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BNL NEUTRAL BEAM DEVELOPMENT GROUP
PROGRESS REPORT FY 1979

K. PRELEC AND TH. SLUYTERS

January 15, 1980

ACCELERATOR DEPARTMENT

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

UNDER CONTRACT NO. DE-AC02-76CH00016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY

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BNL 51193
UC-20a
(Plasma Systems - TID-4500)

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RESEARCH SPONSORED BY
DIVISION OF MAGNETIC FUSION ENERGY
U.S. DEPARTMENT OF ENERGY, WASHINGTON, D.C.

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $4.00; Microfiche $3.00

Introduction

The objective of the BNL Neutral Beam Program is to develop a 250 keV neutral beam system suitable for heating experiments in toroidal or mirror plasma devices. The system will be based on acceleration and neutralization of negative hydrogen ions produced in and directly extracted from a source. The objective of source studies is to develop a unit delivering 10 A of negative ion currents in pulses of 1 s duration or longer, operating with extracted current densities of at least 0.5 A/cm^2 and having acceptable power and gas efficiencies and good beam optics. The 250 keV accelerator development work covers different structures, including those separated from the source by a bending magnet or a beam transfer system. During FY 1979 substantial progress was achieved toward the objectives of the program; in the same period the BNL program was reviewed by a panel, resulting in suggestions for a better orientation toward prospective users' requirements and in establishment of contacts with Princeton Plasma Physics Laboratory (TFTR Project) and Lawrence Berkeley and Livermore Laboratories (MFTF Project). A cooperative effort with Westinghouse was initiated in the second half of FY 1979 in order to utilize industrial facilities and expertise.

BNL Approach

Components of a negative ion source based neutral beam system can be identified as follows (Fig. 1).

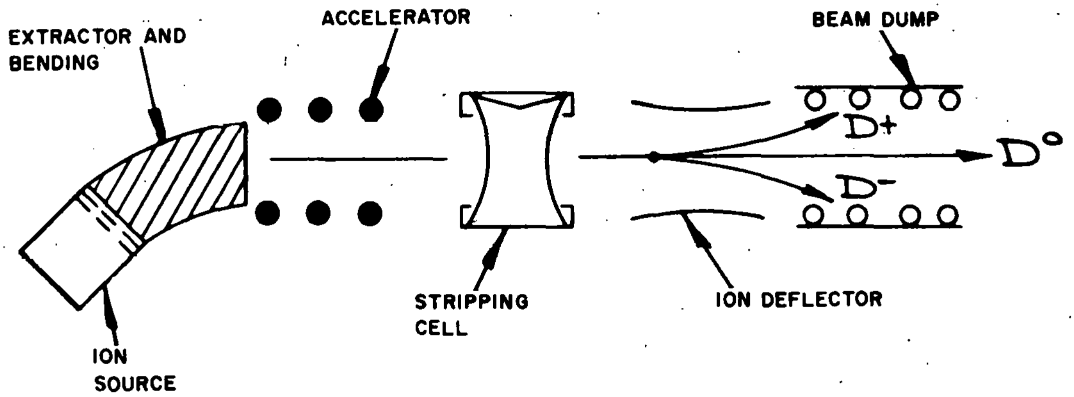

Figure 1

1) Ion source;
2) Extractor and beam transport;
3) Accelerator;
4) Stripping (neutralizing) cell;
5) Ion deflector;
6) Ion beam dump.

In FY 1979 work has been in progress on first three components only.

Two types of direct extraction ion sources have been studied, a standard magnetron source and a Penning source with an auxiliary electrode to enhance the H^- production. In either source a hydrogen-cesium plasma is established in the interelectrode gap and serves as the source of particles to bombard a cesium covered electrode (cathode, auxiliary electrode), where negative hydrogen ions are produced. All BNL sources are of a compact design and operate with high extracted H^- current densities (space charge limited); for operation with pulses longer than 0.1 s source electrodes and extractor grids have to be cooled. In addition to the magnetron and Penning sources, a new source, planar magnetron, has been under consideration because of a substantially improved power efficiency and possibly an improved gas efficiency. Although the size of existing sources does not allow H^- current yields above 1-2 A in pulses longer than 0.1 s, once the preferred configuration has been identified a large, cooled module will be designed to deliver 10 A in long pulse/steady state mode of operation.

