IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

A 50-mA NEGATIVE HYDROGEN-ION SOURCE

Charles W. Schmidt and Cyril D. Curtis*†

ABSTRACT

An ion source of the magnetron type,[1,2] which produces a 50-mA negative hydrogen-ion beam of good quality for accelerator injection, has been developed.[3,4] This source has been in use for over a year and has become the principal ion source for all modes of accelerator operation at Fermilab. Details of the design and operation of this source along with information regarding beam quality and reliability are presented.

INTRODUCTION

A 30-mA negative hydrogen-ion beam of long duration is being used at Fermilab for multiturn-charge-exchange injection into the booster.[5] In addition this beam is also convenient for producing a short low-intensity beam for the cooling-ring experiments as well as a long pulse for producing large neutron dosages for cancer therapy use.[6] The source is capable of producing 50 mA of H^- ions from the 750-kV column with a pulse length of 60 μsec at a repetition rate of 15 Hz.

ION SOURCE

H^- ions are produced by a surface-plasma source of the magnetron design (figure 1). This source has an oval-shaped cathode surrounded by an anode and operates in a magnetic field parallel to the cathode surface. When filled with hydrogen to a pressure of several hundred millitorr and energized with a few hundred volts, electrons confined to spiral around the anode-cathode gap by the E x B fields produce a dense plasma in the gap. Negative ions are created by positive ions striking the cathode. The positive ion either acquires two electrons upon entering the surface and is reflected as a negative ion or sputters atoms from the surface which may leave as negative ions. Cesium introduced into the source coats the cathode surface and increases the H^- ion production by lowering the surface work-function. The negative ion is accelerated through the narrow plasma to the anode with minimal loss. Between the anode aperture and the dense plasma is a narrow depression in the anode where the plasma density decreases to reduce the electrons extracted from the source. Ions passing by the anode aperture are accelerated by the extractor electrode to a few tens of kilovolts.

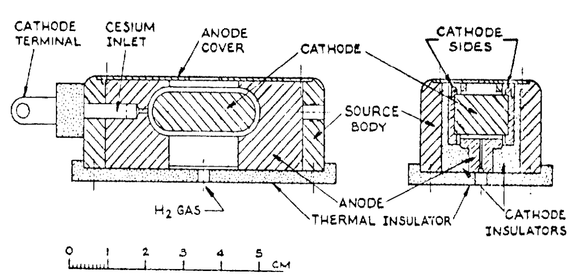

Figure 1. Fermilab H^- Magnetron Ion Source.

Ion current densities of several amperes per cm^2 exist at the extraction gap and pose serious space charge problems which can result in beam blow-up. Control of the space charge force is achieved by a high gradient 90° bending magnet[7] which further removes electrons and unwanted ions and shapes the H^- ions into a beam suitable for injection into the accelerating column (figure 2).

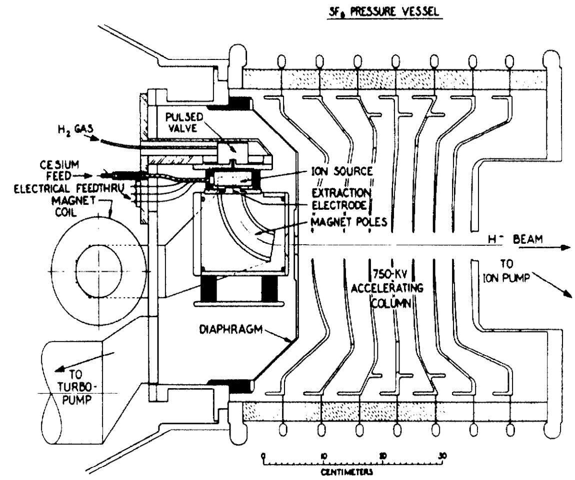

Figure 2. H^- Ion Source Assembly.

Much information regarding the development and construction of the Fermilab source has been reported in previous papers[3,4] and is being recompiled and updated by the authors as a future Fermilab technical memo. Since the last reporting the source has been in operation for over a year and several observations and improvements which affect the long-term operation have been made. Most of these improvements were in the electronics and operational procedures for assembling or running the source.

