Abstract

Neutron sources are in a great demand in many area like research, nuclear waste management, industrial process control, medical and also security. Major sources of neutrons are nuclear reactors, radioisotopes and accelerator based neutron generators. For many field applications, reactors cannot be used due to its large size, complicated system, high cost and also safety issues. Radioisotopes like Pu-Be, Am-Be, Cf, are extensively used for many industrial applications. But they are limited in their use due to their low source strength and also handling difficulties due to radioactivity. They are also not suitable for pulsed neutron applications. In contrast, compact size, pulsed operation, on/off operation etc. of accelerator based neutron generators make them very popular for many applications. Particle accelerators based on different types of neutron generators have been developed around the world. Among these deuteron accelerator based D-D & D-T neutron generators are widely used as they produce mono-energetic fast neutrons and in particular high yield of D-T neutron can be obtained with less than 300KV of accelerating voltage.

Introduction

As a part of departmental programs, various types and size of deuteron accelerator based neutron generators are developed in NXPD at Purnima, BARC. These can produce neutron source strength of $10^5 - 10^{10}$ n/s. Neutrons are produced using following two reactions:

$$D + T \rightarrow ^4\text{He} + n + 17.6\text{ MeV}, En = 14.1\text{ MeV} \quad (1)$$
$$D + D \rightarrow ^3\text{He} + n + 3.3\text{ MeV}, En = 2.45\text{ MeV} \quad (2)$$

D-T reaction has a large cross-section even at low energy from 50-300 keV and it is almost 100 times higher than D-D reaction at this energy. Hence 300 kV accelerator based D-T neutron source is widely used to obtain higher neutron yield.

**300 kV deuteron accelerator based neutron generator**

This neutron generator (PNGF) has been designed for 300 kV accelerating voltage and 1 mA deuterium beam current installed in Purnima hall [1]. This can produce neutrons strength upto $5 \times 10^{10}$ n/s neutron yield. It is an Electrostatic DC accelerator. The Schematic layout...
and photograph of neutron generator is shown in Fig. 1 and 2 respectively.

**System description**

Neutron generator consists of a Radiofrequency (RF) ion source shown in Fig 3. The deuterium gas is supplied to ion source through a gas inlet and its flow is controlled by a motorised needle valve which is connected with deuterium gas cylinder. The plasma is produced using capacitor coupled 100 MHz, 200W RF power.

D\(^+\) ion beam is extracted from ion source by applying extraction voltage which is focused by 30 kV DC electrostatic Einzel lens. The ion source, beam chopper and focusing lens with their all power supplies are kept in 300 kV electrically isolated dome. The electrical power of 230 VAC, 50 Hz for ion source power supplies inside the ion source dome is supplied by 300 kV DC isolation transformer.

The dome is connected with 300 kV power supply for acceleration. It is an 8 stage crocroft-Walton type 300 kV, 10 mA power supply designed by RRCAT, Indore. Accelerating column provides uniform acceleration of ion beam upto 300 kV. To align the beam in X-Y plane on the target, an electrostatic beam steerer is provided. It has two horizontal and two vertical plates connected with regulated 10 kV DC power supply. Beam diagnostic components like beam profile monitor and Faraday cup are incorporated to get the information of beam profile and current of accelerated beam.

At end of accelerator, target holder assembly is installed which can accommodate Tritium or Deuterium target as shown in Fig. 4. Tritium or Deuterium gas adsorption in titanium layer deposited on a copper backing plate of 0.5-1 mm thick is used as a target. Target holder is designed to accommodate 25 to 45 mm diameter target with a cooling system to dissipate beam heat. Target is continuously cooled by closed loop chilled water system.

High vacuum Turbomolecularpump with rotary pump is used to obtain vacuum in the order of 10\(^{-6}\) mbar inside neutron generator for its proper operation. Two He-3 detectors and a SSB based neutron monitoring system has been installed for online measurements of neutron yield during operation. These neutron monitors are also used for neutron interlock for safe operation of NG. All important parameters of the neutron generator are controlled and monitored through a computer based centralized system from the control
room. For the safe and reliable operation of the neutron generator, a PLC based interlock system has been incorporated in the facility.

**Pulsing of neutron generator**

Many applications like fissile material detections, explosive material detection, Keff measurement and dynamic behavior studies of sub-critical system, time of flight measurement require pulse neutron source. For such applications, three different techniques have been developed and installed in the neutron generator to produce pulsed ion beam for pulsed neutron source.

1. Extraction voltage pulsing
2. Beam chopping
3. RF power pulsing

**Extraction voltage pulsing**

A variable 6 kV extraction power supply has been designed and developed which can be operated in DC as well as pulsed mode. Positive pulse voltage upto 6 kV is applied to probe of RF ion source for extraction of pulsed beam. The power supply can be operated from 1 Hz to 2 kHz repetition rate and 1-100% duty cycle with rise and fall time less than 1 μS.

**Beam Chopping**

A specially designed beam chopper has been developed to provide vary accurate beam pulse having rise and fall time in order of 100- 200 nS. It is electrostatic beam deflector with beam dumper. The beam chopper can be operated at 1kV with 1 Hz to 10 kHz repetition rate and 1-100% duty cycle.

**RF power pulsing**

The easiest way to obtain pulsed beam is to simply pulse the plasma. This can be achieved by modulating the input RF power. Pulsed RF power supply of 13.56 MHz frequency is used to generate the pulsed plasma. Due the limitation of power supply, it can be operated upto 4 Hz with 50% duty cycle.

**Transportable neutron generator**

Transportable neutron generator is designed and developed for field applications like explosive detection, fissile material detection and waste management applications where neutron yield is required of the order of 10^8-9 n/s [3]. This deuteron accelerator is similar to
Purnima neutron generator but designed for 150 kV accelerating voltage. The photograph of the neutron generator is shown in Fig.7. The neutron generator is mounted on a movable trolley to ease maintenance where area is restricted for the occupation.

**Compact single gap neutron generator**

Accelerator based compact neutron generators are being developed which are capable of producing $10^5$–$10^8$ n/s neutrons. The advantage of a compact neutron source Fig. 8 is its small size that makes it suitable for many field experiments and also for various other applications like fissile material detection, baggage inspection for explosive detection, Oil well logging, routine activation analysis etc [4]. Ita single gap accelerator which consists an ion source, single and target assembly. The turbo molecular pump constantly evacuates the accelerator. In conventional deuteron accelerator ion source is kept positive floating on accelerating voltage and target at ground potential whereas in this compact neutron generator target is kept at negative 100-125 kV voltage and ion source is kept at ground potential.

**Conclusion**

Purnima neutron generator has been designed and upgraded for safe and reliable operation up to $10^{10}$ n/s and it is the strongest indigenously developed D-T neutron source in India. Many experiments have been conducted with this neutron generator by various divisions in BARC. The facility has also been used for experiments of Coincidence and Time of Flight (TOF) measurements using APT technique in collaboration with Padova University, [2] Italy and neutron radiography for VSSC, Thiruvananthapuram. At present, PNGF is coupled with India’s first sub-critical system. Transportable & a series of compact neutron generators have been designed, fabricated and installed. These generators are under testing for neutron production.

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**References**