The purpose of the extractor system is to extract negative ions from the source, form a beam with a sufficient current density and having good optical properties, separate electrons and, possibly, remove them to an electrode at a lower potential. Except in the case of an immediate acceleration (close coupled system), a beam transport system is required to transfer the beam from the extractor to the accelerator. For that purpose a bending magnet has been studied, with additional advantages of an easier pumping, better matching to the accelerator and full removal of all unwanted components from the beam (e.g. heavy negative ions).

Earlier in the BNL program close coupled accelerating structures have been studied and the conclusion was that they do not offer a practical solution for high current long pulse beams due mainly to a high background pressure, presence of Cs vapors in the accelerator, and the existence of a large beam halo. In order to eliminate these problems the new approach calls for a 90° bending magnet separating the high current density source from the much lower current density accelerator, the latter being a single aperture structure accepting the total beam. Acceleration to 250 kV would be accomplished in two steps.

Stripping cell is a beam line element common (except possibly in details) to all negative ion based systems. Gas or metal vapor jets, plasmas and lasers have been considered but no decision has been made yet. No studies have been made on the ion deflector and beam dump, either.

Project Goals for FY 1979

Negative ion sources. The project goals are: to continue studies of Mk IV Penning and magnetron sources (without cooling) with the objective to extract H^-/D^- beams in pulses of 50-100 ms and with an intensity limited by cathode heating; to fabricate a Penning jet type source and test the discharge; to build and test a computer system for monitoring and control of sources; to design and procure elements of a test stand for studies of long pulse/steady state ion sources with nucleated boiling electrode cooling; to initiate a cooperative program with Westinghouse, including nucleated boiling studies, cesium transpiration studies, and design and fabrication of cooled sources.

Negative ion transport and acceleration. The project goals are: to study negative ion beams at 15 keV level, including emittance measurements, for different source slit and extractor geometries, as function of source parameters; to study the transport of beams through bending magnets having different field indexes; to design and test components of the new 250 keV beam facility. As part of the cooperative effort with Westinghouse to start studies of a conceptual design of a neutral beam line.

Progress in FY 1979

Negative ion sources. Studies of the Mk IV models (without cooling) of magnetron and Penning sources have continued, with the objective of gaining experience for the design of sources that would operate reliably with long pulses (> 1 s) and would deliver higher currents. It was found that machinable glass electrode supports were the main cause for breakdowns and contamination of the source. The design was subsequently changed and all insulators removed from the vicinity of the discharge chamber and placed inside pole tips (Fig. 2); complications due to the presence of electric and magnetic fields in the same region were also greatly reduced. Addition of biased shields between the cathode sides and the anode further improved the operation. The first successful run of the modified source lasted about two months, with the source operating 24 hours a day and often 7 days a week; the reliability was better than 95%. Parameters of the discharge were limited by the cathode heating to a discharge current of about 120 A and a pulse length of 50-100 ms. During the run about 75,000 pulses were accumulated, corresponding to an integrated time of more than 1 hour. Cesium was fed into the discharge from a separately heated container, making the diffusion rate independent of source operating parameters.

