CONF-9609289--1
SAND96-2784C
SAND--96-2784C

ION SOURCES FOR SEALED NEUTRON TUBES

E. J. T. Burns
Neutron Tube Department, Sandia National Laboratories, P.O. Box 5800, Albuquerque, N.M. 87185-0516

G. C. Bischoff
Lockheed Martin Specialty Components, P.O. Box 2908, Largo, Florida 34649-2908

In this paper, we will compare a number of gas ion sources that can be used in sealed neutron tubes. The characteristics of the most popular ion source, the axial Penning discharge will be discussed as part of the zetatron neutron generator. Other sources to be discussed include the SAMIS source and RF ion source.

INTRODUCTION

Fast and thermal neutron activation analysis with sealed neutron generators has been used to detect oil(oil logging), hazardous waste, fissile material, explosives, and contraband(drugs). Sealed neutron generators have also been used to measure body fat, sulfur in coal and constituents in cement.[1] Sealed neutron generators, used in the above applications, must be small and portable, have good electrical efficiency and long life. The ion sources used in the sealed neutron tubes require high gas utilization efficiencies or low pressure operation with high ionization efficiencies. Sealed neutron tubes operate on the low pressure side of the Paschen curve. Efficient and reliable ion source operation at low pressures is achieved by maximizing the electron path in the ion source region through the use of magnetic fields or alternating electric fields(RF). On the other hand, high pressure operation: (1)limits the high voltage; (2) causes energy loss of the incident ion beam and charge exchange in the accelerating portion of the neutron tube resulting in the production of molecular ions at the expense of incident atomic ions; and (3) causes increased secondary electron production which results in loading of the power supply. The net result of high pressure operation is lower neutron output.

Ion sources for sealed neutron tubes are different from all other accelerator based ion sources by the requirements placed on them by their applications. By far, the largest application of sealed neutron tubes is in the area of geophysical logging, primarily oil. The most stringent requirement for the above application is the diameter of the neutron generator and thus the neutron tube and ion source. This requires the ion source to have linear geometry as opposed to radial or spherical geometry. The requirements of the neutron tube and therefore the ion source are: (1) the diameter should not exceed .055 m.; (2) the source should generate primarily atomic deuterium or tritium ions as opposed to molecular ions at the lowest possible gas pressure; (3) the source should operate in either continuous or pulsed mode; (4) the source should be capable of generating up to 1 A/cm^2 in pulsed mode; (5) the sources should be rugged in terms of shock, vibration, and temperature; (6) the operating life of the source should be several hundred hours; and (7) the power consumption of the tube and source should be less than 100 watts.

In this paper we will discuss the characteristics of the most popular ion source used in sealed neutron generators, the axial penning discharge. Specifically, we will discuss the characteristics of this source as it applies to the zetatron neutron generator.[2] We will discuss,the neutron output of the zetatron using the axial penning discharge as a function of pressure. We will also discuss two new ion sources that produce mainly atomic ions, the SAMIS source and the RF ion source.

AXIAL PENNING ION SOURCE

The zetatron neutron generator is shown in Figure 1.[3] The axial penning ion source is located on the left side of the figure within the 0.06 T cylindrical magnet. The high voltage glass insulator is located just to the right of the axial penning ion source. Most of the volume of the zetatron neutron generator is taken up by the high voltage transformer and target bias resistor.

FIGURE 1. The zetatron neutron generator. The penning ion source is located to the left of the figure inside the 0.06 T magnet and next to the high voltage glass insulator.

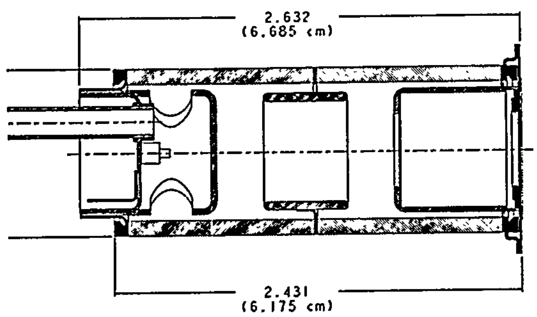

FIGURE 2. Penning ion source in the zetatron neutron generator. Annular ring is the anode between 2 cathodes. Ions are extracted through the hollow cathode on the right.

