Design and Beam Extraction Simulation of a Penning Ion Source for Applying Movable Neutron Generator

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1. Introduction

Movable neutron generator has a promising demand in nuclear and material studies. Low neutron flux in the order of 10^6 - 10^8 n/s is in demand for elemental analysis of materials, which makes it easy to measure the prompt gamma emission form (n,ɣ) reaction and safer to operate rather than the radioactive neutron sources. This is operated both in steady mode and in pulse mode. For a movable neutron generator to produce neutron flux of the above order, ion source that generate a plasma in the chamber plays a vital role. Deuterium ions of a few tens of microamperes and > 60 keV energy are required to produce neutron of 10^6 - 10^8 n/s from D-D or D-T reaction. To produce ions of such characters, we designed one ion source, which works on the basis of penning discharge [1, 2]. This requires easy instrumentation, can be made compact in size, and be operated either in steady state or in pulse mode. The penning ion source which works on the basis of penning discharge was designed and simulated to generate a plasma in a vacuum chamber. A hydrogen gas in the simulation code was injected to test the designed ion source. In this paper, the design parameter and simulation results were discussed.

2. Penning Ion Source

A penning ion source [2] is a low current ion source, but it is simple and stable in a low power operation condition. Therefore, the penning type ion source is suitable to be used in a movable neutron generator, and we select this type as an ion source.

2.1 Design

The penning ion source consists of four main components: (1) cathode body, (2) anode, (3) permanent magnet, and (4) plasma electrode. The cathode body is an iron rod that has been machined to the dimensions and geometry shown in Fig. 1. A samarium cobalt permanent magnet is used to generate magnetic field because it is resistant to high temperatures. The magnet is held in place by its own magnetic force. The anode is fabricated by thin stainless steel into the shape of a cylinder with a hole. This shape can be obtained by cutting a strip of sheet metal and then bending and folding it into the require form. Finally, the plasma electrode is designed using the same iron rod as the cathode body. Schematics and the dimensions of all of these parts are shown in Fig. 1. Three holes are machined in the cathode body. Two holes are used to support the anode and the third is used as a gas inlet. Tubes will be inserted and connected into the two holes used for anode support and for biasing positive voltage, and a 1/8 inch stainless steel tube will be inserted into the gas inlet. Essentially the anode floats inside the cathode body. The plasma electrode is placed over the cathode body. The magnetic force created by the permanent magnet may hold the electrode.

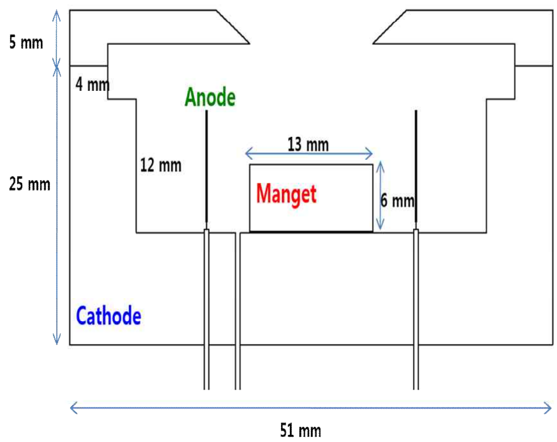

Fig. 1. Schematics and the dimension of the penning ion source. The three holes are machined in the cathode body. The two holes are used to support the anode and the one hole is used as a gas inlet.

2.2 Simulation

The Opera-3D code was used to simulate magnetic field and beam formation of the penning ion source. The code can solves nonlinear magneto-static, electro-static field and current flow in three dimensions. Fig. 2 shows magnetic field of the penning ion source. It can be confirmed that the magnetic field in the areas of the cathode body and the plasma electrode has a value of approximately zero since the areas have a zero voltage. Whereas, the magnetic field in the anode that has a positive voltage (~10 kV) is strong because of influence of the permanent magnet. When hydrogen gas is injected in the penning ion source to generate a plasma, the hydrogen beam is generated and extracted through the plasma electrode. The plasma discharge starts at around 1 kV of anode voltage. Ions formed in the plasma can be extracted in the form of a beam and accelerated by the strong electric field. The hydrogen beam is formed from the plasma and extracted by applying a high voltage to the anode.

