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10 Hz Deuterium Pellet Injector for 1000 s Continuous Fuelling

VINIAR Igor*, SKOBLIKOV Sergey and LUKIN Alexander
PELIN Laboratory, Ltd., Moscow, 125212, Russia

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Abstract

A new deuterium pellet injector for plasma fuelling in a steady state mode has been developed. A technique for continuous solid deuterium ice extrusion by a screw extruder is suggested for the production of an unlimited number of pellets. A cylindrical rod of 2 mm in diameter and over 100 m in length made from transparent solid deuterium ice was extruded continuously for over 3000 s at the temperature of 16 K and 35 mm/s speed. Over 25000 deuterium pellets of 2 mm in size were produced by the injector in the steady state mode at the rates from 1 to 14 Hz and accelerated to 600-700 m/s. Three series of 12103, 12584 and 14600 deuterium pellets were continuously injected at 10 Hz with the reliabilities of 99.2, 98.8 and 99.5 %, respectively. All pellets in flight were recorded by a CCD-camera and a computer and were found to be intact.

Keywords:

fuelling, pellet, injector, extruder

1. Introduction

Future fusion reactors should be equipped with a fuelling system operating in a steady state mode. There are three techniques for plasma fuelling: by gas puffing, by compact toroids and by injection of pellets produced from solidified hydrogen isotopes. A key task of the injection is to develop a reliable pellet injector capable of injecting, in the steady state mode, an unlimited number of pellets into the plasma core. Several techniques for continuous pellet production have been proposed. One is an extrusion method using 3 extruders operating in sequence [1]. Another technique is to produce pellets by a porous generator [2]. Recently, the first screw extruder for hydrogen pellet production has been designed and tested [3]. The design and test results of a pneumatic injector with a new screw extruder for deuterium pellet production are described below.

2. Pellet Injector Design

A schematic diagram of the pellet injector is shown in Fig. 1. It consists of the following main parts: a high vacuum chamber (1) with an extruder (2), equipped with a helium heat exchanger (3) and a screw (4), a rotating driver (5) connected to the screw, a propellant gas valve (6), an electromagnetic pellet chopper (7), a gun barrel (8), and a diagnostic chamber (9). The inner barrel diameter is 2.7 mm and its length is 400 mm. There is a narrow slit (1 mm) between the barrel and the extruder nozzle. Two thermal sensors are installed in the extruder body. A transparent chamber (10) is attached to the extruder exit. It is equipped with a pumping system (11) and has a scale for the extruded deuterium rod measurement. The new injector somewhat differs from the injector equipped with a hydrogen screw extruder [4]. The extruder length is increased to 200 mm. The helium heat exchanger surface is increased by 30 %.

*Corresponding author's e-mail: tvpelin@delfa.net

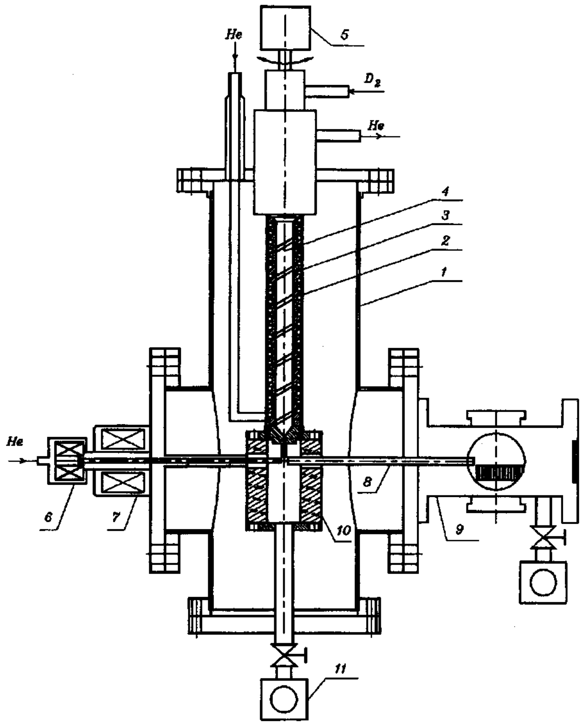

Fig.1 A schematic diagram of the pneumatic pellet injector with a screw extruder.