The only change to the ion source proper has been an increase in the diameter of the gas channel from the pulsed valve to the discharge region, a length of 2 cm. Originally the diameter was 3.2 mm and was increased to 4.8 mm to reduce the effect of cesium hydride. CsH is formed by cesium from the source reacting with the hydrogen gas and depositing on the channel walls. After several hundred hours the smaller channel became so restricted that considerably higher than normal gas consumption was needed to maintain source operation. In addition the cesium boiler temperature was reduced to give lower cesium pressure in the source and thereby to decrease the production of CsH. Good operation after lowering the cesium pressure was restored by reducing the arc power and hence reducing the cathode temperature to maintain the proper cesium coating on the cathode. In fact, the stability and intensity of the source increased with lower cathode temperature. With these changes CsH has not been a problem. The source now operates with a cathode temperature of 325-375°C and a cesium boiler temperature of 191°C. The cesium consumption is about 1.5 mgm/hr which corresponds to an average cesium pressure of 10^{-6} torr.

Another problem related to the cesium system caused sporadic source operation. The arc voltage would increase abruptly and slowly return to normal as though the source suddenly received too much cesium which subsequently slowly evaportated. The problem became more severe when the temperature of the cesium feed tube was accidentally lowered. Correction was achieved by increasing the operating temperature of the cesium valve and feed tube. These temperatures are now in excess of 300°C, much higher than the boiler temperature. Speculation is that cesium droplets or compounds were condensing in the tube and suddenly bursting, overloading the source with cesium. Increasing

*Fermi National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510.

†Operated by Universities Research Association, Inc., under contract with the U. S. Department of Energy.

0018-9499/79/0600-4120$00.75 © 1979 IEEE

the temperature has prevented this formation.

Pulsing of the extraction voltage became necessary for long operation. A cleaned source assembly would hold d.c. extraction voltages of 18-20 kV for several days before serious arcing and heating of the extraction electrodes would occur. The extraction load current would increase due to surface emission and require lowering the voltage to 10 kV or less to prevent overloading of the power supply or damage to the source. Pulsing of the extraction voltage, using an isolated high-voltage series-tube modulator, has eliminated the problem so that 18 kV can be maintained without arcing or heating of the electrodes and without requiring more than 1 mA average current from the high voltage supply.

Improvements of the gas-valve system have also been important. Piezoelectric gas valves as used for the source are subject to considerable temperature variations. As the source starts up the valve temperature changes by 30-40°C, shifting the valve operating point. To correct for this variation a d.c. supply of ± 100 V is placed in series with the pulsed voltage to the valve. The pulsed supply is operated at 100 V with a pulse width of 150-200 μsec occurring 1.5 msec before the arc. The d.c. supply is adjusted to maintain this operating point as major changes in the valve occur. Small changes are corrected by a software feed-back loop using the micro-processor control system.[8] The micro-processor continuously monitors the pressure as measured by an ion gauge near the turbopump and changes the pulse width to maintain a set pressure. The bias supply and pulse width feed-back have provided stable gas operating conditions.

Contamination of the ion source is a potentially serious problem. On two occasions the source has shown difficulty in starting and never conditioned into the low arc-voltage (130-140 V) mode indicative of good operation. In each instance work had been done to change the gas bottle or on the gas handling system and there was either evidence of a hydrocarbon residue in the source or the possibility of hydrocarbon vapor entering the source. To reduce contamination problems research-grade hydrogen is being used along with a better gas system and better handling techniques.

Starting a source requires a high gas pressure (several times operating pressure) and a large arc voltage of 300-400 V. A small voltage of 2 kV on the extractor electrodes produces some gas ionization and helps to strike the arc. The arc current is initially very low so that long pulses of several milliseconds are used to heat the source. The arc voltage drops dramatically and the arc current rises as the source becomes hot and acquires cesium from the boiler. The arc width must be shortened to maintain the proper cathode temperature and the gas pressure may be slowly reduced. As the source becomes conditioned the arc voltage will decrease to 130-140 V while the beam intensity increases. Beam intensities of 30 mA are generally achieved after 4-6 hours but intensities of 50 mA or better usually require one or more days of conditioning.