The axial penning ion source as used in the zetatron neutron generator is shown in Figure 2. The axial penning cold cathode discharge, as reviewed by Hooper,[3] is characterized by 5 modes of plasma behavior depending on the voltage, current, pressure and magnetic field. Modes (I) and (II) correspond to the lowest pressure and Mode (V) corresponds to the highest pressure. In modes (I) and (II), the ion density is much lower than the electron density. Modes (I) and (II) are **stable.** In Mode (III)and (IV), the plasma is quasi-neutral, but these modes are **unstable.** Mode (V) is the glow discharge region. Mode (V) is **stable.** In the case of the zetatron with accelerator voltages at or above 100kV, the zetatron can be operated DC at low pressure in modes (I) and (II). However, in the high pressure mode (V), the zetatron can only operate in a pulsed mode at low duty cycles. At high duty cycles in Mode V, the voltage must be lowered to prevent high voltage breakdowns.

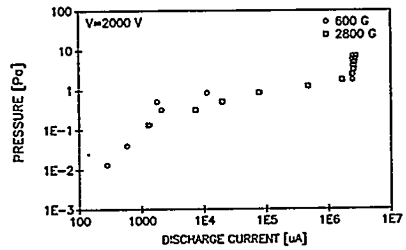

FIGURE 3. Pressure vs. Discharge current for 2kV applied voltage and 0.06 T and 0.28T applied magnetic fields. This figure is analogous to Figs. 5 and 9 in reference 4.

The pressure vs. discharge current of a cold cathode discharge in a deuterium-tritium gas as a function of pressure is shown in Figure 3 at one applied voltage, and two different applied magnetic fields. This figure is analogous to Figs. 5 and 9 in reference 3. The discharge current is the source current as opposed to the extracted ion beam current. There was no ion beam extraction for the data taken in figure 3. All measurements were pulsed with 100 μsec wide pulses at a frequency of 10 Hz. Each data point represents the average of 100 individual data points. The data below 0.32 Pa (2.4 mTorr) pressure represent the Penning ion source operating in Modes I or II. At pressures between 0.32 and 2.4 Pa (18 mTorr) the discharge is operating in Modes III and IV and is unstable. Above 2.4 Pa, the discharge is operating in Mode V and is stable again.

If operating the zetatron DC, the optimum pressure, according to figure 3, would be approximately 0.32 Pa to maximize the discharge current and thereby maximize the extracted ion beam current. However, this is close to the Mode II to III transition, where the discharge goes unstable. At 0.32 Pa from figure 3, the discharge current is 7.4 mA at 0.28 T vs. 2.1 mA at 0.06 T which suggests that large magnetic fields will maximize the discharge current in this pressure regime. The next section will compare the neutron output of ion sources that produce primarily atomic ions vs. the Penning ion source that produces mainly diatomic or molecular ions.

If operating the zetatron in a pulsed mode, from figure 3, the maximum discharge current is achieved at pressures 2.4 Pa and above. The discharge current is roughly independent of pressure and magnetic field above 2.4 Pa. As will be shown in the next section, the lower the pressure, the higher the neutron yield. At 2.4 Pa the penning ion source switches from Mode IV(unstable) to Mode V(stable). Therefore, high neutron output must be balanced against operational stability.

The dependence of the discharge current on applied voltage is shown in Figure 4 as a function of pressure. Above 2kV, there is very little dependence on applied voltage.

