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NEGATIVE ION SOURCE AND BEAM DEVELOPMENT AT BNL*

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Summary

Neutral beam injector based on H^- ions for Tokamak fusion reactors is gradually evolving from the accumulated research results at BNL. Progress is reported on both Penning and magnetron surface plasma ion sources for direct extraction of negative ions. Schemes for transporting and accelerating of the ion beam are also described. Test results of the gas jets for $H^- \rightarrow H^0$ conversion are also included. The next generation of a high energy neutral injector test stand to be completed in the coming months is also presented.

Introduction

Injection of high energy beams of neutral hydrogen atoms for plasma heating in Tokamak fusion devices has been very successful. To produce such neutral beams hydrogen ions of either polarity have to be created, accelerated and neutralized.¹ Because of the much higher neutralization efficiency of H^- ions with almost no dependence on beam energy,² negative ion based systems are preferred for energies above 150 keV. There are basically two approaches: negative ions are either extracted directly from a source or produced by double electron capture from positive ions at a low energy (0.5-10 keV). A schematic comparison of these two approaches is shown on Fig. 1.

of a dense plasma with cesium vapor covered electrodes. Several models have been constructed and tested. The BNL MK III magnetron with the cesium compound in the cathode cavity (Fig. 2) is still the most intense and efficient one among the surface plasma (S.P.) sources (see Table I).

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Fig. 2. Magnetron (MK III).

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DOUBLE ELECTRON CAPTURE

SYSTEM BASED ON D- SOURCE

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Fig. 1. Principles of the direct and indirect production of negative ions.

At Brookhaven National Laboratory, we have been developing neutral beam systems based on direct extraction of H^- ions from surface plasma sources.

Negative Ion Sources

Two types of ion sources have been used at BNL, the magnetron and the Penning source. In these sources negative hydrogen ions are produced via the interaction

Table I The parameters of the BNL sources.

Parameters	Source	MAGNETRON		PENNING	
		BNL (MK III) H_2	BNL (MK III) H_2	BNL (MK III) D_2	BNL (MK III) D_2
H^- (D^-) current	A	0.9 (0.6)*	0.44	0.2	0.2
H^- (D^-) current density	A/cm ²	0.7 (0.45)	0.44	0.2	0.2
Pulse length	ms	10 (20)	3	6	6
Discharge current	A	250 (180)	65	40	40
Cathode current density	A/cm ²	20 (14)	33	20	20
Discharge voltage	V	110	110	400	400
Total discharge power	kW	30 (22)	14.3	16	16
Cathode power density	kW/cm ²	1.5	4.8	5.3	5.3
Power efficiency	mA/kW	30 (20)	20	12	12
Gas Efficiency	%	2-3	1.1		

*Parameters for 20 ms pulses are given in parentheses.

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If there is no cooling of the cathode, the pulse length and extracted current are limited by the temperature rise of the cathode surface.

Penning discharges (Fig. 3) have also been investigated. Achieved H^- currents are generally lower than

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from magnetron sources (Table I) due to smaller dimensions of presently operating source. It seems that a Penning source with a separate emitting electrode opposite to extraction slits may improve the performance by a factor of 2.

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Fig. 3. BNL MK IV Penning Source with emitter.

A larger BNL MK IV source has been constructed and is being tested (Fig. 4). A 50 ms long pulse has been achieved. This source can be operated in either magnetron or Penning mode. Besides having a larger cathode surface for H^- production and an independently heated cesium chamber, this source design also incorporates cooling passages in the cathode body. An enhanced heat removal from the cathode will allow longer pulses and higher discharge power densities.

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Fig. 4. MK IV Magnetron.

Nucleated boiling of the pressurized water is intended to be used³ as the means of heat removal. A test facility for this project has been assembled and is operating. Cathode structures have been tested with heat loads of 300 W/cm^2 , with nucleated-boiling cooling. The final goal is to remove a heat flux of $1\text{-}2 \text{ kW/cm}^2$, while maintaining a cathode surface temperature between $300\text{-}600^\circ\text{C}$. The surface temperature will be controlled by the heat removal rate, via adjustment of the water pressure in the circuit.

A modification of the MK IV source, a jet source, is also being studied. In this configuration (Fig. 5) the gas inlet of the source has the form of rearward-aiming jets. A pumping port at the back of the source

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Fig. 5. Jet Source.

helps to remove the neutral gas flow. With the help of the directivity of the gas jet, the evacuation of gas through the back of the source is expected to greatly reduce the gas load along the beam line. The H^- ions will still be extracted by the high extraction potential from the front of the source. The jet source is now being tested on a new test stand, but without the discharge.

