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CHARACTERIZATION OF D$^+$ SPECIES IN THE 2.45 GHz ECRIS FOR 14-MeV NEUTRON PRODUCTION

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Abstract

The Institute for Plasma Research has set up a 14-MeV neutron generator facility. The stability, quality, and repeatability of the D$^+$ ion beam are critical parameters for ensuring the reliable operation of the neutron generator. Hence, a 2.45 GHz ECR ion source has been installed to produce the deuterium beam. The primary D beam characteristics are assessed by varying extraction voltage, microwave power, gas flow, and solenoid current of the ECRIS. By optimizing these parameters, the maximum design beam current is achieved. The D ion beam contains various species, including D$^+$, D$_2^+$, D$_3^+$, and impurities. Accurate measurement of the D$^+$ content within the D ion beam is the key parameter for a neutron generator. Multiple experiments were conducted to determine the D$^+$ species and optimise the ECRIS parameters for maximum production of D$^+$ species. Two beam current measurement devices, the DCCT and the Faraday Cup, were installed in the beamline to measure the total deuterium beam current and D$^+$ beam current, respectively. Especially, the variation in the D$^+$ fraction primarily depends on the operating parameters of the ECRIS, such as extraction voltage, microwave power and gas flow. This paper presents the results of the D$^+$ ion current as a function of extraction voltage, microwave power, and gas flow rate. Understanding and characterizing the D$^+$ species are essential steps toward achieving stable and efficient neutron production in fusion applications.

INTRODUCTION

The Institute for Plasma Research (IPR), India, has recently commissioned a 2.45 GHz Electron Cyclotron Resonance Ion Source (ECRIS)-based high-yield 14 MeV neutron generator. This sophisticated system is designed to produce a remarkable 10^{12} neutrons per second, both in continuous mode and pulse mode [1-3]. Deuterons, extracted from the SILHI ECRIS [4-6], are directed onto a solid titanium tritide (TiT) target. The collision of deuterons with the TiT target results in the production of fast neutrons. These fast neutrons are essential for various applications, such as benchmark experiments for the Fusion Evaluated Nuclear Data Library (FENDL), neutron spectroscopy measurements, double differential cross-section measurements, and neutron diagnostics, all aimed at the development of future fusion reactors. Additional applications of the neutron generator include neutron radiography, medical isotope production, explosive detection, and the characterization of electronic components used in space applications. The Institute for Plasma Research (IPR) has developed an accelerator-based D-T neutron generator capable of producing 10^{12} neutrons per second as shown in Fig. 1 [7].

The 2.45 GHz Electron Cyclotron Resonance (ECR) ion source is a critical component of the 14 MeV neutron source, significantly contributing to its stability, reliability, and performance. This paper details the experimental setup of the accelerator-based 14 MeV neutron generator and presents experimental results on ion beam characterization and neutron yield measurement using various diagnostic techniques.

Figure 1: Photograph of Accelerator based 14 MeV Neutron Generator.

EXPERIMENTAL SETUP

The beam characterization process begins at the ion source and is carried out in a step-by-step manner. To ensure smooth and successful beam characterization, extensive preparatory work on accelerator physics and hardware has been conducted. The beamline is evacuated to a base pressure of 10^{-7} mbar before the production of the deuterium beam. Deuterium plasma is generated in the Electron Cyclotron Resonance Ion Source (ECRIS), from which the deuterium ion beam is extracted.

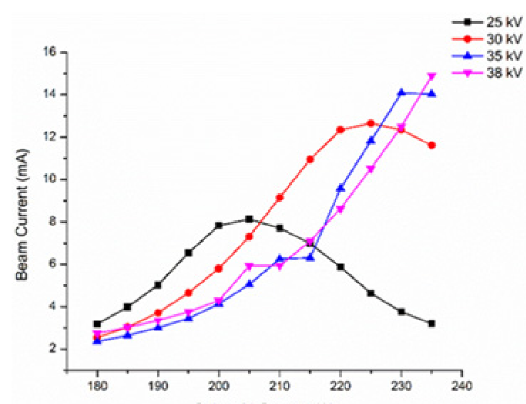

Figure 2: Beam current as function of solenoid current at different extraction voltage.

The extracted deuterium ion beam is then focused into the acceleration column via the Low Energy Beam Transport (LEBT) system and further accelerated using

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electrostatic acceleration. The parameters of the accelerated deuterium ion beam are measured using the Beam Diagnostic System (BDS). The primary beam was measured by varying extraction energy, microwave power, gas flow rate, and solenoid current. By tuning these parameters, the maximum design beam current was obtained. Figure 2 shows the results of beam current measurement as a function of solenoid current at different extraction voltages. Figure 3 shows the results of beam current as a function of extraction voltage and RF power. The deuterium ion beam comprises species such as D^+, D_2^+, D_3^+, and impurities. It is crucial to measure the D^+ content within the deuterium ion beam.

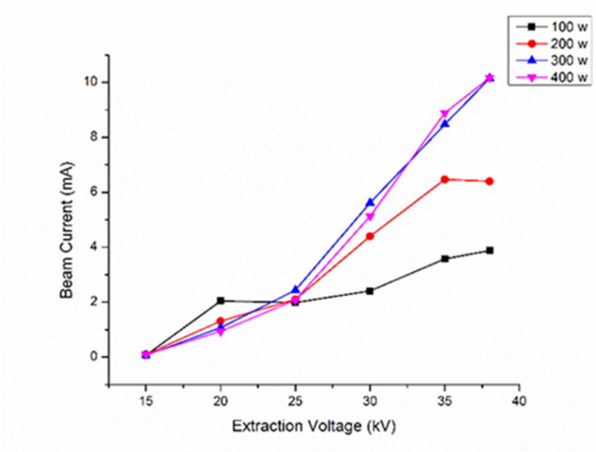

Figure 3: Measured beam current as a function of extraction voltage at different MW power.