Discharge currents in the penning ion source for hydrogen are shown in Fig. 3. In general, the plasma discharge ignites easily at voltage more than 1 kV and as the anode voltage increases, the discharge current increase because of increasing of the discharge voltage. As the voltage increases, electrons present in the discharge gain more energy, have more ionization collisions, and produce more plasma. As the voltage increases, the discharge current increases rapidly from 1 to 6 kV and the current is saturated at larger the anode voltage. The discharge current with 0.51% standard error is 0.0401 A at 6 kV and saturated, respectively. Thus, the penning ion source must be operated at 6 kV to operate stably the ion source.

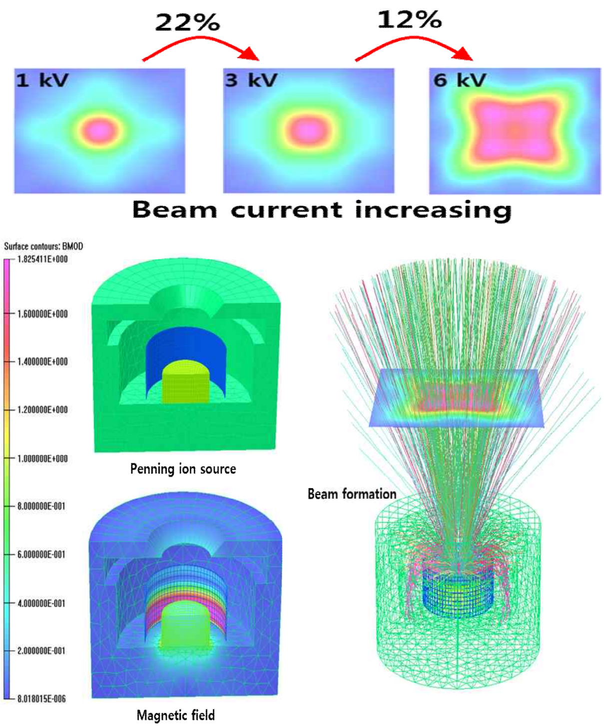

Fig. 2. Magnetic field (Left) of the penning ion source. When hydrogen gas is injected in a vacuum chamber, the hydrogen beam is generated and extracted through a plasma electrode (Right).

3. Conclusions

A penning ion source was designed to apply a movable neutron generator. The magnetic field and discharge current of the ion source were calculated by using the Opera-3D code. As an anode voltage in the ion source increases, the discharge current for hydrogen gas increases and is saturated a 0.0401 A at 6 kV, respectively. The design parameter is suitable for generating and extracting ion beams in the movable neutron generator. In future study, the penning ion source will be fabricated and tested by injecting the hydrogen gas. An optimization will be conducted to search for experimental condition to extract stably the ion beam.

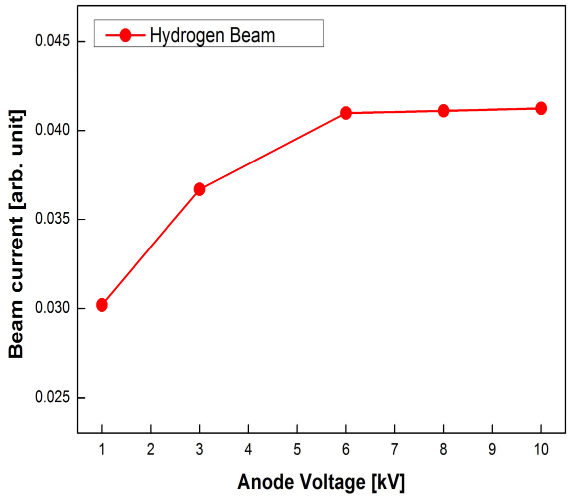

Fig. 3. Discharge current which is calculated by the Opera-3D code when hydrogen gas is injected into a penning ion source. Saturation anode voltage is a 6 kV.

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