Development of the Intense Neutron Generator SNEG-13

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Abstract

The Neutron Generator SNEG-13 has been developed and built to produce a high intensity flux of 14 MeV neutrons for exploring various problems of applied neutron physics. The generator contains a 250 keV deuteron accelerator and a target assembly. The electromagnetic system is used for deuteron beam scanning over the target circumference. A maximum neutron yield of 10^{13} n/s has been obtained at 70 mA deuteron beam. The works on the modernisation of the generator so as to increase the neutron flux density in the irradiated sample are under way. The duoplasmatron has replaced with an ECR ion source. The rotating target assembly to provide a small size of neutron source has been developed.

1. INTRODUCTION.

Researches in the field of the controlled thermonuclear fusion, mainly aimed at the construction of an experimental reactor by 2005 are at present, one of the first priority lines in the atomic power engineering [1]. To accomplish this end a wide range of investigations in various field of science and engineering are to be done. Among the main problems are radiation material studies, designing and calibration of diagnostic systems . Experimental investigations of inhomogeneous models of fusion reactor shield and verification of computational codes for 3-dimensional compositions of inhomogeneous shields are required.

To solve successfully the aforementioned problems one need a unique experimental apparatus allowing to simulate the radiation conditions of a future fusion reactor.

The SNEG-13 neutron generator is designed and manufactured in the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA) and since 1986 has been used as a high-intensity source of DT and DD neutrons for the solution of various problems of neutron physics. In 1993 works on updating of the generator were started with the aim of improving its parameters and its more effective using for researches into fusion.

2. GENERAL CHARACTERISTICS OF THE FACILITY.

The SNEG-13 generator produces neutrons as a result of the $^{3}_{1}H\ (^{2}_{1}H,n)^{4}_{2}He$ reaction . A beam of deuterium ions, produced by a duoplasmatron-type source and accelerated up to 250 keV, is scanned by an electromagnet over the circumference of the fixed target in the circular direction.

Main parameters of the generator are presented in Table 1.

The source ensures production of ion beam with a current of more then 100 mA at a comparatively low extraction voltage (up to 30 kV) . The atomic ion content is about 65%. The ion-optical system of the accelerator provides focusing of the beam with a current up to 100 mA on the generator target located at the 2m-distance from the accelerating tube [2].

Table 1 Basic technical specification of the SNEG-13 neutron source.

Neutron yield	$1.0\cdot10^{13}$ n/s (DT)
Deuteron current	10-100 mA
Deuteron energy	100-300 keV
Target diameter (overall)	43 cm
Diameter of tritium layer	15-40 cm
Diameter of deuteron beam at target surface	1.5-2.5 cm
Scanning frequency	50 Hz
Tritium activity in active layer	above 2.5 kCi

The neutron generator target is the 2 mm thick copper-zirconium alloy substrate onto which a titanium layer is deposited and then saturated with tritium. The target substrate is cooled with water, flowing in the 1 mm wide gap between the substrate and the shield.

The neutron field in the irradiation zone depends on a variety of physical processes as well as the design features of the source. The deutron beam scanning along the circumference target and, resulting periodical varying of the distance between the irradiated samples and the neutron emitting surface cause the change in the neutron flow intensity inside the sample. Change of coordinates of the point, being irradiated, causes the alterations in the mean integral flux however smaller compared to the point neutron source with a rotating target. This construction offers the possibility of comparatively uniform irradiation of samples large in volume or area [3].

However, the version of the generator with a fixed target and the beam scanning appreciably limits the areas of applications because of relatively low neutron flux inside the irradiated sample.

3. MAIN CHARACTERISTICS AND DESIGN OF THE UPDATE NEUTRON GENERATOR.

The SNEG-13 generator was updated with the aim to appreciably increase the neutron flux inside the irradiated sample what should be realised due to higher neutron yield (up to $2\cdot10^{13}$ neutrons/s) and creation of a point neutron source. For this purpose a new ion source, accelerating tube and target assembly with a rotating target were developed and at present are installed on the generator and under experimental testing now.

The updated neutron generator is shown schematically in Figure 1.

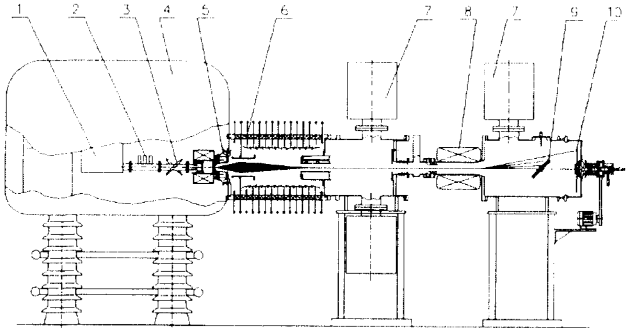

Figure 1. Schematic layout of the updated Neutron Generator SNEG-13.
1-magnetron unit (2.45 GHz); 2-3 stub tuner; 3-directional coupler; 4-H/V terminal; 5-ion source; 6-accelerating tube; 7-pump; 8-electromagnet; 9-beam shutter; 10-tritium target assembly.