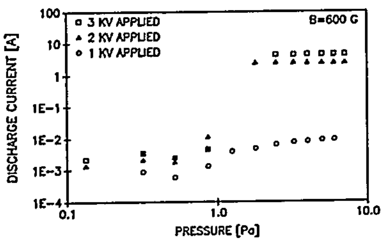

FIGURE 4. Discharge current vs. pressure for 3 different applied voltages for the penning ion source in the zetatron neutron generator. The black data points mean the discharge is unstable.

ZETATRON NEUTRON OUTPUT

To understand the neutron output as a function of pressure for the zetatron neutron generator, we have used a 1-dimensional transition matrix code[4] for ion and fast neutral transport through gas with a large applied electric field. The code calculates the number of ions and neutrals as a function of energy and position. The particle trajectories are integrated across the total distance, storing the total number of particles at each position with their energy. No backward scattering is allowed under the influence of the electric field. The program calculates a transition matrix which describes for each ion or neutral species at each spatial position and energy, the probability of going to the next spatial cell for all possible final energies.

Figure 5 shows, for 3 different ion sources, the calculated neutron yield as a function of pressure for a 100 keV deuterium ion beam transported through 4 cm of neutral deuterium(D_2) gas and strikes a range thick titanium tritite (TiT_2) target.

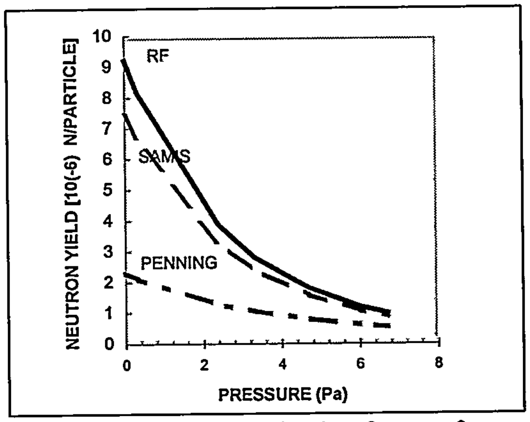

FIGURE 5. Neutron yield as a function of pressure for an incident 100 keV deuterium ion beam transported through 4 cm of D_2 gas and striking a range thick TiT_2 target. The ion species are: (1) Penning, 85% D_2^+, 10% D_3^+, and 5% D^+; (2) SAMIS, 70% D^+, 15% D_2^+, 15% D_3^+; and (3) RF ion source, 90% D^+, 5% D_2^+, 5% D_3^+. The incident ion species are assumed to be independent of pressure.

The incident ion species for the three ion sources are measured in references 1, 5, and 6. This simulation is typical of a zetatron at the beginning of life, prior to mixing of the deuterium and tritium gas. The calculation shows that the incident ion beam is little affected by the background gas at pressures below 0.32 Pa. However, at higher pressures, the neutron yield is strongly affected by the background gas. At the present time, we have not made a direct comparison of the neutron yield with the calculation due to the current loading on the present zetatron high voltage transformer which lowers the high voltage output on the target. In the future, we will make direct comparisons with the calculation by monitoring the high voltage on the target with a capacitive voltage divider and maintaining a constant high voltage on the target as a function of gas pressure.

ATOMIC SPECIES ION SOURCES

At the present time we are investigating a couple of ion sources that produce primarily atomic deuterium and/or tritium ions that are drop-in replacements for the penning ion source in the zetatron. These sources are the: (1) the Solenoidal and Monocusp Ion Source (SAMIS)[5]; and (2) the RF ion source.[6]

Figure 6 shows the SAMIS source coupled to a ceramic zetatron tube with a demountable or removeable LaB_6 cathode and gas flow system. The diameter of the SAMIS source is 0.025 m without the magnets and 0.04 m with the monocusp and solenoidal magnets in place. The length of the SAMIS source itself without the accelerator and demountable cathode is less than 0.15 m. The final version of the sealed ceramic zetatron with a SAMIS source, internal gas reservoir, and LaB_6 cathode will be no more than 0.2 m in length.

