Present Status of an Electron Cyclotron Resonance Ion Source-based D–D Neutron Generator Development at KAERI

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1. Introduction

Neutron-based technologies are becoming increasingly critical in a range of applications, including materials research, security screening, and advanced nuclear studies. These demands have led to the development of compact, high-flux neutron sources capable of delivering stable and continuous neutron beams. Given these needs, the Korea Atomic Energy Research Institute (KAERI) has undertaken the development of a 10^9 neutron/sec (n/s) - class neutron generator based on an ion source, named K-ANGUS (KAERI Advanced Neutron Generator for Universal Solution). This neutron generator is designed to be a compact yet versatile system suitable for a variety of applications, offering both reliability and ease of operation.

2. Current Development Status of K-ANGUS

The ion source is an essential part of the neutron generator for providing deuteron ions (D^+ ions). An electron cyclotron resonance (ECR) ion source was selected for its ability to provide intense ion beams at relatively low operating pressures—ranging from sub-mTorr to a few mTorr—thereby minimizing collision-induced energy losses. A compact permanent magnet ECR ion source system has been fabricated for the neutron generator [1–4]. This source features a plasma chamber with an inner diameter and length of 10 cm each. Its operating frequency is 2.45 GHz, while the corresponding ECR magnetic field strength (B_ECR) is 875 G. Microwave power of up to 1,500 W can be applied.

Because the ion source is maintained at a high voltage relative to ground to enable beam extraction/acceleration, a high-voltage DC break is employed to electrically isolate the plasma-generation section from other subsystems, enhancing both safety and stability. To ensure optimal microwave coupling and robust plasma generation, a four-step ridged waveguide has also been designed. This specialized waveguide structure effectively matches the impedance between the transmission line and the plasma chamber, thereby improving overall power efficiency and plasma density.

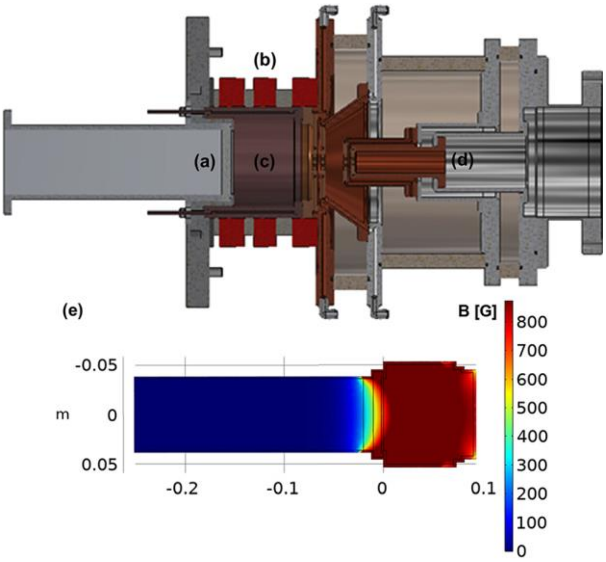

Fig. 1. Drawing of ECR ion source and contour plot of the magnetic field strength.

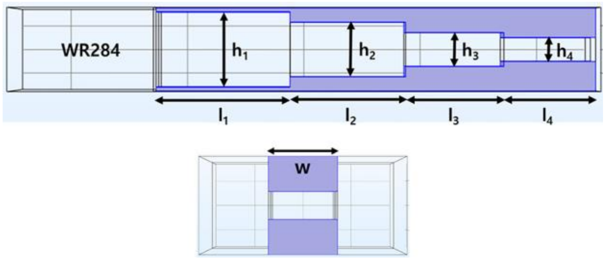

Fig. 2. Drawing Geometry of a four-step ridged waveguide with parameters of length (l) and height (h) of each ridge section and ridge width (w).

Once the plasma is generated, the deuteron beam is extracted and accelerated through a four-electrode system that has been carefully optimized using IGUN simulations.

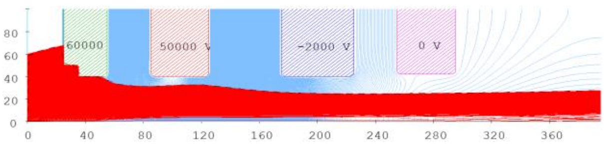

Fig. 3. A result of IGUN simulation.

These electrodes are designed to minimize undesirable losses while balancing beam current and beam quality.

By adjusting the electrode voltages, operators can tailor the beam's final energy to meet specific requirements. Moreover, the multi-electrode design offers reduced beam divergence, enhanced transmission efficiency, and a high degree of operational flexibility.

The accelerated deuteron beam is subsequently directed onto a "drive-in" target, where deuterium implantation occurs, followed by fusion reactions that generate neutrons.

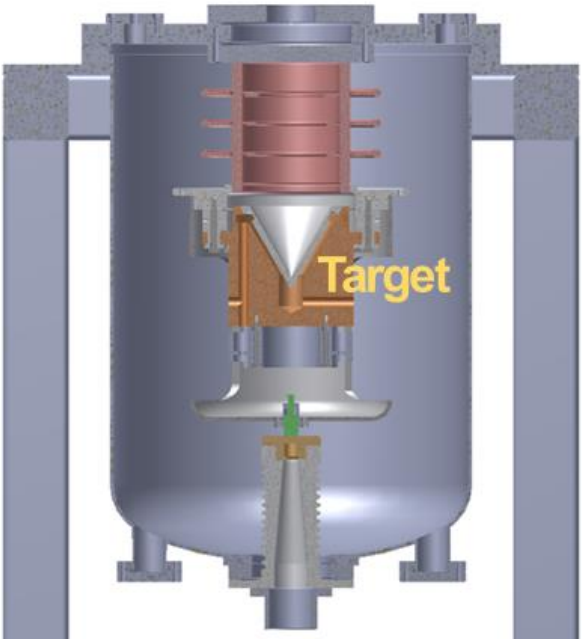

Fig. 4. A drive-in target in K-ANGUS.

Equipped with a specialized cooling system, this target assembly can effectively dissipate heat resulting from sustained ion bombardment. Target materials and configurations have been selected to achieve high neutron production rates while maintaining long-term reliability.

3. Experimental Results

Initial tests demonstrated stable system operation for one hour at a hydrogen ion beam current of 50 mA.

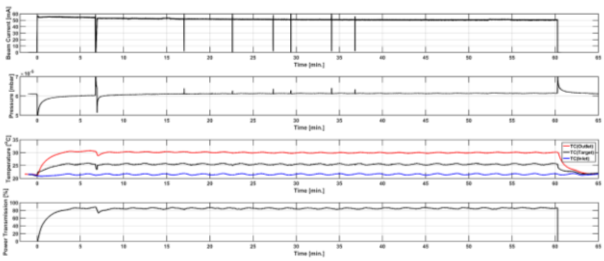

Fig. 5. Performance test results of K-ANGUS

Under these conditions, based on cross-sectional data and measured system parameters, the predicted neutron yield is approximately 10^9 n/s. These results underscore the generator's potential to deliver a high neutron flux suitable for applications ranging from nuclear data production to nuclear fuel inspection.

4. Future Work

KAERI is currently seeking regulatory approval for K-ANGUS. Comprehensive safety assessments covering high-voltage management, radiation shielding, and operational protocols have been conducted as part of the licensing process. Once licensure is complete, K-ANGUS will undergo more extensive performance evaluations and demonstration trials in actual use cases. Moving forward, further improvements will focus on broadening the beam energy range, upgrading thermal management strategies for the drive-in target, and introducing advanced diagnostic tools to bolster reliability and operational efficiency.

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