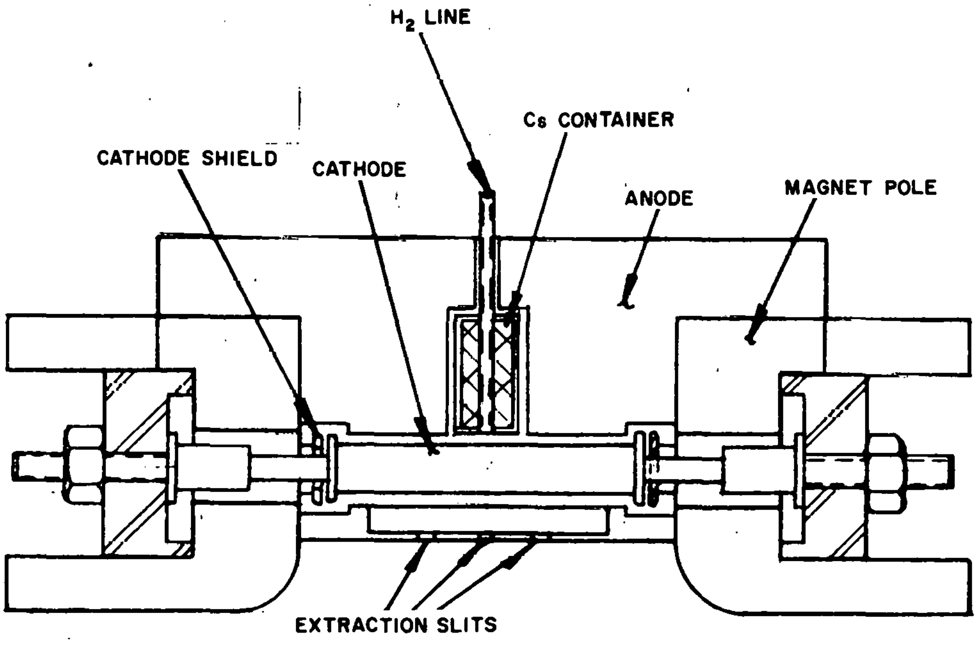

Figure 2

A second problem that has plagued Mk IV sources was the extractor, with frequent sparking due to a poor shielding and showing overheating during long pulse operation caused by E x B drifting electrons. The extractor was redesigned and an electrode on a potential much lower than the extractor was added; the objective was to collect electrons from the source with a much lower energy (improved power efficiency, lower heat load). Tests have shown an extracted current limit of about 0.2 A of H^-, at a pulse length of 0.1 s, due to electrode heating; initial results of electron collection have been encouraging, with more than 30% of electrons collected at the low voltage.

The design of the Mk IV Penning source has been improved by adding electrodes to fully shield the cathodes (Fig. 3). The parasitic magnetron mode, previously observed in the Mk IV Penning source, has been eliminated and reliable operation achieved. In the hydrogen mode, the source has accumulated more than 200,000 pulses, 0.1 s long, while in the cesium mode 10,000 pulses were achieved at cathode current densities of 5-7 A/cm^2 and a pulse length of 20 ms. The duration of the cesium run was limited by the cesium supply. Studies of the extraction of beams from the Penning source have not been concluded. The Penning jet source has been put into operation and low current

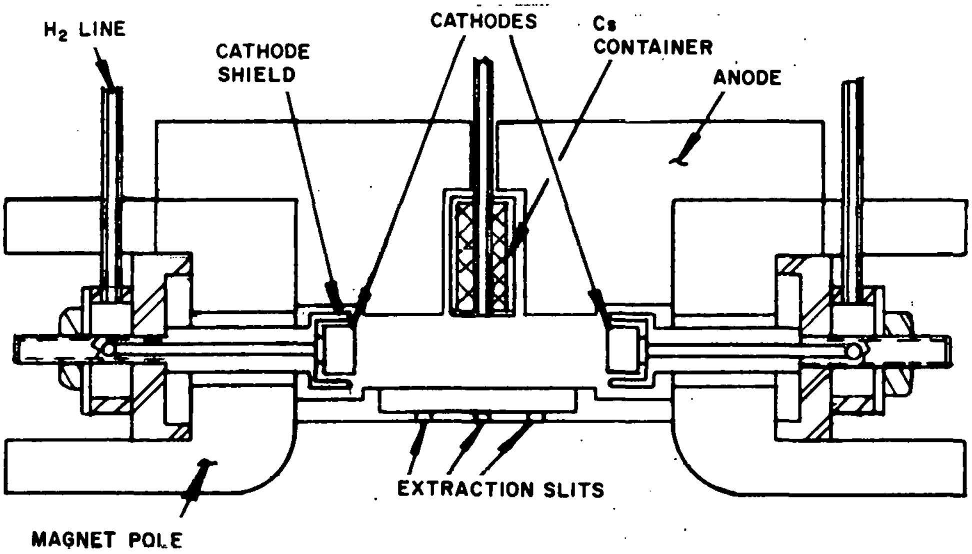

Figure 3

density discharge in the hydrogen mode obtained. Expectations about a subtantially improved gas efficiency have been confirmed, but due to the departure of the physicist in charge of this experiment the work has proceeded with a low priority.

A computer system for source monitoring and control was designed, built and tested with the source. Its purpose is first, to monitor the operation of the source overnight and during weekends and change parameters if necessary, and, second, to serve for source conditioning according to a predetermined schedule. A substantial saving in time and manpower will result by using such a system.

Studies of nucleated boiling cooling of a Mk IV Penning cathode were completed. Previous computer studies have shown that this design should be usable for heat fluxes up to 0.5 kW/cm^2, the limitation being due to the turbulence at the water passage exit. The test run confirmed these conclusions and at 0.5 kW/cm^2 the surface temperature in the center of the test piece was 360°C, while opposite the fluid exit channel it was 430°C.

