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Discharge characteristics of a penning ion source for compact neutron generator

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ABSTRACT

We investigate the discharge characteristics of a penning ion source for a compact sealed neutron generator in DC mode. A measuring system consisting of console, vacuum gauges, and teslameter is established. By using the measuring system, the discharge current as a function of ion source voltage, gas pressure, and magnetic field is studied. The results show that the neutron generator can operate in a safe and steady state when the experimental parameters are as follows: ion source voltage of 1.2–2 kV, gas pressure of 4×10^{-2}–8×10^{-2} Pa, and magnetic field of 0.3–0.5 T. Within these ranges, the neutron yield of the generator can reach 2×10^{8} n/s.

1. Introduction

Compact sealed neutron generators have been widely used for a variety of industrial applications because they are small in volume, easy to be controlled, and safe to operate [1–5]. For example, these neutron generators can be used in the detection of explosives and fissile material in cargo or luggage, oil well logging, and structural evaluation. How to improve the neutron yield is always a hot topic, for compact neutron generators with high neutron yield may open up more opportunity of applications. As we know, the neutron yield is mainly related to two factors: the characteristics of ion sources, and the properties of target materials [6,7]. So in recent years, researches of ion sources have been widely developed. Many methods have been carried out to optimize the ion source for smaller size, longer lifetime, or better discharge characteristic [8–14].

In this paper, we will investigate the discharge characteristics of a penning ion source for a compact sealed neutron generator. Due to their low power consumption, ease of operation, and ability for compactness, penning ion sources have long been used in neutron generator [9,10,12]. In the following, the neutron generator and the penning ion source are introduced. A measuring system consisting of console, vacuum gauges, and teslameter is established. By using the measuring system, the discharge characteristics of ion source when the experimental parameters (ion source voltage, pressure, and magnetic field) are varied are investigated. Finally, the effect of discharge current on the neutron yield is discussed.

2. Experimental setup

The compact neutron generator (named Φ50 neutron generator) used in this experiment is a portable and on–off sealed-tube D-T neutron generator based on drive-in target technology which is provided by the Radiation Technology Institute of Northeast Normal University. For their small sizes and high performances, different models of generators produced by Radiation Technology Institute of Northeast Normal University have been used in many application areas [15,16].The Φ50 neutron generator has a small volume (with a diameter of 50 mm and length of 200 mm), long lifetime (more than 500 h), and high neutron yield (about 10^{8} n/s order), which is suited for industrial applications. The generator can operate in DC, pulse, and multiple pulse modes, while in this paper, only the discharge characteristics in DC mode are investigated.

Fig. 1 presents the schematic diagram of penning ion source in the Φ50 neutron generator. The penning ion source mainly consists of two cathodes (spinned by a kovar plate), one hollow cylindrical anode (made of non-magnetic stainless steel), and a permanent magnet (made of Nd–Fe–B). The anode with a diameter of 18 mm and a height of 10 mm is placed 2 mm away from the cathodes. The 3 mm thick soft irons are in the cathode positions with the same diameter as that of anode, serving as

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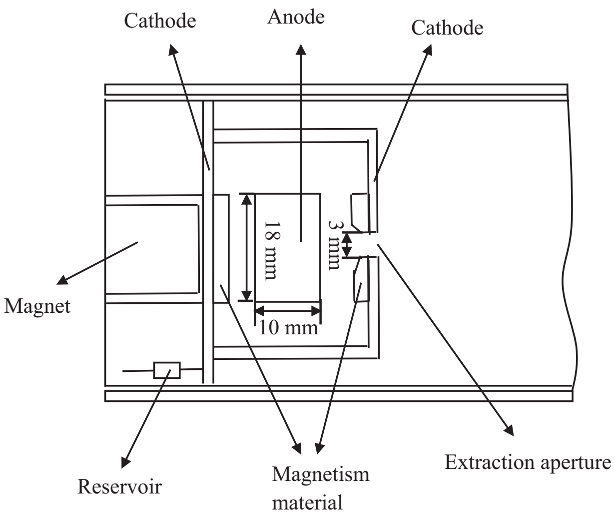

Fig. 1. Schematic diagram of the penning ion source.