The future source development at BNL will be concentrated on the scaling up of either the magnetron or Penning source to the multiampere dc range. Parallel to this effort, a study is underway on how to stack several sources in order to reach the higher beam currents.

Extraction, Acceleration and Neutralization

A one ampere H^- beam extracted from the BNL MK III magnetron source and accelerated to 120 kV in our close coupled, single gap accelerator system (Fig. 6) has been obtained.⁴ At the source exit slit 0.3 A/cm^2 of H^- ions was extracted at 3 ms pulse length. At 15 cm

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Fig. 6. Close coupled arrangement.

downstream the density was about 25 mA/cm^2 with a divergence of $10\text{-}15^\circ$. Ideally this source-accelerator structure has intrinsically low beam losses during fast acceleration of the ions. However, the closeness of the accelerating electrodes to the source also causes unreliable operation of the high gradient accelerator due to the localized high density gas background, the large beam halo from the source and the contamination of the electrodes by cesium vapor that leaks out of the source in between beam pulses.

In a preliminary low beam current transport experiment with a 3" diameter magnetic quadrupole doublet (Fig. 6), a 150 mA negative ion beam was focused on a Faraday cup mounted 75 cm downstream. This focused beam was limited by the acceptance of the quadrupoles, which was located 20 cm from the single aperture accelerator. Nevertheless, the quadrupoles, acting as a mass filter, did confirm that less than 15% of the beam was composed of electrons.

A new neutral beam system (Fig. 7) based on H^- ions is being built at BNL to advance the research effort. As high as 10 A H^- beam then can be accelerated up to 250 keV at 100 ms pulse length. A double gap 250 kV single aperture accelerator is going to be used.⁵ The beam transportation also takes on a new configuration in that the extractor is to be separated from the accelerator by a 110° bending magnet. Electrons, neutral particles and heavy ion impurities,

Neutralization with gas jets² is intended to be used for conversion of H^- into H^0 . The cross beam configuration allows the neutralizer jet to be caught and evacuated with separate pumping capacity without burdening the beam line pumps.

Effusive and supersonic gas jets of CO_2 have been formed on a separate test stand. The choice of the target gas is a compromise between the neutralization efficiency on one hand and the required target thickness and ease of pumping on the other. CO_2 gas was tested because it creates the least gas load at its optimum target thickness. Even then, it was only able to run tests with less than 1/30 of the designed full scale with total pumping capacity of approximately 25,000 l/s in our test stand. It was confirmed that the pumping need for the neutralizer jet rivals that of the ion source, if not greater.

The profiles of the present gas jet on the test stand were plotted⁶ and a divergency of less than 13° half angle at half centerline flux intensity can be obtained. Up to 85% of the jet was caught by a catcher located 2" downstream to the skimmer of the jet source.

In conclusion, it appears reasonable to assume that with adequate cooling of the cathode and independent cesium control, a multiampere quasi steady state negative ion surface plasma source can be realized. The application of post acceleration with bending magnet(s) seems to have more future for multiampere high energy neutral injectors than close coupled systems.

References

1. Sluyters, Th. and Prelec, K., Neutral Beam Workshop, Culham Lab., Abingdon, U.K., June 1978.
2. Lam, C., Proc. Symp. on the Production and Neutralization of H^- Ions and Beams, Brookhaven National Laboratory, BNL Rep. 50727, Sept. 1977.
3. McKenzie-Wilson, R., Ibid., Pg. 140.
4. Lam, C. and Sluyters, Th., Proc. 7th Symp. on Engineering Problems of Fusion Research, Knoxville, TN, October 1977.
5. Kovarik, V., BNL AGS Division H^- Tech. Note No. 46, April 1978.
6. Lam, C., IEEE Int'l. Conf. on Plasma Sci., Monterey, California, May 1978.

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Fig. 7. A 250 kV Neutral Beam System.

therefore, will not enter the beam line. Differential pumping of the source chamber and the accelerator chamber can be effected. High voltage hold-off characteristic is expected to be better because of the absence of localized high pressure and of Cs contamination of electrodes. In addition, the bending magnet, with strong focussing properties in the plane perpendicular to the emission slit, provides some control of the beam entering the accelerator.

An experimental bending magnet has already been built and is being tested with H^- ions extracted up to 15 kV but without acceleration. The magnet has shaped cross section at the poles and 700 gauss field at the center of the gap. H^- ions from a BNL MK III magnetron were transported. Extensive investigation will be needed to evolve a well characterized bending magnet.