The existing ion source test stand has limited capabilities: a pumping speed of 10,000 ℓ/s, a discharge power supply delivering 500 A in pulses of 0.1 s and no electrode cooling system. In order to be able to study sources that operate with higher currents and much longer pulses and requiring cooling of electrodes, it was decided to build a new ion source test stand. The design parameters are: a vacuum system with a pumping speed of 80,000 ℓ/s for hydrogen; a discharge power supply delivering 500 A at 450 V and in 30 s pulses or 25 A at 1000 V, steady state; a power supply for the first extractor grid delivering 5 kV, 3 A d.c.; a power supply (existing) for the second extractor grid delivering 25 kV, 5 A in 5 s pulses or 3 A steady state; a cooling system using deionized water for source electrode (anode, cathode) and extractor grid cooling. All main elements of the new test stand have been designed and procured and construction has proceeded on schedule.

There have been three types of sources, all of them incorporating electrode cooling, under consideration and they have reached different design and fabrication stages. A Penning source, similar in size to Mk IV model but with cathodes to be cooled by nucleated boiling, has been designed and fabrication has begun at Westinghouse; the design of a magnetron source cooled by water flow has begun, and concept studies of a planar magnetron source cooled by water flow have begun.

As part of the cooperative effort with Westinghouse and in addition to the fabrication of a cooled Penning source, different shapes of cathode cooling channels have been studied and the construction of a test facility has begun where the optimum cathode channel design will be determined by experiment. Cesium transpiration studies have begun as well and results indicate that porous wall transpiration method could be used to feed the cesium into the discharge chamber.

Negative ion transport and acceleration. Negative ion beam studies have been done at an energy level of 15 keV. A computer controlled emittance monitor was constructed and brought into operation to study the beam parameters (density distribution, divergence, emittance). Beam parameters have been first measured after the extractor and it was found that for beams up to 0.5 A beam divergence and emittance depend little on the extraction geometry and that beams from single and multiple slit geometries should be transportable through a 90° dipole magnet having an 8 cm gap and a 20 cm bending radius. Second, beam properties were measured after the 90° bend, for beam currents up to 0.5 A. It was found that an extracted beam with an initial density of 0.5 A/cm^2 can be transported through the bending magnet with an efficiency of better than 80%, resulting in a low divergence beam with a density of 10-15 mA/cm^2. This lower density beam is well suited for large single aperture acceleration to high energies. Almost complete space charge neutralization occurs in the negative ion beam during its passage through the magnet due to ionization of the background gas (pressure $\approx 5.10^{-5}$ torr). Comparison of measured optical properties with the theory shows a good agreement.

The new building to house the 250 keV neutral beam test facility has been completed. Progress was made with the conversion of the short pulse (10 ms), low current (1 A) accelerator test stand into a long pulse (0.1 s), high current (10 A) test facility, located in the new building. The 14 ft long vacuum vessel has been constructed and delivered and some vacuum equipment has been ordered. The 25 kV and 150 kV power supplies were modified to include computer control. A computer control system has been designed and partially constructed.

By means of a trajectory computer program and using experimentally determined beam emittances after the 90° bend, several designs of a 250 kV, four electrode accelerating structure have been studied and its parameters finalized.

Plans For FY 1980

Negative ion sources. The main objective of the program will be to achieve the proof-of-principle for negative ion sources: to design a source and extract a 20 keV beam having an intensity of at least 1 A, in pulses of 1 s duration or longer. The source should have a good power efficiency so that the heat can be removed by water flow (no nucleated boiling cooling), and operate with an acceptable gas efficiency. Studies of the existing Mk III and Mk IV sources will continue to gain information on the best shape of source electrodes (cathode, anode) and on the electron collector and extractor system (distribution of the electron component as function of the ratio of voltages and the geometry of the system). Based on these data, the Mk V cooled models will be designed and fabricated, with parameters adequate for the proof-of-principle requirements. The test stand for studies of cooled sources will be put into operation and tests of such sources will begin in the second half of the year. Studies of the nucleated boiling cooling will be finished, with the goal to reach heat inputs of 1 kW/cm^2.

Negative ion transport and acceleration. Studies of 15 keV beam properties of Mk III and Mk IV sources (density distribution, divergence, emittance) will continue, with the goal to get information on different sources, operating under different conditions, and with different extraction systems, without and with a bending magnet. Beam transport and accelerating systems (single aperture, d.c., quadrupole, Meqalac) will be studied theoretically. Work on the construction of the new accelerator test facility will continue with a low priority; it is expected that the Phase I (vacuum system, source, 30 kV extraction power supply) will be finished and that studies of 30 keV beam properties and transport will begin.

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