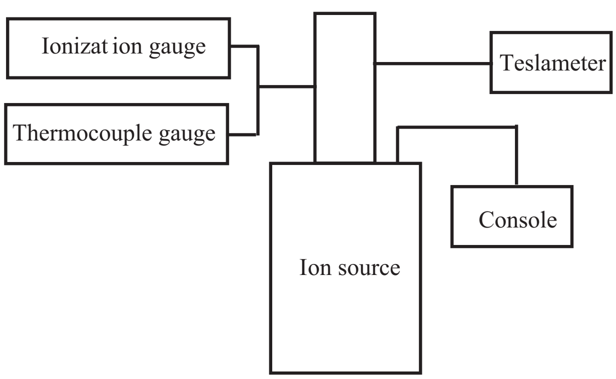

Fig. 2. Schematic diagram of the experimental setup.

the permeability magnetic material. The permanent magnet of 18 mm diameter and 20 mm height is applied along the axis of anode, which can be changed to get various magnetic fields. Due to the existence of the magnetic field, the electrons are confined in the area between anode and cathodes, thus stable discharges can be obtained [17]. The ions from the plasma region are extracted through the extraction aperture with a diameter of 3 mm. Because of the small size of penning ion source, the magnet is often placed on one side and the extraction aperture is on the other side, which will lead to a deep decrease of magnetic field between the magnet and the extraction aperture. To avoid this, an AlNiCo5 magnetic ring (with a limit working temperature 550 °C and a Curie point 890 °C) is embedded in the extraction cathode to improve the magnetic field of extraction aperture (not shown in Fig. 1). The reservoir is used to adjust the inside gas pressure of ion source.

Schematic diagram of the measuring system is shown in Fig. 2. The ionization gauge and thermocouple gauge is used to measure the gas pressure of high vacuum and low vacuum, respectively. In order to measure the inside pressure of neutron generator synchronously, the vacuum gauges are sealed with the generator. After being exhausted, the system is fixed firmly on a base. The gas pressure is varied by adjusting the current of reservoir where some Deuterium have been inflated in advance. The reservoir current and ion source voltage are controlled by the console coming with the neutron generator, and their values can be displayed on the LCDs of console. The value of discharge current is also displayed by the console. In order to measure the magnetic field when the permanent magnet is varied, a teslameter (measurement range: 0–1 T, measurement accuracy: 0.5%) is applied.

3. Results and Discussions

3.1. Effect of ion source voltage on the discharge characteristics

As the discharge current of ion source is related to three physical quantities in this experiment: ion source voltage, gas pressure, and magnetic field, the relations among the four quantities cannot be presented easily and intuitively in one figure. In order to focus on the relationship between ion source voltage and discharge current, the effect of magnetic field is not considered here, and the field is fixed at 0.4 T in this section. The experimental procedures can be described as follows. The power supply of console is turned on firstly, and the vacuum gauges are opened to measure the gas pressure of ion source. The reservoir current is adjusted from 0.4 A to 1 A to vary the gas pressure, thus the range of pressure can be set from 5×10^{-3} Pa to 1×10^{-1} Pa. After the pressure is set at a certain value, the ion source voltage is increased slowly from 0 kV to 2.5 kV (too high voltage will lead to the discharge breakdown) by adjusting the console. The value of discharge current can be displayed synchronously on the LCD.

The discharge current as a function of ion source voltage with different gas pressures is shown in Fig. 3. For simplicity, only four typical gas pressures (5×10^{-3} Pa, 1×10^{-2} Pa, 5×10^{-2} Pa, and 1×10^{-1} Pa) are presented. It can be seen that, the breakdown voltage is some different when the gas pressure is different, and higher pressure leads to a lower breakdown voltage. After breakdown, the discharge current increases linearly as the ion source voltage increases. In order to make the neutron generator work well, stable discharges are needed and too high or too low discharge currents are both unfavorable for applications of neutron generator. Too high discharge current will cause heating of the anode and make the anode release gases, resulting in the uncontrolled gas pressure in the neutron generator. Thereby, the neutron output will become unstable. If the discharge current is too low, the number of ions extracted will decrease with the accelerating voltage keeping constant, which reduces the neutron yield. According to extensive experimental results, it is found that the neutron generator can work with a stable and high neutron yield when the discharge current is in the range of 200–500 μA. We ascertain that the proper working voltage range is 1.2–2 kV based on the results shown in Fig. 3. Within this range, the discharge current is about 200–500 μA under proper gas pressures. Certainly, even if within this voltage range, the discharge current can also be too low or too high with improper pressures, which can also be seen in Fig. 3. The effect of gas pressure on the discharge current is investigated in the following to find optimum pressure range.

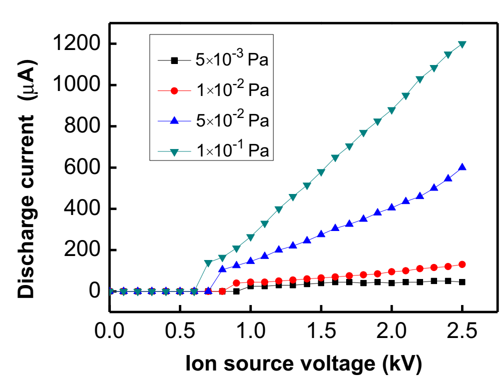

Fig. 3. Discharge current as a function of the ion source voltage with different gas pressures. Magnetic field: 0.4 T.