Typical good operating parameters for the source are:

Repetition Rate	15	Hz
Arc Voltage	135 ± 10	V
Arc Current	150 ± 10	A
Arc Width	60-65	μsec
Cathode Temperature	325-375	°C
Anode Temperature	150-200	°C
Source Magnetic Field	1.3	kG
Extraction Voltage	18	kV
Extraction Current during Pulse	~200	mA
Bending Magnetic Field	2.4	kG
Cesium Boiler Temperature	190-192	°C
Cesium Valve and Feed Tube Temperature	>300	°C
Turbopump Pressure	$3\text{-}3.5\times10^{-5}$	torr
Ion Pump Pressure	$2\text{-}2.4\times10^{-6}$	torr.

For the past year the H^- source has been in operation for a total of 331 days with most of the down time occurring during the early part of the year when the system was new or during maintenance periods. The source has caused between 0.2 and 3.5% of the down time in the physics program in any given month with significant improvements for the later months. Most of the failures were due to problems of the electronic equipment in the high voltage dome that required debugging.

The ion source has required removal for cleaning and occasional cathode replacement seven times in slightly more than one year. A new or cleaned source will operate at near maximum intensity for approximately six weeks after which a slow decrease in the beam intensity begins. After another two weeks the intensity will be about half the normal operating value and will continue to decrease. The source therefore provides about two months of operation before requiring 1-2 days maintenance.

During normal operation the beam intensity from the 750-keV preaccelerator will be 50-60 mA. The beam typically will be increasing in intensity during the pulse and have about 10% or less high frequency modulation. A typical beam pulse of 50 mA x 80 μsec as observed by a current toroid following the 750 kV column is shown in figure 3. The amplitude, rise time, modulation and slope are critically dependent on various parameters such as source pressure, arc voltage and current, cathode temperature, cesium pressure and source longevity.

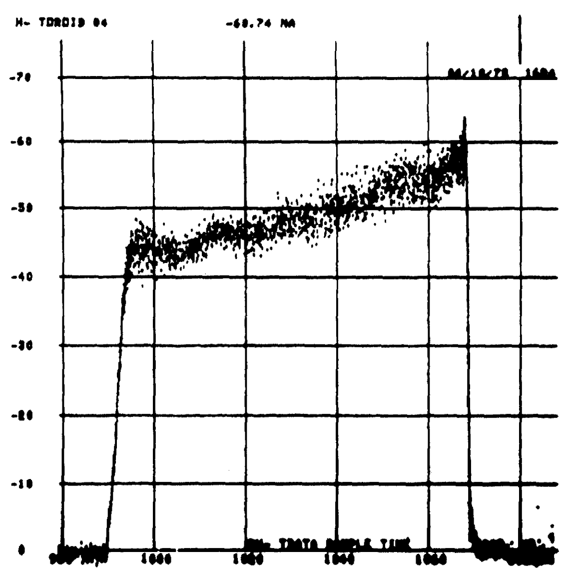

Figure 3. H^- Ion Beam from Preaccelerator. -10 mA/div. x 20 μsec/div.

The normalized emittance of a 50 mA H^- beam emerging from the preaccelerator at 750 keV, as measured by a slit scanner, is:

$$E_{nh} = 0.088\ \pi\ \text{cm-mrad},$$
$$E_{nv} = 0.15\ \pi\ \text{cm-mrad}.$$

These measurements are for 90% of the beam (figures 4 and 5).

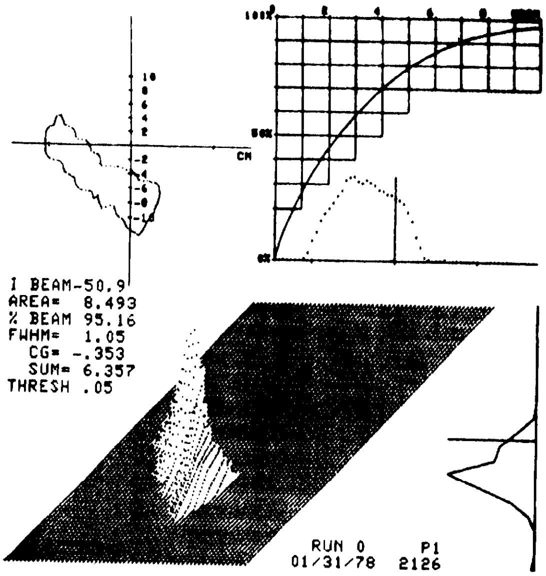

Figure 4. Horizontal Beam Emittance Area from Preaccelerator (750 keV).

