow into the source is shown in Fig. 5 for a 42 keV beam. All currents vary linearly with pressure, and exhibit an intercept that is zero or very close to it. The linear dependence with gas flow indicates that the most probable origin of these currents is secondary electron emission resulting from the impact of ions or neutrals on the negative electrodes. The fact that the intercepts are near zero indicates that there is very little direct beam interception; it is most likely, therefore, that the secondary electrons result from the impact of neutral H atoms that were created by electron detachment collision of the beam with the background gas.

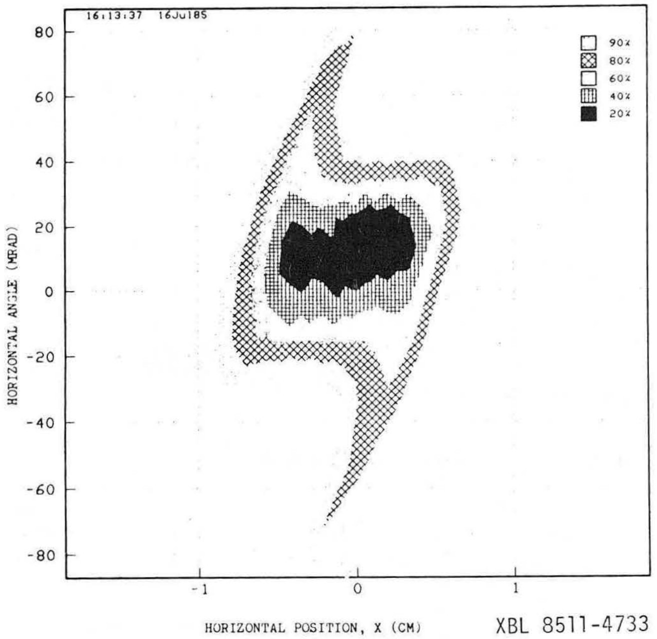

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Fig. 3. Emittance diagram of a 57 keV H$^-$ beam produced by the accelerator.

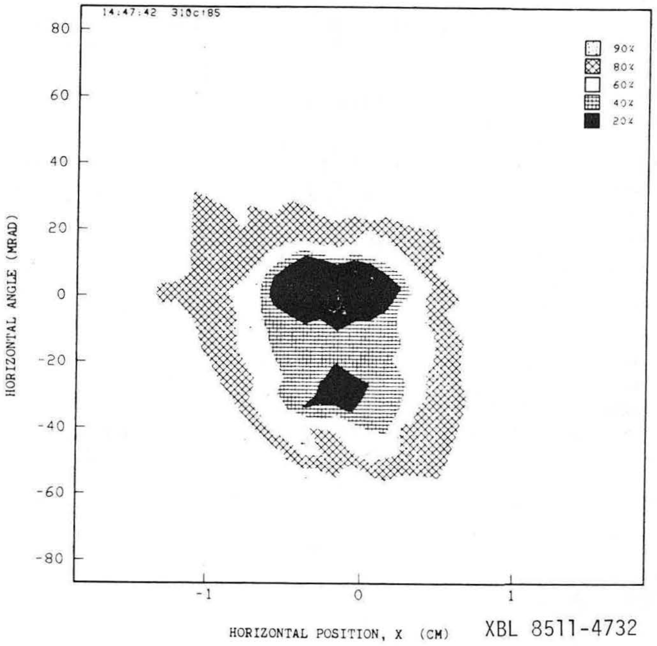

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Fig. 4. Emittance diagram of a 57 keV H$^-$ beam after passing through the TFF M/P section.

Another contribution to the electrode currents results from electrons emitted from the intermediate electrode of the accelerator (the "gradient grid"), which are collected on the positive TFF electrodes. A simple model taking these effects into account yields an estimate of the secondary emission coefficient for the first negative TFF electrode (an array of molybdenum tubes); the values are in the range of 3 to 5. These values are probably reasonable, considering that some of the neutrals strike the surfaces of the tubes at grazing incidence, and that there is also the possibility of cesium contamination of the surfaces.

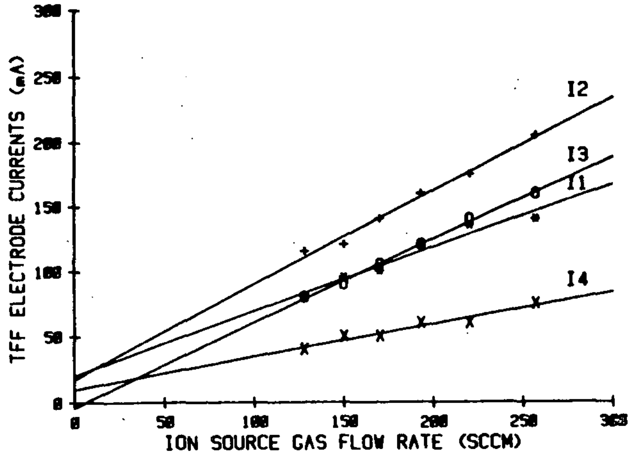

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Fig. 5. Electrode currents versus gas flow rate.

Conclusions and Future Plans

The 1 A, 80 keV accelerator performs exactly as expected. Beam pulses up to 30 seconds long have been obtained. From our preliminary data, beam transporting in the TFF M/P section also performs as expected, with the exception that the currents to the TFF electrodes are larger than anticipated and there is some apparent emittance growth. We are now taking steps to reduce these currents to a more manageable level: 1) we are installing the cryopumps (mentioned earlier) in the TFF M/P section to reduce the gas pressure, 2) we are considering increasing the anode area of the source, so that we can operate it at lower pressure, 3) we are considering surface treatment of the TFF electrodes to reduce the secondary emission coefficient, and 4) we are considering modifications to the gradient grid to reduce the flow of secondary electrons from the gradient grid to the positive TFF electrodes. To help resolve the question of apparent emittance growth, we are now installing regulated HV power supplies.

An additional TFF acceleration module has been designed and nearly completed.[7,8] This accelerator will add 100 keV to the 80 keV of the preaccelerated beam, yielding a 1-A, 180 keV H^- beam.

Acknowledgments

The authors wish to thank their co-workers for valuable advice and support, especially G. Ackerman, C.F. Chan, J. deVries, T. Jackson, G. Koehler, W. Kunkel, A. Lietzke, K.N. Leung, C. Matuk, A. Paterson, P. Purgalis, R. Pyle, L. Soroka, A. Wandesforde and D. Williams.

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LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720