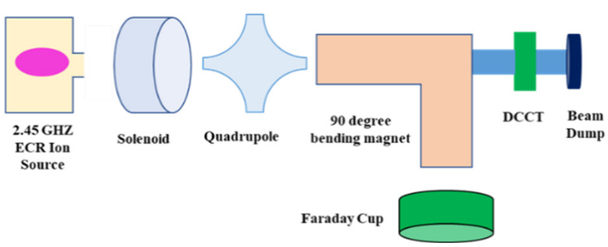

Figure 4: Schematic of the experimental setup for D^+ fraction measurement.

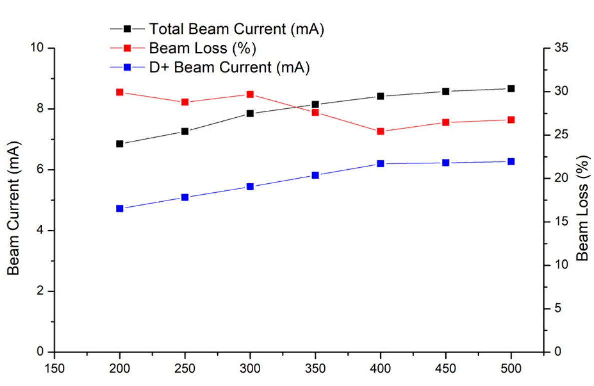

Figure 5: Measured beam loss as function microwave power at 30 kV extraction.

An experimental setup has been established to measure the D^+ ion species, as illustrated in Fig. 4. The Direct Current Current Transformer (DCCT) and Faraday Cup (FC) have been installed to measure the total beam current and the D^+ beam current, respectively, as shown in Fig. 4. Initially, the extracted beam passes through the DCCT with the bending magnet power supply turned off, allowing for the measurement of total beam currents. In the subsequent step, the bending magnet is activated, and the magnetic field is adjusted to allow only the D^+ species to pass through. The beam is then focused onto the FC for the measurement of the D^+ beam current.

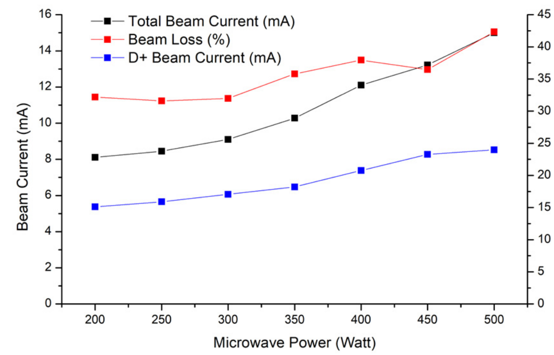

Figure 6: Measured beam loss as function microwave power at 35 kV extraction.

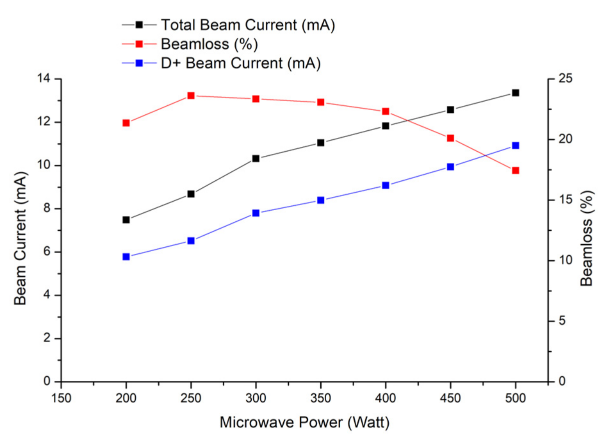

Figure 7: Measured beam loss as function microwave power at 38 kV extraction.

RESULTS AND DISCUSSION

Several experiments were conducted to measure the D^+ fraction as a function of microwave power and extraction voltage. The results of the D^+ fraction measurements as a function of microwave power are presented in Figs. 5, 6, and 7. The percentage beam fraction is calculated from the total beam current and the D^+ current. This percentage includes fractions of D_2^+, D_3^+, and impurities. It was observed that the variation in the D^+ fraction is primarily dependent on the operating parameters of the ECR ion source,

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such as extraction voltage and microwave power. The maximum and minimum D^+ fractions obtained are approximately 82% and 60%, respectively. Notably, the variation in the D^+ fraction primarily depends on the operating parameters of the Electron Cyclotron Resonance Ion Source (ECRIS), such as extraction voltage, microwave power and gas flow. Understanding and characterizing the D^+ species are essential steps toward achieving stable and efficient neutron production in fusion applications.

SUMMARY

An accelerator-based 14 MeV neutron generator has been successfully commissioned at IPR. The following critical aspects were thoroughly investigated. Rigorous measurements were conducted for beam current, beam profile, deuterium fraction, and emittance. The beamline underwent evacuation, achieving a base pressure of 10^{-7} mbar. Within the plasma chamber, deuterium plasma was efficiently produced. An extraction system facilitated the efficient extraction of the ion beam. Extraction performance was systematically studied, considering extraction voltage, microwave power, and mass flow rate. A robust 14 mA ion beam, containing all species, was successfully extracted from the ion source. Specifically, an 11 mA D^+ (deuterium) beam was obtained after passage through the analyzing magnet. This achievement represents a significant milestone in neutron research, with promising implications for fusion studies and practical applications.

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