An ion beam produced in the source is accelerated up to 300 keV in the accelerating tube with a uniformly distributed potential and is separated in masses in the magnet. In front of the rotating target we placed a beam shutter to collect D_2^+ and D_3^+ beams in the process of operation.

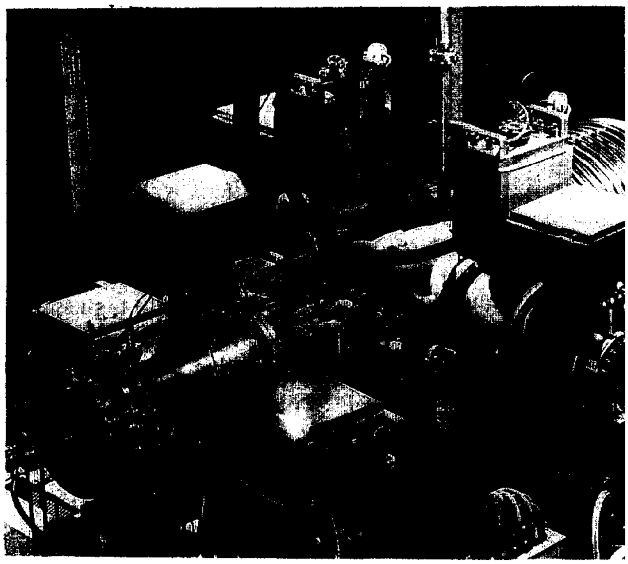

Figure 2. View of the updated neutron generator

The system for high-vacuum pumping out is made on the basis of turbomolecular pumps installed on the vacuum chamber of the accelerator and titanium pumps placed on the target device chamber.

3.1. The ion source and accelerating tube.

In recent years much success has been achieved in the development of ECR sources for high current oxygen ion accelerators [4]. These accelerators produce ion beams with current up to 200 mA with high optical parameters, that's why an ECR source was chosen for the updated SNEG-13.

General view of the ion source is shown in Figure 3. The microwave power is supplied to the plasma chamber from a magnetron via a waveguide through a multilayer dielectric window. A 3-stub tuner and a directional coupler are installed between the magnetron and ion source. The dielectric window is made of three layers: the quartz glass, disk of alumina and a plate of silicon nitride.

Time of the ECR-source continuous operation is determined by the dielectric window damage with secondary electrons. Under the tests of the source the silicon nitride disk was functioning for several hundred hours with insignificant damages (cavities 2-3 mm in depth).

The magnet system,. consisting of two coils with separate current control, allows to obtain the necessary profile of the magnetic field along the plasma chamber axis. The area of the electron-cyclotron resonance (ECR) and, consequently, the area with the maximum plasma density is located in the vicinity of the ion extraction zone.

Depending on the required beam current, a single or multi-aperture system for ion extraction can be adopted in the source. The SNEG-13 generator at the first stage is equipped with the seven-aperture system with an aperture diameter of 5 mm, providing production of an ion beam with a current up to 100 mA at the microwave power input of about 600 W and the extraction voltage up to 35 kV.

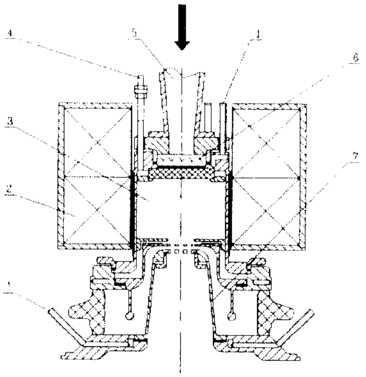

Figure 3. ECR ion source.
1-cooling water; 2-magnet coils; 3-discharge chamber; 4-gas inlet; 5-rectangular waveguide; 6-microwave window;; 7-extracting electrode.

One of the main advantages of the ECR-sources is the high content of atomic ions in the beam even at a comparatively low microwave power input into the plasma. Figure 4 shows the content of atomic and molecular ions versus the power input to the discharge.

As the source is installed directly onto the accelerating tube, a two-electrode system is employed for ion extracting.