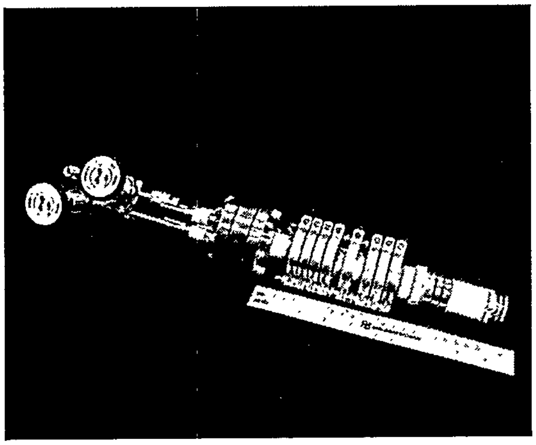

FIGURE 6. The solenoidal and monocusp ion source (SAMIS) coupled to a demountable ceramic zetatron.

The SAMIS source routinely produces 70% atomic hydrogenic ions with proper positioning of the external magnet at pressures as low as 0.4 Pa. Below this pressure the arc is extinguished.

In the zetatron neutron generator, we operated the SAMIS at a pressure of 1.0 Pa, 330 V arc voltage, and 9 amps current with a 30 μsec pulse, at 30 Hz(~ 0.1% duty cycle). The indirectly heated LaB_6 required 250 watts of power DC. The neutron output at 100 kV target voltage was consistent with 60 mA of 60% D^+, 20% D_2^+, and 20% D_3^+ ions. This corresponds to an increase of a factor of 4 over the Penning ion source with 40 mA of 85% D_2^+, 10% D_3^+, 5% D^+ at the same voltage.

Another ion source that is a potential drop-in replacement for the Penning ion source is the multicusp RF ion source with an internal antenna. The latest results from this source will be described at this conference. With proper positioning of the antenna, the source has achieved 25 mA of hydrogen ion current (0.8 A/cm^2) with over 90% atomic ions at 0.6 Pa with a pulsed RF power of 70 kW at a frequency of 2 MHz.

In evaluating the high atomic species ion sources, neither of the two ion sources above have met all the requirements as listed in the introduction. Strictly speaking, those requirements apply mainly to logging applications. The major issue with the SAMIS source is the electrical efficiency and lifetime of the hot cathode. Radiant heating of the LaB_6 cathode with a tungsten filament requires a minimum of 200 watts power. Direct heating of the LaB_6 cathode requires 500 watts of power. The major issue with the RF ion source is the RF power supply. If the ion source can be operated reliably at high peak powers and low average power at 13.58 MHz, the cost of the power supply will surely be reduced. Other issues are the lifetime of the internal antenna and the size of the impedance matching network.

CONCLUSIONS

We have characterized an axial penning discharge ion source as used in a zetatron neutron generator. The source can be operated DC at low currents below 0.32 Pa. At high currents, the optimum pressure is at 2.4 Pa or above for pulsed operation. Atomic species ion sources, such as the SAMIS and RF ion source, have higher neutron output at the expense of electrical efficiency.

ACKNOWLEDGEMENTS

This work was supported by the US Department of Energy under Contract No. DEC04-76-DP00789.

REFERENCES

1. Weinlein, J.H, O'Neal, M. L., and Bacon, F. M., Nucl. Instrum. Methods Phys. Res. B 56/57, 904(1991), and references therein.
2. Manufactured commercially by MF Physics Corp., Colorado Springs, Colorado. Phone: (719)-598-9549.
3. Hooper, E. B.. "A Review of Reflex and Penning Discharges," in Advances in Electronics and Electron Physics Vol. 27, New York: Academic Press, 1969, pp. 295-343.
4. Parker, G.J., Tischenko, N., Bardsley, N. and Burns, E.J.T., to be published.
5. Burns, E. J. T., Brainard, J.P., et al, Rev. Sci. Instrum. 67, No. 4, 1657-1661(1996).
6. Perkins, L. T. et al, Rev. Sci. Instrum. 67 No. 3, 1057-1059 (1996).