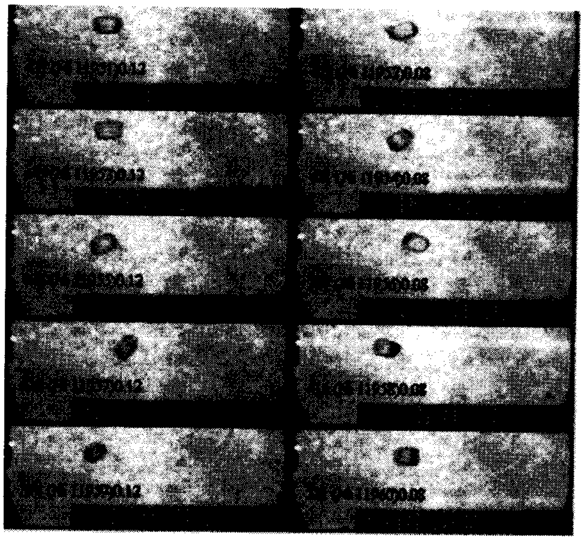

Fig. 2 A series of deuterium pellets injected at 10 Hz.

The diameter and length of the tube between the transparent chamber and the vacuum pumping system are increased to 12 mm and 300 mm, respectively. This has reduced the pre-start injector operation time to 20 minutes from the beginning of the injector cooling and increased the screw extruder production rate.

3. Operation and Results of the Injector Tests

During the test, the screw was rotated continuously in the extruder at 10–30 rpm, pushing out the compressed solid deuterium. The chopper moved the tube for the propellant gas admission into the barrel, thereby cutting off a piece of the solid deuterium rod to form a pellet. The propellant gas valve was open for 50 ms after that, and the pellet was accelerated inside the barrel. The chopper was returned to the initial position, and the cycle was repeated.

The steady state extrusion was registered at 16 K at the rotation rate of 25–30 rpm and the extrusion speed of 35–45 mm/s. As compared with the previous hydrogen extruder [3], the new extruder production rate was increased from 65 to 140 mm^3/s. A 100 m transparent deuterium rod of 2 mm in diameter was extruded continuously for 3000 s. Without the withdrawals, over 50000 pellets could be produced from this rod. At the same time, a 10 cm^3 volume of solid deuterium (or 1600 pellets) was placed in the extruder during the operation time.

Several pellet production and acceleration runs were performed in the repetitive steady state mode. Over 25000 deuterium pellets of 2 mm in size were produced and accelerated to 600–700 m/s at the rates of 1–14 Hz with a step of 1 Hz. Three series of 12103, 12584 and 14600 pellets were continuously injected into the diagnostic chamber at 10 Hz. The propellant gas pressure in the diagnostic chamber was maintained at 0.01-0.02 MPa level. All pellets in flight were illuminated by a nanoflash lamp in the diagnostic chamber and recorded by a CCD-camera and a computer. They were transparent and intact, as shown in Fig. 2. The pellet number in a series is given in brackets, and the time in seconds between the previous pellet and the pellet in this frame is indicated behind the brackets. The pellet velocities are indicated before the brackets in meters per second. After the intact pellets were counted, the reliabilities of pellet injection in the three series were found to be 99.2, 98.8 and 99.5 %, respectively. No temperature deviations of the extruder were registered and the injector operation in the steady state mode was terminated because of the high deuterium cost, since over 1 kg of solid deuterium was extruded during the tests.

4. Summary

A reliable pneumatic injector with a screw extruder providing a continuous injection of an unlimited number of deuterium pellets in the steady state mode has been successfully tested. The injector screw extruder contains a 10 cm^3 volume of solid deuterium and is capable of producing up to 140 mm^3/s extruded deuterium ice for pellet production in the steady state mode. Injection of 2 mm pellets was demonstrated at the rate of 10 Hz for over 1000 s of continuous operation with a 99% reliability.

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