The accelerating tube is made of porcelain insulators and stainless steel electrodes bonded with a high-temperature polymer adhesive. A focusing electrode with a controlled potential is installed at the accelerated

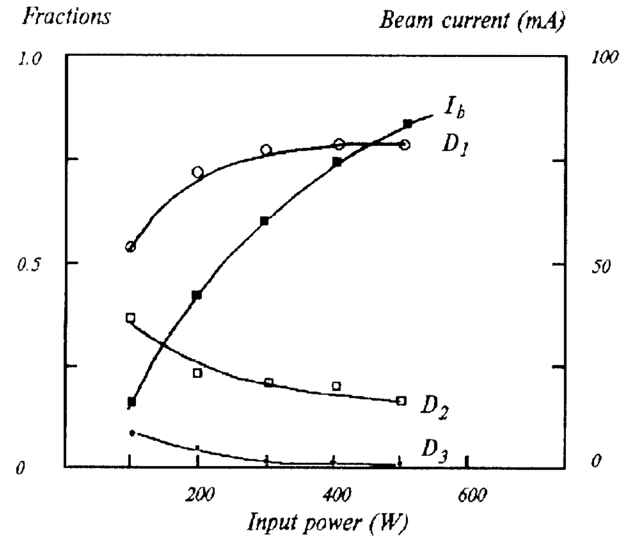

Figure 4. Ion beam composition as function of input microwave power.

tube inlet. The potential distribution between the accelerating tube electrodes is specified by means of a water voltage divider.

3.2 Target assembly

At the first stage of operation the power density on the target is expected to be about 20 kW/cm^2 at a beam current of 100 mA and the 15 mm beam diameter. This makes necessary effective cooling of the target and its rotation with a high speed.

The design of the target device is presented in Figure 5.

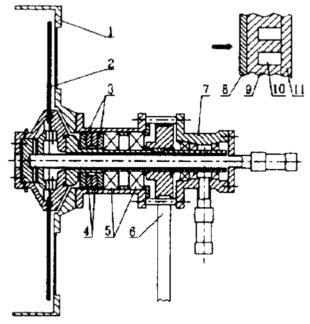

Figure 5. Layout of the target assembly.
1-target chamber; 2-tritium target; 3-seal; 4-magnets; 5-bearings; 6-belt; 7-cooling water; 8-TiT layer; 9-copper alloy; 10-cooling channel; 11-copper

The target is 420 mm in diameter, the outer diameter of the active layer is 400 mm, the inner - 150 mm. The substrate of the target is cooled with water, flowing in the 1×0.8 mm channels, etched inside the substrate.

The general appearance of the target assembly is shown in Figure 6.

The substrate is manufactured at the Efremov Institute (NIIEFA) and then a titanium layer is deposited on it and saturated with tritium at the Institute for Nuclear Researches (Kiev, Ukraine). The target activity is about 2500 Ci.

The target is installed onto the arrangement for the target rotational motion input into the vacuum chamber through the channels of which the cooling water is delivered. The target rotation speed at the first stage of operation is 2000 rev/min. Vacuum sealing of the fixed and rotating details is provided with magnetic liquid confined by a strong magnetic field within the intersurface gap. Tests of the target device have shown a reliable operation of the target rotation unit.

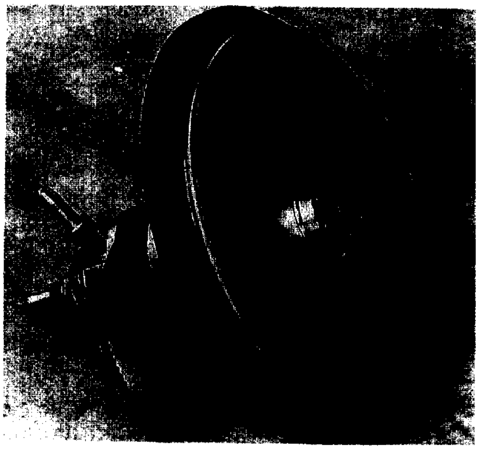

Figure 6. Rotating target assembly.

4. CONCLUSION.

The SNEG-13 neutron generator has been in successful operation for several years with the neutron yield in the range between $5 \cdot 10^{12}$-10^{13} neutron/s. The updating of the generator performed nowadays, provides for the obtaining of the neutron yield of 10^{13} neutrons/s with the point source already this year. Further we plan to obtain higher neutron yield up to $3 \cdot 10^{13}$ neutrons/s. For this purpose higher current will be needed what can be accomplished by applying larger number of apertures in the ion extraction system as well as by larger power input to the plasma. The researches aimed at the increase of the rotation speed of the titanium-tritium target are carried out.

5. REFERENCE.

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