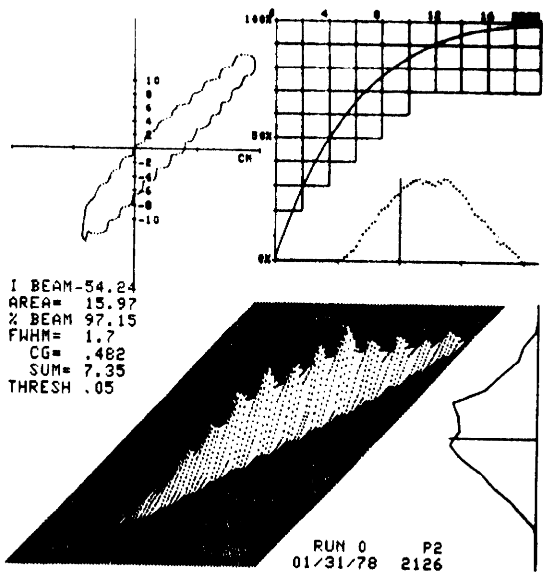

Figure 5. Vertical Beam Emittance Area from Preaccelerator (750 keV).

CONCLUSION

Operation of the accelerator with H^- ion beams has been very successful. H^- injection into the Booster began on February 24, 1978, and eight days later an all time booster intensity record of 2.6×10^{12} protons per booster pulse was achieved. Since then the booster record has again been broken and a new intensity record for the main accelerator has been made. Presently the main accelerator intensity record is 2.7×10^{13} protons per main ring pulse.

Because of the convenience with which H^- ions have satisfied the accelerator needs the proton source has been placed in standby. Conversion of the proton preaccelerator to provide an H^- beam is in progress and should be completed late this year. With two H^- preaccelerators some redundancy toward source failure will be provided and additional studies to improve the lifetime, beam quality and reliability of the source will be possible.

With the success that has been demonstrated at Argonne and Fermilab for H^- charge-exchange injection into synchrotrons, other accelerator laboratories are planning to use this method. Fermilab is currently building a complete H^- source assembly for the Chinese 50-GeV accelerator project. A magnetron assembly has been made for Brookhaven National Laboratory for use in studies leading to H^- injection into the AGS.

ACKNOWLEDGMENT

The authors are grateful to Th. Sluyters and K. Prelec of the Brookhaven neutral beam group for their support and for providing Fermilab with an early model magnetron source which lead to the development of the Fermilab source.

REFERENCES

1. Yu. I. Belchenko, G. I. Dimov, V. G. Dudnikov, Proc. 2nd Sym. on Ion Sources and Formation of Ion Beams, Berkeley, CA. VIII-1, LBL-3399(1974).

2. K. Prelec and Th. Sluyters, Proc. 1975 Particle Accel. Conf., IEEE Trans. Nucl. Sci. NS-22, No. 3 (1975)1662.

3. C. Schmidt and C. Curtis, Proc. 1976 Proton Linear Accel. Conf., Chalk River Nuclear Lab., Ontario, AECL 6577 (1976)402.

4. C. W. Schmidt and C. D. Curtis, Proc. Symp. on the Production and Neutralization of Negative Hydrogen Ions and Beams, BNL, Sept. 26-30, 1977, BNL50727, p. 123.

5. C. Hojvat, et al., this conference.

6. C. D. Curtis, G. M. Lee, C. W. Owen, C. W. Schmidt, and W. M. Smart, this conference.

7. Paul Allison, Proc. 1977 Particle Accel. Conf., IEEE Trans. Nucl. Science, NS-24, No. 3(1977) 1594.

8. R. W. Goodwin, R. F. Kocanda and M. F. Shea, Proc. 1976 Proton Linear Accel. Conf., Chalk River Nuclear Lab., Ontario, AECL 6577(1976)264.